An empirical investigation of the speed of information aggregation: a study of IPOs

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Abstract: This paper researches the microstructure of the price process after the IPO, to gain insight into the information aggregation process of secondary market trading. We investigate a sample of 2,040 US IPOs between 1993 and 2000 and find that it takes approximately one week for all IPO-related information to be reflected in the market price. Using a novel methodology to gauge event-time volatility, we attribute this fast information aggregation to the bookbuilding process and to the extraordinary liquidity in the IPO aftermarket.

Keywords: market microstructure; initial public offerings; IPOs; information aggregation; volatility.

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1 Introduction

When a company issues public equity for the first time, there is much uncertainty about the market price of the new security. This is evident in the large differences between first day returns. For all US IPOs between 1993 and 2000, we find a cross-sectional standard deviation of initial returns of 57%, which is 11 times larger than the standard deviation of the daily returns of the same firms one month after the IPO. The large standard deviation is not surprising, given the lack of an efficient and transparent market. Once a secondary market is established, profit-maximising traders quickly incorporate all relevant public and private information into the market-clearing price.[1] This study is the first to investigate how fast the abundant and scattered information concerning IPO firms is aggregated into secondary market prices.

Theoretical market microstructure research suggests that the volatility process provides the answer to our key research question. In Kyle (1985), a single informed trader rations her trades and incorporates information progressively, until exogenous revelation takes place. The information monopolist's optimal trading strategy causes the return variance to progressively decrease over the time period between private and public revelation. Holden and Subrahmanyam (1992) and Foster and Viswanathan (1994) shows that if there are more informed traders, the volatility decreases faster and that the speed of information revelation increases exponentially in the number of informed traders. Using these insights, empirical studies such as those of Biais et al. (1999) and Corwin and Lipson (2000), have investigated the volatility process to gain insight in the price discovery process.[2]

In this paper, we present a novel maximum likelihood technique that estimates event-time volatility and idiosyncratic volatility simultaneously. Our analysis shows that, on average, it takes approximately one week before all IPO-related information is incorporated in the stock price, at least for our sample of 2,040 US IPOs over 1993 through 2000.

We also analyse the evolution of bid-ask spreads and trading volume in event time. We found that spreads are initially low and increase until they become stationary after approximately two weeks of stationary market trading. Trading volume is very high during the first weeks of trading and decreases to a stationary level. Our results contrast strongly with those reported by Ellul and Pagano (2006), who find that, for 337 British IPOs, it takes several months before the price and quote process becomes stationary.

We suggest two explanations for the fast convergence to stationary volatility in our dataset of US IPOs. First, the price discovery process that North American underwriters employ may be better in extracting dispersed information from market participants. US firms use the book building method, which enables the underwriters to efficiently 'sound out' the market through a targeted approach of large informed investors. Models of Benveniste and Spindt (1989) and Busaba and Chang (2002) shows that implicit promises of higher allocations, in return for positive information, achieve improved information production and aggregation. The commitment to penalise flippers further enhances the price discovery mechanism (Aggarwal, 2003). North American underwriters also have more freedom to adjust the offer price or issue size. Benveniste and Busaba (1997) show that this bookbuilding feature enables better price discovery. Finally, the use of over allotment options and the commitment to engage in price stabilisation aids is common for US IPOs but not for British stock market flotations. Benveniste et al. (1996) show that a credible promise to support the secondary market price *ex post*, entices underwriters to expend more price discovery efforts *ex ante*.

A second explanation for the quick aggregation of dispersed information is the extraordinary liquidity in the IPO aftermarket. We found that during the first trading day, the volume of trading is more than 20 times the long-term average trading volume. For a subsample of 979 IPOs, on which we have intraday data from the Trade and Quote (TAQ) database, 105% of the newly placed shares changed hands on the first trading day. The turnover for the subset of dot.com companies in our sample was a staggering 179%. We also look at the development of the bid-ask spread in the aftermarket and find that they are low and increasing. These findings are similar to those of Corwin et al. (2004), who report that for 220 NYSE IPOs, bid-ask spreads increase during the first two weeks of trading.[3] The development of bid-ask spreads in US markets suggests that during the first days of trading, most aftermarket trading is of the uninformed kind. These findings are very different of what Ellul and Pagano (2006) find for British IPOs: they document an average turnover of 13% and bid-ask spreads that are high and decreasing.[4]

We suspect that some of the uninformed trade in the hectic first days of secondary market trading represents portfolio rebalancing, following uncertain allocations. However, we also notice that recent IPOs constitute a focal coordination for day trading speculators. Ofek and Richardson (2003) argue that uninformed speculators are attracted to the high liquidity, volatility and visibility of these stocks. The presence of uninformed traders entices informed traders to trade more aggressively, analogous to the intraday coordination of uninformed and informed trade (Admati and Pfleiderer, 1988). The multitude of uninformed investors that flock to the IPO aftermarket entices more sophisticated investors, produce information and aggressively trade on it, resulting in a speedy aggregation of information (Holden and Subrahmanyam, 1992).

To gauge further insight in the nature of the aftermarket trading process, we decompose the bid-ask spread employing the trade indicator method used by Madhavan et al. (1997). Our analysis, carried out on a subsample of 979 IPOs for which TAQ data was available, reveals that the volume of both informed and uninformed trading is initially high and decreasing, but that the 'proportion' of informed trades is low and increasing. This confirms our conjecture that, for our sample, the lack of liquidity is not a constraint in the aggregation of information, but that thanks to abundant uninformed trading, informed parties are able to quickly capitalise on their informational advantage and incorporate their signals into the market price.

In summary, our results reveal that information pertaining to initial offerings of US firms is aggregated into prices much faster than in the UK. We attribute this informational efficiency to the bookbuilding mechanism and, more importantly, to the frenzy of uninformed trading in the secondary market. Although both countries are stock market oriented, we casually observe that 'playing the stock market' is much more popular among a larger audience in the US, particularly during our sample period. During the late nineties numerous dedicated television channels provided stock market commentaries to US investors (Bhattacharya et al., 2004) and day trading was in its heydays. We believe that, spurred on by the media, for many private investors, the trading of volatile IPO stocks may constitute a legal alternative to recreational gambling on sports and current events that are pervasive in the UK (Shiller, 2000).

Miller and Reilly (1987) were, to our knowledge, the first to study the post-IPO price process in detail. For 510 firms that went public during 1982–1983, they report no significant drift in the price over the first five days of trading of newly issued stocks. Recent research largely corroborate the martingale properties of the post-IPO price but find that other trading statistics, such as volatility, trading volume and order imbalance, show significant post-IPO drifts that can last for up to several weeks. Hegde and Miller (1989) find that for approximately the first eight weeks of trading, volumes are higher, while bid-ask spreads are lower for IPO firms than for seasoned proxies. Barry and Jennings (1993) find the volatility to be abnormally high for the first couple of days after the IPO. Ellis et al. (2000) found that the number of shares negotiated, as percentage of the float, decreases from 61.9% on Day 1 to 2.0% on Day 60. They also look at the order flow imbalance, underwriter's fraction of trading volume and the market maker's inventory position and found that only after approximately 30 trading days stationarity sets in. Corwin et al. (2004) found, for 220 NYSE stocks, patterns of low increasing bid-ask spreads and decreasing order imbalances. Li et al. (2005) found a low and increasing adverse selection component, which they attribute to the fact that the lead underwriter is the dominant market maker and to regulations such as the quiet period and the lock-up. These findings lead us to suspect that the complete aggregation of the pre-IPO information may not be as fast and efficient as previously thought. Our main research question therefore asks how long it takes for dispersed pre-IPO information to be incorporated into the secondary market prices and how the speed of information aggregation relates to market microstructure and IPO characteristics.

In the next section, we provide details on the IPOs analysed in our sample. Section 3 explains how our empirical tests are conducted, while Section 4 presents our main empirical findings. In Section 5, we conduct a decomposition of the bid-ask spread on a subsample of IPOs for which we have intraday data and the final section concludes.

2 Sample selection and data

Our sample is composed of all IPOs from January 1993 through December 2000, which are listed on the Security Data Corporation's (SDC) new issue database and have information on stock prices available on Center for Research on Security Prices (CRSP) tapes for at least 30 days after the initial listing date. To be consistent with prior literature on the topic, we eliminate firms that raise less than \$10 million, reverse LBOs, spin-off and carve-out IPOs, offerings of 'units' of shares and warrants and American/Global Depository Receipts or Shares (ADRs, GDRs and ADSs). We also exclude all IPOs of financials and utilities with SIC codes that begin with 6 and range from 491 to 494. This screening procedure reduces the initial sample from 3,019 to 2,040 IPOs. Similarly to Ofek and Richardson (2003), we further dichotomise our sample into dot.com IPOs as firms whose names ended in '.com' or had 'e-commerce', 'online', 'internet' or 'web' in the SDC business description and non-dot.com IPOs.

We singled out stabilised issues, because we expect the microstructure variables of such IPOs to be artificially different from non-stabilised issues. Price stabilisation, the posting of a 'support bid' equal to the offer price by the lead underwriter, is a key component of the bookbuilding method used during the sample period.[5] Following the literature, we denote an IPO stabilised when its initial return is less than 2% and has, on at least two of the first five days of trading a closing price equal to the offer price. With this procedure, we dichotomise our 2,040 IPOs into 262 'stabilised' and 1,772 non-stabilised IPOs.

Table 1 reveals that our sample of 2,040 IPOs is evenly distributed over the time period. The highest number of 394 IPOs are recorded in 1996 and the lowest number of 157 in 1998. The greatest average proceeds, the lowest percentage offered and the highest average underpricing occurs between 1998 and 2000. Very high initial returns during 1999 and 2000 can explain the high average underpricing of 30.2% in our full sample. To a great extent, this can be explained by the increase in the proportion of dot.com IPOs that were on average underpriced by 75.4% over the sample period. Interestingly, over 1999 and 2000, also the non-dot.com IPOs were highly underpriced, with an average initial return of 60.2%, significantly higher than the average initial returns of 15.0% observed in all non-dot.com IPOs over 1993 to 1998. Another trend worthy of mention concerns the notable jump in cross-sectional standard deviation in the initial returns of IPOs in 1999. The rapid increase in variance is accompanied by increased average initial returns, which is consistent with most underpricing theories. A quick inspection on firm characteristics suggests that during the latter years of our sample period, riskier and younger firms came to the market, floating smaller proportions of the firm's equity in their primary listing. We attribute the increase in the first two moments of underpricing to the changing risk characteristics of IPO firms (Ritter, 1984).

The last column in Table 1 shows that the average first day trading turnover has increased from 67% in 1993 to 152% by 2000. The average trading turnover of dot.com IPOs was an astounding 179%. For the entire sample period, the average first day turnover of all IPO is 105%, significantly higher than the 58% documented by Krigman et al. (1999) for 1,323 IPOs between 1988 and 1995 and the 62% reported by Ellis et al. (2000) for a sample of 306 NASDAQ IPOs from September 1996 through July 1997.

Table 1 IPO summary statistics

Year	*# IPOs*	*Average proceeds ($ millions)*	*Percentage offered*	*Initial return*			*Number of dot.coms*	*Stabilised*	*TAQ subsample*	*Average first day trading turnover*
				Average	*Median*	*Standard deviation*				
1993	246	37.65	40%	14%	7%	20%	2	37	29	67%
1994	197	36.86	41%	11%	5%	17%	1	39	24	64%
1995	256	45.41	42%	22%	13%	30%	5	28	49	102%
1996	394	50.19	32%	17%	10%	23%	16	57	93	83%
1997	259	46.87	35%	16%	10%	21%	14	43	97	73%
1998	157	87.86	29%	26%	11%	50%	18	20	155	101%
1999	299	96.44	26%	73%	44%	97%	153	23	299	188%
2000	232	87.71	22%	59%	31%	82%	74	15	232	152%
Entire sample	2,040	60.32	33%	30%	13%	57%	283	262	978	105%
dot.coms	283	64.05	23%	75%	47%	93%		11	281	179%
Non-dot.coms	1,757	59.96	34%	25%	11%	49%		251	697	101%
Stabilised issues	262	55.32	39%	1%	0%	3%	17		77	81%
Non-stabilised issues	1,778	61.10	32%	35%	17%	59%	266		901	125%
TAQ subsample	978	89.71	26%	47%	26%	69%	281	77		116%

Notes: Our sample consists of all IPOs from January 1993 through December 2000 in the SDC database, which had proceeds of at least $10 million. We exclude LBOs, spin-offs, offerings of 'units' of shares and warrants and ADRs, GDRs, and ADSs. IPO-firms in financial services (SIC code starting with 6) and in the utilities industry (SIC codes from 491 to 494) are also excluded. Percentage offered is computed as the number shares sold divided by the shares outstanding after the IPO. Initial returns are calculated from the closing price of the first trading day and the offer price. IPOs are denoted 'dot.coms' if their business name ended in .com or the SDC business description contained 'e-commerce', 'online', 'internet' or 'web'. Issues are considered to be stabilised if the initial return is less than 2% and if on two or more days of the first trading week the closing price is equal to the offer price. Average turnover on the first trading day is computed as volume scaled by the total number of outstanding shares taken from CRSP.

3 Theory and methodology

Market microstructure literature offers many models that study how information is aggregated into the market price over time. Kyle (1985) and Glosten and Milgrom (1985) develop one shot model in which traders at some initial date possess different pieces of information on which they strategically trade over several trading rounds so as to maximise wealth. The number of rounds it takes before the price is fully revealed crucially depends on the number of informed traders. In Glosten and Milgrom's model, the speed of information aggregation is a quadratic function of the number of informed traders. If informed traders share the same information and compete in a Kyle (1985) model, the number of informed traders has an even bigger effect on the speed of information aggregation. Holden and Subrahmanyam (1992) shows that if informed traders hold similar signals and compete in the aftermarket, the revelation speed increases exponentially in the number of informed traders. Foster and Viswanathan (1994, 1996) and Vives (1995) on the other hand, argue that if insiders' signals are uncorrelated, information aggregation is hampered, particularly if informed investors are risk averse. As the theoretical literature offering opposing predictions, the question of how quickly information is aggregated into the market price is an interesting empirical question.

To shed light on this important issue, we borrow some modelling and notation from the theoretical literature and express the observable market price as the sum of an unobservable true value $\tilde{v}_t$ and a pricing error: $\tilde{p}_t = \tilde{v}_t + \tilde{\varepsilon}_t$. In the steady state market setting, both $\tilde{v}$ and the information asymmetry captured by $\tilde{\varepsilon}$ are constantly renewed by i.i.d. increments $\delta\tilde{v}$ and $\delta\tilde{\varepsilon}$ so that in a stationary trading process, we expect the cross sectional variance of changes in $\tilde{p}_t$ and hence, returns to be constant in event-time.[6]

The event on which we focus is of course the IPO. On this day, there will be an initial shock in both $\tilde{v}$ and $\tilde{\varepsilon}$. In the days immediately following the IPO, the distribution of the changes in $\tilde{v}$, denoted $\delta\tilde{v}$, will fall to its stationary distribution, while $\delta\tilde{\varepsilon}$'s, the incremental pricing errors, will not immediately be following a stationary distribution. If we assume that $\text{cov}(\delta\tilde{v}_t, \delta\tilde{\varepsilon}_t) = 0$, we have $\sigma_t^2(\delta\tilde{p}) = \sigma_t^2(\delta\tilde{v}) + \sigma_t^2(\delta\tilde{\varepsilon})$, which means that we can utilise the return volatility to study the time it takes for event-related information to be aggregated into the stock price.

The problem of gauging volatility is that multiple observations are needed, making it difficult to estimate the time dependency of the process. This quandary is further exacerbated by the fact that most data-providers only make available daily return data. To adapt to these constraints, we propose a new methodology that is capable of estimating event-time volatility using a cross section of daily stock returns, while allowing for idiosyncratic variances of each stock in the sample.

The return generating process that we postulate for our IPO firms assumes that the volatility of any security at any given point in time, $\sigma_{i,t}$, is the product of a firm-specific component and an event-time component. For the first moment, we assume a simple market-adjusted model, while allowing for an abnormal event-time specific drift:

$$R_{i,t} - R_{m,t} = a(t) + \tilde{\varepsilon}_{i,t}; \quad \tilde{\varepsilon}_{i,t} \sim N(0, \sigma_{i,t}); \quad \sigma_{i,t} = \sigma(i)K(t) \tag{1}$$

In equation (1), $R_{i,t}$ is the return on security i, from event-date $t - 1$ to t, $R_{m,t}$ is the contemporaneous return on the equally weighted market portfolio (obtained from CRSP) and $\sigma_{i,t}$ is the standard deviation of the error term, which is constrained to be the product of a constant idiosyncratic volatility $\sigma(i)$ and a event-time volatility-multiplier $K(t)$.

We estimate the parameters of this model using a maximum likelihood procedure. The input for the model is a matrix X of $N \times T$ return observations where N is the number of securities and T the number of event days considered. The output of the estimation is a coefficient-vector θ, consisting of N idiosyncratic volatilities $\sigma(i)$, T volatility multipliers $K(t)$ and T abnormal returns $a(t)$.[7]

If we write AR for the excess return over the market, the likelihood of observing X, given θ becomes:

$$L\left(X\left|\theta\right.\right) = 2\pi^{-\frac{TN}{2}} \prod_{N} \prod_{T} \frac{1}{\sigma(i) K(t)} e^{-\frac{1}{2}\frac{\left(AR_{i,t} - a(t)\right)^2}{\sigma(i)^2 K(t)^2}} \tag{2}$$

To find the θ that maximises the likelihood function, we minimise the negative log-likelihood, with respect to the $a(t)$'s, the $\sigma(i)$'s and the $K(t)$'s until convergence obtains. For our starting values, we take a as the null-vector, K as a vector of ones and for the $\sigma(i)$'s the observed standard deviation of the securities' returns over the first hundred days:

$$\sigma(i) = \sqrt{\frac{\sum_{t=1}^{100} \left(AR_{i,t} - \frac{1}{100} \sum_{t=1}^{100} AR_{i,t} \right)^2}{99}} \tag{3}$$

The abnormal returns generated by this model are different from those computed using event-studies in the extant corporate finance literature, as our model specifically accounts for time varying pricing errors. It can easily show that if the model is correctly specified, our method is significantly more efficient than plain vanilla event studies.

4 Empirical findings and interpretations

4.1 Time varying volatility

The results on the 'volatility-event-study' applied to our IPO data are presented in Table 2. For brevity, we only report the $a(t)$'s and $K(t)$'s over the first 30 days following the primary listing date. The $a(t)$'s and $K(t)$'s are reported in paired columns for the full sample of 2,040 IPOs, the subsets of non-dot.com firms, dot.coms, not stabilised issues and stabilised IPOs. A separate estimation procedure was performed on each subset, so that the abnormal returns of the entire sample are not necessarily the weighted averages of the abnormal returns of the subsets.

Three interpretable phenomena surface from an inspection of Table 2. First, for the first week of secondary market trading, the average abnormal returns are not significantly different from zero while volatilities are abnormally high and statistically significant, at the 5% level or less. We interpret this as evidence of an efficient arbitrage free aftermarket in which previously dispersed information is rapidly incorporated in the price.

Table 2 Abnormal returns and abnormal volatilities

Day	Full sample of IPOs, Average σ(i) = 5.39%				Non–dot.com IPOs, Average σ(i) = 4.80%				Dot.com IPOs, Average σ(i) = 7.75%			
	a(t) (%)		*K(t)*		*A(t)*		*K(t)*		*a(t)*		*K(t)*	
1	30.20				25.48				75.37			
2	0.44		1.55	**	0.40		1.46	**	–0.39		1.85	**
3	–0.02		1.18	*	0.11		1.14	*	–1.21		1.24	*
4	–0.14		1.26	**	0.04		1.16	**	–1.28		1.56	**
5	–0.53	(*)	1.21	**	–0.37		1.10	*	–0.71		1.56	**
6	–0.19		1.10	*	–0.03		1.07		–1.05		1.22	*
7	0.04		1.06		0.09		1.06		–0.36		1.10	
8	–0.09		1.05		–0.12		0.97		0.49		1.31	**
9	0.26		0.93		0.15		0.89		0.89		1.10	
10	–0.03		0.89		0.00		0.88		0.05		0.96	
11	–0.19		0.98		–0.09		0.93		–0.48		1.15	
12	–0.10		1.05		–0.05		1.06		–0.04		1.02	
13	0.29		1.01		0.16		0.96		1.06		1.18	
14	0.34		1.12	*	0.25		0.98		0.63		1.58	**
15	0.24		0.98		0.16		0.92		0.64		1.23	*
16	0.26		0.94		0.19		0.90		0.56		1.09	
17	0.16		0.92		0.29		0.93		–0.95		0.90	
18	0.40	*	0.99		0.36		0.95		0.35		1.16	
19	0.39	*	0.93		0.34		0.92		0.63		0.99	
20	0.05		0.95		0.02		0.92		0.39		1.05	
21	0.43	*	1.05		0.43		1.05		–0.20		1.07	
22	0.80	**	1.05		0.58	**	1.04		1.27	*	1.08	
23	0.85	**	1.02		0.55	**	1.02		1.81	**	1.00	
24	1.00	**	1.07		0.71	**	1.04		1.70	**	1.15	
25	0.71	*	1.09		0.53	*	1.07		1.02		1.17	*
26	0.51	*	1.19	*	0.48		1.17	**	0.21		1.25	*
27	0.17		1.14	*	0.27		1.15	*	–0.64		1.11	
28	0.06		1.07		0.09		1.03		0.13		1.23	*
29	–0.07		1.05		–0.02		1.03		–0.28		1.12	
30	–0.36		0.94		–0.27		0.95		–0.21		0.95	

Notes: Our sample consists of 2,040 US IPOs from 1993 to 2000. IPOs are denoted 'dot.coms' if their business name ended in .com or the SDC business description contained 'e-commerce', 'online', 'internet' or 'web'. Issues are considered to be stabilised if the initial return is less than 2% and if on two or more days of the first trading week the closing price is equal to the offer price. Daily returns during the first 140 calendar days of public trading are taken from CRSP. We use a maximum likelihood to estimate the following model:

$R_{i,t} - R_{m,t} = a(t) + \tilde{\varepsilon}_{i,t}; \quad \tilde{\varepsilon}_{i,t} \sim N(0, \sigma_{i,t}); \quad \sigma_{i,t} = \sigma(i) K(t),$ where $R_{m,t}$ is the equally-weighted NYSE-AMEX-NASDAQ return. We report the average firm-specific volatilities σ(*i*), as well as the abnormal returns, *a*(*t*) and event-day specific volatility multipliers, *K*(*t*), for the first 30 calendar days. The significance indicators */(*) and **/(**) denote that under the hypothesised return generating model and restrictions *a*(*t*) = 0 and *K*(*t*) = 1, the observed *a*(*t*) would constitute <5% and <1% probability events.

Table 2 Abnormal returns and abnormal volatilities (continued)

Day	Non-stabilised IPOs Average σ(i) = 5.56%				Stabilised IPOs Average σ(i) = 4.39%			
	a(t)		K(t)		a(t)		K(t)	
1	34.61				0.87			
2	0.42		1.62	**	–0.51	(**)	0.49	(**)
3	0.02		1.23	**	–0.47	(**)	0.48	(**)
4	–0.07		1.31	**	–0.50	(**)	0.55	(**)
5	–0.45	(*)	1.25	**	–0.71	(**)	0.69	(**)
6	–0.17		1.12	*	–0.37		0.80	(*)
7	0.06		1.09		–0.25		0.81	(*)
8	–0.13		1.06		0.03		0.95	
9	0.16		0.95		0.31		0.80	
10	0.10		0.91		–0.80	(**)	0.72	(*)
11	–0.18		1.00		–0.07		0.76	
12	–0.04		1.07		–0.36		0.87	
13	0.29		1.03		–0.28		0.71	(*)
14	0.29		1.05		0.07		1.70	**
15	0.23		0.98		–0.11		1.02	
16	0.24		0.92		–0.07		1.14	
17	0.25		0.94		–0.53		0.81	
18	0.40	*	0.99		0.02		1.06	
19	0.38	*	0.95		0.18		0.79	
20	0.06		0.96		–0.21		0.83	
21	0.42		1.06		–0.13		0.95	
22	0.72	**	1.04		0.13		1.15	
23	0.70	**	1.03		0.33		0.90	
24	0.77	**	1.07		0.91	**	1.03	
25	0.57	**	1.12		0.42		0.82	
26	0.46	*	1.19	*	0.12		1.13	
27	0.11		1.16	*	0.41		0.94	
28	0.06		1.06		0.07		1.21	*
29	–0.09		1.06		–0.16		0.91	
30	–0.31		0.95		–0.25		0.93	

Notes: Our sample consists of 2,040 US IPOs from 1993 to 2000. IPOs are denoted 'dot.coms' if their business name ended in .com or the SDC business description contained 'e-commerce', 'online', 'internet' or 'web'. Issues are considered to be stabilised if the initial return is less than 2% and if on two or more days of the first trading week the closing price is equal to the offer price. Daily returns during the first 140 calendar days of public trading are taken from CRSP. We use a maximum likelihood to estimate the following model:

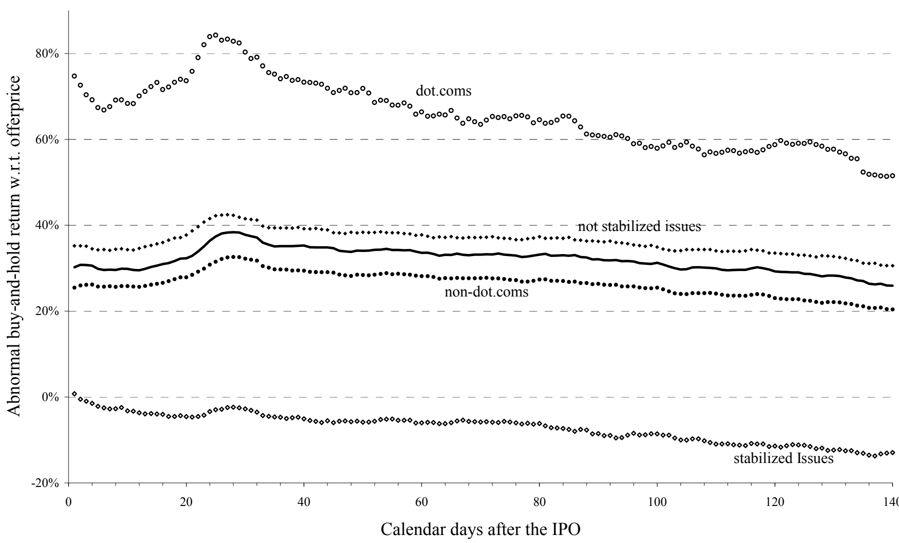
$R_{i,t} - R_{m,t} = a(t) + \tilde{\varepsilon}_{i,t};\quad \tilde{\varepsilon}_{i,t} \sim N(0, \sigma_{i,t});\quad \sigma_{i,t} = \sigma(i)K(t),$ where $R_{m,t}$ is the equally-weighted NYSE-AMEX-NASDAQ return. We report the average firm-specific volatilities σ(*i*), as well as the abnormal returns, *a*(*t*) and event-day specific volatility multipliers, *K*(*t*), for the first 30 calendar days. The significance indicators */(*) and **/(**) denote that under the hypothesised return generating model and restrictions *a*(*t*) = 0 and *K*(*t*) = 1, the observed *a*(*t*) would constitute <5% and <1% probability events.

Second, IPOs that we identify as being stabilised display significant negative abnormal returns combined with significantly low volatilities during the first week of post-IPO trading. We attribute the negative returns to the fact that firms in this subset drop to and then through, the stabilisation floor (the issue-price) during the first week of trading. However, over the subsequent two weeks of trading, there is a strong rebound in returns and volatility returns to a stationary level.

Third, we can clearly discern the quiet period, which for our sample, IPOs ends 25 calendar days after the date of initial flotation. The trend in abnormal returns around the 25th day after the IPO is consistent with that reported by Bradley et al. (2003), who observe a deluge of newly released analyst reports at the end of the quiet period and find as we do, a significant price build-up leading to Day 25. Interestingly, volatility peaks on Days 25 and 26 when analyst reports come out.

Less easy to interpret are the significant negative average abnormal return on the fifth day after the IPO and the conspicuously high volatility on event-day 14. Whereas, the latter finding can be attributed solely to a single outlier, the former phenomenon does not disappear if we remove outliers from the data. We conjecture that this may be a result of stock price stabilisation.[8]

Figure 1 Abnormal buy-and-hold returns

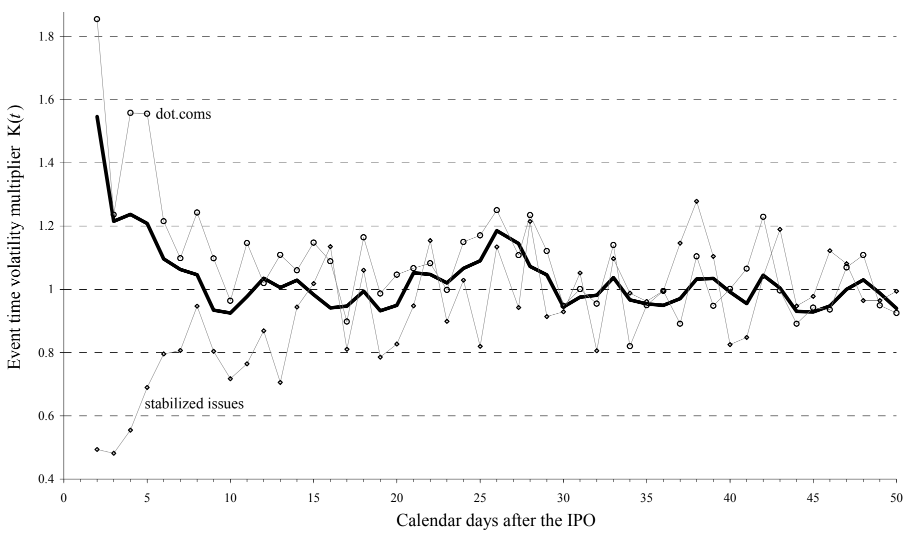


Notes: Estimated abnormal returns with respect to the equally-weighted NYSE-AMEX-NASDAQ returns are compounded for up to 140 calendar days after the IPO. The middle line gives the abnormal buy-and-hold return of the entire sample.

Figure 1 graphically displays the equally weighted post-IPO abnormal buy and hold returns over the first 140 days of public trading, calculated as $\frac{1}{n}\sum_i\left(\Pi_t\left(1+a(t)\right)-1\right),$ for the entire sample and the four subsamples. A price build-up before the expiration of the quiet period is clearly visible. The abnormal buy and hold return over the first 25 calendar days was 7.4%, which was only marginally significant due to the large standard deviations. Figure 1 also shows that stabilised IPOs book consistently negative and statistically significant abnormal returns over the first week of trading. We measure a compounded effect of –4.5%, comparable to earlier findings.[9] It is interesting to see that also stabilised IPOs experience benefit from analyst coverage when it first comes available after the quiet period.

The volatility process is shown graphically in Figure 2. To facilitate interpretation, we charted the *K*(*t*) estimates computed from outlier-purged samples. The main difference with the results in Table 2 is a missing outlier induced volatility spike on Day 14. Figure 2 clearly indicates that during the first days of secondary market trading volatility is not stationary. In particular, we see that volatility is high during the first week, but quickly decreases to a level that seems slightly lower than the long-term level. We do not believe that this pattern can be ascribed to a very active and then quickly dampening news-flow regarding the IPO firm's business. If anything, there would be 'less' news during the first three weeks of public trading: The SEC explicitly prohibits the release of any analysis on the firm's business as long as the issue is 'under registration', which is the case until the 25th calendar day after the actual flotation. In practice, the first three weeks of public trading are conspicuously quiet with respect to news and announcements (Bradley et al., 2003). Hence, we interpret the high but quickly decreasing volatility to reflect the information aggregation process.

Figure 2 Return volatility of the outlier-purged sample



Notes: For every event-day, we purged our samples of the five highest and five lowest returns, before estimating the model $R_{i,t} - R_{m,t} = a(t) + \tilde{\varepsilon}_{i,t}; \quad \tilde{\varepsilon}_{i,t} \sim N(0, \sigma_{i,t}); \quad \sigma_{i,t} = \sigma(i) K(t).$ Charted are the event-time volatility multipliers *K*(*t*) over time.

4.2 Post-IPO trading volume

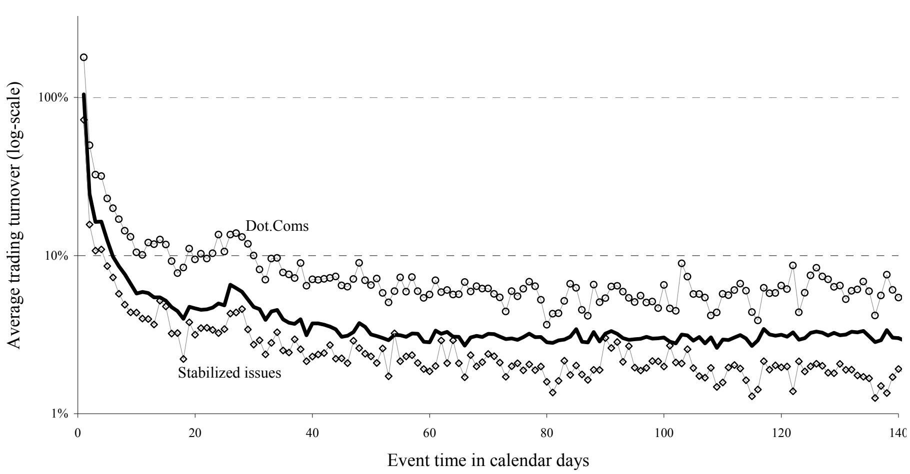
Unlike the second moment of the price process, trading volume can easily be derived from daily CRSP data. As is customary in the literature, we focus our attention on the trading turnover measure, as defined as the number shares negotiated divided by shares offered at the IPO. Table 3 displays this measure of trading volume for the first 140 post-IPO days, for the full sample and our four subsets.

From the second column of Table 3, we observe that trading volume is extremely high in the few days following the IPO and then decreases over our event window until which time it stabilises at around 3% for the full sample. With the exception of dot.coms, trading turnover drops to around 6% within seven days of the IPO. For the subset of 195 dot.coms, it takes approximately four weeks to reach the 6% average trading turnover mark. The kink in volume between Days 3 and 4 can be attributed to the fact that we report event-time in calendar days rather than in trading days.[10]

Also in the volatility data, we find evidence of the quiet period dynamics. Specifically, there is a discernable increase in volume around Day 25, which lasts for approximately three days.

An inspection of Figure 3, which displays trading turnover graphically for our four subsets of IPOs, shows that the pattern of trading volume is the same for all IPOs, but that trading volumes are significantly higher for dot.coms and significantly lower for stabilised issues. One reason for the high trading turnovers of the dot.com stocks can be traced to their smaller float: the percentage offered for dot.coms is only 23% vis-à-vis 34% for non-dot.coms. Nonetheless, the trading turnover for dot.coms is approximately double than that of non-dot.coms, indicating that even if the float were the same, trading volume for dot.coms would still be appreciably larger. Similarly, the low turnover for stabilised issues may, to some extent, be attributed to the size of the float. However, even after correcting for variation in float size, the stabilised issues would still report lower trading volume after the IPO.

Figure 3 Post-IPO trading turnover



Note: The plot shows the CRSP-reported trading volume as a percentage of the shares issued in the IPO.

Table 3 Post-IPO percentage trading turnover

Day	*Full sample of IPOs*		*Non-dot.com IPOs*		*Dot.com IPOs*	
	Average	*Median*	*Average*	*Median*	*Average*	*Median*
1	104.62	82.77	96.71	77.69	179.39	156.20
2	24.60	16.78	21.91	15.64	49.93	40.04
3	16.35	10.36	14.48	9.25	32.50	23.00
4	16.41	10.41	14.70	9.29	31.86	22.60
5	12.47	8.48	11.33	7.82	22.96	17.81
6	9.82	6.52	8.77	6.04	19.91	13.92
7	8.54	5.17	7.64	4.84	16.99	12.10
8	7.61	4.49	6.91	4.20	14.37	11.44
9	6.62	3.76	5.92	3.40	13.14	9.42
10	5.75	3.21	5.23	3.03	10.47	8.41
11	5.89	3.42	5.44	3.14	10.11	6.58
12	5.80	3.47	5.14	3.16	12.10	7.64
13	5.44	3.16	4.77	2.82	11.80	7.83
14	5.44	2.98	4.67	2.70	12.62	6.23
15	5.19	2.90	4.50	2.75	11.74	6.20
16	4.73	2.64	4.26	2.50	9.23	6.87
17	4.46	2.39	4.11	2.21	7.75	5.75
18	3.99	2.40	3.52	2.25	8.40	5.76
19	4.75	2.60	4.06	2.36	11.06	5.52
20	4.63	2.48	4.12	2.25	9.45	6.12
21	4.54	2.51	3.93	2.25	10.26	5.91
22	4.57	2.27	4.04	2.01	9.56	6.27
23	4.69	2.14	4.11	1.95	10.34	6.50
24	4.98	2.38	4.08	2.16	13.58	6.60
25	4.84	2.31	4.22	1.98	10.59	7.01
26	6.53	2.94	5.75	2.58	13.58	8.64
27	6.23	3.05	5.42	2.82	13.85	9.09
28	5.90	2.66	5.16	2.39	13.12	7.28
29	5.28	2.43	4.57	2.18	11.85	6.30
30	4.74	2.07	4.18	1.86	10.01	5.23
40	3.73	1.71	4.19	1.98	8.17	5.12
60	2.83	1.33	3.59	1.80	7.05	4.89
80	2.83	1.33	3.87	1.93	9.57	5.10
100	2.81	1.13	3.98	1.94	9.66	4.49
120	3.15	1.06	3.53	1.89	7.82	4.89
140	3.00	1.12	3.36	1.70	7.60	4.91

Notes: Our sample consists of US IPOs from 1993 to 2000. IPOs are denoted 'dot.coms' if their business name ended in .com or the SDC business description contained 'e-commerce', 'online', 'internet' or 'web'. Issues are considered to be stabilised if the initial return is less than 2% and if on two or more days of the first trading week the closing price is equal to the offer price. Daily trading volumes (#-shares) over the first 140 days of public trading were taken from CRSP. We divided these volumes by the total shares offered (excluding the Green Shoe option) to arrive at the reported turnovers, expressed in percentages.

Table 3 Post-IPO percentage trading turnover (continued)

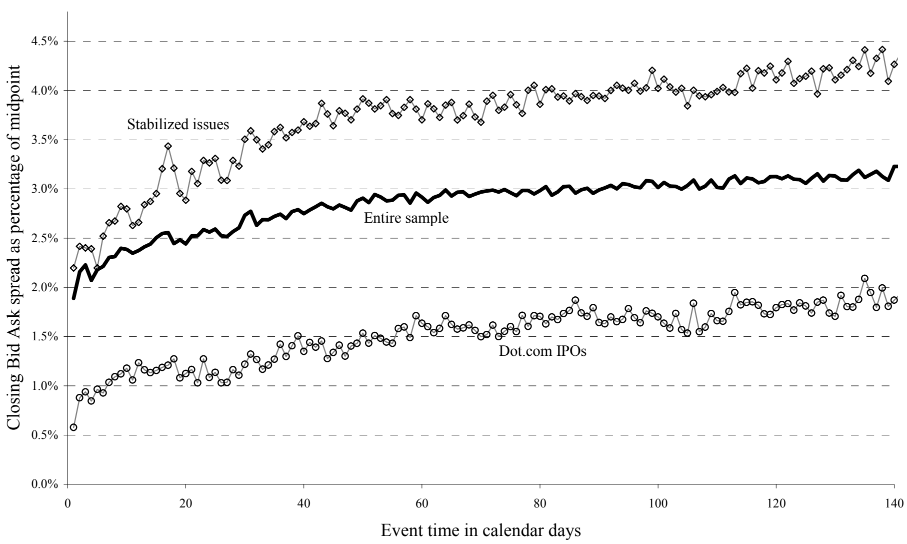
Day	*Non-stabilised IPOs*		*Stabilised IPOs*	
	Average	*Median*	*Average*	*Median*
1	109.41	88.52	72.22	50.09
2	25.96	17.60	15.72	9.39
3	17.32	11.48	10.74	5.86
4	17.18	10.93	10.95	5.94
5	13.00	9.00	8.59	4.25
6	10.20	6.96	7.27	3.90
7	8.96	5.50	5.73	3.43
8	8.02	4.92	4.89	2.19
9	6.97	4.07	4.38	2.06
10	5.97	3.49	4.36	2.00
11	6.15	3.85	4.00	1.83
12	6.05	3.64	3.97	1.86
13	5.69	3.44	3.66	1.78
14	5.48	3.17	5.19	1.58
15	5.25	3.05	4.77	1.96
16	4.96	2.85	3.22	1.86
17	4.65	2.55	3.24	1.60
18	4.24	2.63	2.22	1.28
19	4.88	2.87	3.78	1.57
20	4.84	2.68	3.16	1.58
21	4.70	2.63	3.48	1.51
22	4.72	2.47	3.50	1.42
23	4.89	2.31	3.39	1.32
24	5.26	2.55	3.24	1.30
25	5.05	2.48	3.42	1.50
26	6.85	3.26	4.30	1.73
27	6.50	3.21	4.37	1.90
28	6.10	2.92	4.59	1.66
29	5.56	2.59	3.41	1.54
30	5.05	2.28	2.74	1.30
40	4.84	2.27	2.92	1.25
60	4.15	2.16	2.37	1.24
80	4.67	2.42	2.80	1.19
100	4.70	2.22	3.28	1.42
120	4.16	2.17	2.51	1.23
140	3.95	1.99	2.44	1.22

Notes: Our sample consists of US IPOs from 1993 to 2000. IPOs are denoted ‘dot.coms’ if their business name ended in .com or the SDC business description contained ‘e-commerce’, ‘online’, ‘internet’ or ‘web’. Issues are considered to be stabilised if the initial return is less than 2% and if on two or more days of the first trading week the closing price is equal to the offer price. Daily trading volumes (#-shares) over the first 140 days of public trading were taken from CRSP. We divided these volumes by the total shares offered (excluding the Green Shoe option) to arrive at the reported turnovers, expressed in percentages.

4.3 Post-IPO bid-ask spreads

A second important microstructure parameter is the quoted bid-ask spread that traders are subjected to. For our entire sample of IPOs, we take the closing bid and ask quotes from the CRSP database and in line with prior IPO studies, express the spread as a percentage of the mid-price.[11] Table 4 and Figure 4 present the results of this bid-ask spread analysis for the full sample and our four subsets. For all IPOs in our sample, the relative spreads are low immediately after the IPO and then gradually increase over an event window of 140 days. Dot.com IPOs have, on average, lower spreads, that might be explained by higher trading volume. Interestingly, stabilised IPOs have slightly higher spreads than non-stabilised offerings. This finding diverges from those of Weiss-Hanley et al. (1993), who report lower spreads in stabilised IPOs during the first days of trading in their sample of 1,523 NASDAQ listed IPOs between 1982 and 1987. We can nevertheless reconcile our findings with theirs by pointing to the dramatic increase in trading turnover of all IPO stocks over the last two decades, which we believe is responsible for the low post-IPO spreads in our sample. Moreover, we find, as did Weiss-Hanley et al. (1993), that the increase in spread over the first two weeks for stabilised issues is higher than for non-stabilised issues, indicating that during the first weeks, spreads do benefit from stabilising activity, also in our sample.

Figure 4 Post IPO bid-ask spreads



Note: Development of the closing bid-ask spreads, as a percentage of the midpoint, over the first 140 calendar days after the IPO.

Table 4 Post-IPO percentage bid-ask spreads

Day	*Entire sample*		*Non-dot.com IPOs*		*Dot.com IPOs*	
	Average	*Median*	*Average*	*Median*	*Average*	*Median*
1	1.89	1.48	2.05	1.65	0.58	0.43
2	2.16	1.79	2.31	2.06	0.88	0.53
3	2.23	1.90	2.38	2.11	0.94	0.73
4	2.07	1.65	2.23	1.90	0.85	0.56
5	2.18	1.90	2.33	2.09	0.96	0.59
6	2.21	1.80	2.36	2.02	0.93	0.64
7	2.30	2.01	2.46	2.21	1.04	0.77
8	2.31	2.00	2.46	2.15	1.09	0.78
9	2.40	2.04	2.55	2.25	1.12	0.80
10	2.39	2.20	2.53	2.35	1.18	0.76
11	2.35	2.02	2.50	2.25	1.06	0.81
12	2.37	2.06	2.51	2.22	1.23	0.90
13	2.41	2.08	2.56	2.28	1.16	0.83
14	2.44	2.11	2.60	2.33	1.13	0.82
15	2.50	2.14	2.66	2.38	1.16	0.78
16	2.55	2.20	2.70	2.44	1.19	0.86
17	2.56	2.25	2.71	2.43	1.21	0.87
18	2.45	2.05	2.58	2.23	1.27	0.83
19	2.48	2.08	2.66	2.35	1.08	0.85
20	2.44	2.07	2.60	2.26	1.12	0.90
21	2.52	2.20	2.68	2.47	1.16	0.77
22	2.53	2.15	2.70	2.41	1.03	0.75
23	2.59	2.28	2.74	2.47	1.27	0.79
24	2.56	2.22	2.74	2.41	1.09	0.75
25	2.59	2.26	2.77	2.48	1.14	0.73
26	2.52	2.15	2.71	2.44	1.03	0.72
27	2.51	2.06	2.69	2.25	1.04	0.75
28	2.57	2.15	2.73	2.43	1.16	0.71
29	2.60	2.22	2.78	2.47	1.11	0.86
30	2.73	2.35	2.91	2.56	1.22	0.87
40	2.74	2.35	2.89	2.56	1.52	0.96
60	2.82	2.35	2.97	2.53	1.55	1.09
80	3.04	2.60	3.20	2.84	1.64	0.88
100	3.17	2.76	3.34	2.94	1.71	1.05
120	3.10	2.60	3.26	2.78	1.77	1.21
140	3.12	2.60	3.29	2.82	1.71	1.05

Notes: Our sample consists of 2,040 US IPOs from 1993 to 2000. IPOs are denoted ‘dot.coms’ if their business name ended in ‘.com’ or the SDC business description contained ‘e-commerce’, ‘online’, ‘internet’ or ‘web’. Issues are considered to be stabilised if the initial return is less than 2% and if on two or more days of the first trading week the closing price is equal to the offer price. Closings bid and ask quotes for the first 140 days of public trading were collected from CRSP. Reported are *percentage* spreads, calculated with respect to the midprice.

Table 4 Post-IPO percentage bid-ask spreads (continued)

Day	*Not stabilised issues*		*Stabilised IPOs*	
	Average	*Median*	*Average*	*Median*
1	1.85	1.42	2.20	1.91
2	2.12	1.75	2.42	2.06
3	2.20	1.83	2.40	2.20
4	2.03	1.61	2.39	1.99
5	2.18	1.90	2.20	1.90
6	2.17	1.75	2.52	2.25
7	2.25	1.92	2.66	2.47
8	2.26	1.91	2.67	2.41
9	2.33	1.98	2.82	2.48
10	2.32	2.11	2.80	2.47
11	2.31	2.00	2.63	2.41
12	2.34	2.04	2.66	2.53
13	2.36	2.02	2.84	2.74
14	2.38	2.06	2.87	2.47
15	2.44	2.08	2.95	2.50
16	2.45	2.13	3.20	2.82
17	2.42	2.14	3.43	3.17
18	2.34	1.97	3.21	3.08
19	2.43	2.06	2.95	2.74
20	2.39	2.04	2.88	2.74
21	2.43	2.12	3.18	2.97
22	2.45	2.09	3.05	2.76
23	2.49	2.15	3.29	3.09
24	2.45	2.09	3.26	3.02
25	2.49	2.18	3.31	2.89
26	2.45	2.12	3.09	2.64
27	2.44	2.02	3.08	2.60
28	2.47	2.08	3.29	3.03
29	2.52	2.12	3.23	2.86
30	2.62	2.25	3.50	3.17
40	2.65	2.28	3.48	3.28
60	2.66	2.26	3.95	3.45
80	2.87	2.50	4.12	3.33
100	3.04	2.67	4.08	3.47
120	2.96	2.50	4.10	3.39
140	2.97	2.50	4.21	3.29

Notes: Our sample consists of 2,040 US IPOs from 1993 to 2000. IPOs are denoted 'dot.coms' if their business name ended in '.com' or the SDC business description contained 'e-commerce', 'online', 'internet' or 'web'. Issues are considered to be stabilised if the initial return is less than 2% and if on two or more days of the first trading week the closing price is equal to the offer price. Closings bid and ask quotes for the first 140 days of public trading were collected from CRSP. Reported are *percentage* spreads, calculated with respect to the midprice.

The key finding that bid-ask spreads are initially low and increasing during the first few weeks of secondary market trading is also consistent with recent research on US data by Ellis et al. (2000), Corwin et al. (2004) and Li et al. (2005), but contrary to the findings of Ellul and Pagano (2006) who study UK IPOs and find high and decreasing spreads. The relatively low bid-ask spreads are intriguing, because information asymmetries regarding IPO firms are generally thought to be significant and would give rise to higher bid-ask spreads. We propose two plausible (and linked) explanations for the low and increasing bid-ask spreads after an IPO.

First, we speculate that despite the presence of informed traders in the IPO market, adverse selection is mitigated due to a large number of uninformed agents trading in IPO stocks. From market microstructure theory [e.g., Glosten and Milgrom (1985)] we know that, in a world without transaction costs, bid-ask spreads are determined by the proportion, not the number of informed trades. With time, the proportion of uniformed agents (such as portfolio rebalancers and day traders seeking 'hot' IPOs) reduces and the spreads widen until equilibrium is reached.

Second, the bid-ask spread is not only a result of adverse selection, but also due to inventory holding and transaction costs. If we believe that investor holding and transaction costs are inversely related to daily volume, then our findings can be explained in terms of economies of scale in inventory holding and transaction costs outweighing any adverse selection costs. In Section 5, we investigate this issue further by decomposing bid-ask spreads into an adverse information component and a fixed cost component.

4.4 Robustness checks

As a check on our daily data analyses on post-IPO volatility, volume and bid-ask spreads, we also examine second-by-second data from the TAQ database for the first 30 days after the IPO. Because not all our IPOs are covered by TAQ, the intraday analysis is carried out on a subsample of 979 IPOs for which TAQ reported at least 25 quote-matched trades during each of the first 30 trading days.

Table 5 reports the intraday volatilities for a 30-day post-IPO period for three subsamples for which TAQ data were available. To control for the bid-ask bounce, we took the midquotes at every minute between 10:00 AM and 3:30 PM for the first trading days. To avoid the extreme volatilities in the opening and closing 30 minutes, we took midquotes at every minute between 10:00 AM and 3:30 PM for Calendar Days 2 to 30. For the first trading day, we trim off the first and last 30 minutes trading. We first point at the extraordinarily high volatility of minute midquote returns. If we scale the minute volatilities to daily volatilities by multiplying by the square root of 329 (the number of minutes in a trading day), we find '10:00 AM to 3:30 PM' volatilities in the range of 11.9% on the first day of dot.com IPOs, to 3.4% on the 30th day of non-dot.coms. These numbers are in line with the average cross-sectional volatilities of $1.85 \times 7.75\% = 14.3\%$ for first-day dot.coms and 4.9% for non-dot.coms reported in Table 2.

Reassuring too is that, the 'pattern' of the intraday volatilities over time closely mirrors that reported in Table 2. Just as our cross-sectional estimation method already uncovered, intraday volatilities are significantly higher than the stationary level for approximately eight calendar days after the flotation. Interestingly, the volatility increase around Day 26 is lower for the intraday measures than for the daily data. This is probably due to the fact that during the end of the quiet period, a larger proportion of the volatility occurs from close to open, instead of intraday: analyst reports are typically published outside trading hours.

Table 5 Post-IPO intraday return volatility as a function of days since IPO

Day	*Full sample of IPOs*		*Non-dot.com IPOs*		*Dot.com IPOs*	
	# Stocks	*Average intraday volatility (%)*	*# Stocks*	*Intraday volatility*	*# Stocks*	*Volatility*
1	979	0.51 **	707	0.44 **	272	0.66 **
2	631	0.31 **	454	0.28 **	177	0.40 **
3	402	0.24 **	289	0.22 **	113	0.30 *
4	531	0.27 **	376	0.24 **	155	0.33 **
5	539	0.27 **	390	0.23 *	149	0.35 **
6	754	0.24 **	549	0.21	205	0.30 *
7	941	0.23 *	683	0.21	258	0.29
8	960	0.23 *	693	0.21	267	0.29
9	627	0.22	451	0.19	176	0.29
10	409	0.20	293	0.18	116	0.26
11	510	0.22	366	0.20	144	0.27
12	543	0.23 *	396	0.21	147	0.30
13	759	0.22	556	0.20	203	0.28
14	945	0.22	681	0.20	264	0.28
15	953	0.22	692	0.20	261	0.28
16	626	0.21	455	0.19	171	0.28
17	399	0.20	285	0.17	114	0.25
18	489	0.22	347	0.19	142	0.28
19	551	0.22	398	0.20	153	0.28
20	759	0.22	554	0.20	205	0.27
21	948	0.22	683	0.20	265	0.27
22	969	0.22	702	0.19	267	0.28
23	627	0.23	455	0.19	172	0.29
24	413	0.22	298	0.20	115	0.29
25	499	0.23 *	350	0.21	149	0.29
26	545	0.25 **	391	0.23 *	154	0.31 *
27	747	0.23 *	544	0.21	203	0.29
28	942	0.23 *	682	0.20	260	0.29
29	961	0.22	692	0.19	269	0.28
30	628	0.21	451	0.19	177	0.25

Notes: Our intraday sample consists of 979 US IPOs from 1993 to 2000. IPOs are denoted 'dot.coms' if their business name ended in .com or the SDC business description contained '-commerce', 'online', 'internet' or 'web'. For calendar days two through 30, the midquotes at 10:01, 10:02,…, 15:29 and 15:30 were extracted from the TAQ database to compute 329 intraday minute-returns. For the first trading day, the first and last 30 minutes of trading was trimmed off. The intraday standard deviations of these minute-returns were then computed for the full sample and two subsamples. The standard deviation of the first trading day was based on an average of 217 intraday minute-returns. The indicators ** and * denote the statistical significance of the difference from the Day 29 and 30 averages (0.214, 0.190 and 0.266 respectively).

Table 6 Post-IPO intraday bid-ask spreads

Day	*Full sample of IPOs with TAQ data (979 observations)*			
	$-cent	*S.E.*	*Percentage*	*S.E.*
1	14.39	*0.54*	0.45	*0.016*
2	18.48	*0.67*	0.67	*0.023*
3	20.44	*0.73*	0.85	*0.026*
4	20.11	*0.71*	0.77	*0.024*
5	20.69	*0.76*	0.72	*0.024*
6	21.58	*0.76*	0.68	*0.021*
7	22.22	*0.78*	0.67	*0.020*
8	23.06	*0.82*	0.69	*0.021*
9	22.71	*0.82*	0.79	*0.025*
10	22.62	*0.83*	0.92	*0.031*
11	24.78	*0.90*	0.91	*0.031*
12	24.26	*0.89*	0.86	*0.029*
13	24.73	*0.90*	0.76	*0.025*
14	25.21	*0.89*	0.75	*0.022*
15	25.18	*0.89*	0.74	*0.023*
16	24.73	*0.89*	0.84	*0.026*
17	25.00	*0.94*	0.95	*0.032*
18	26.62	*0.96*	0.97	*0.033*
19	26.76	*0.96*	0.90	*0.030*
20	26.17	*0.92*	0.77	*0.023*
21	26.15	*0.90*	0.74	*0.023*
22	26.28	*0.89*	0.76	*0.022*
23	25.67	*0.90*	0.85	*0.028*
24	26.45	*0.94*	1.03	*0.037*
25	27.87	*0.96*	1.01	*0.037*
26	26.43	*0.91*	0.89	*0.029*
27	25.56	*0.86*	0.77	*0.023*
28	26.05	*0.87*	0.75	*0.023*
29	26.25	*0.88*	0.75	*0.023*
30	25.91	*0.90*	0.84	*0.027*

Notes: Our intraday sample consists of 979 US IPOs from 1993 to 2000. IPOs are denoted ‘dot.coms’ if their business name ended in .com or the SDC business description contained ‘e-commerce’, ‘online’, ‘internet’ or ‘web’. For the first 30 calendar days of public trading the bid and ask quotes at 10:01, 10:02, …, 15:29 and 15:30 are extracted from TAQ. With these, we compute 329 intraday absolute ($) and relative bid-ask spreads, the latter expressed as a percentage of the midpoint. These spreads are averaged for each stock-day and averaged again to arrive at the average percentage spread for each event day. Standard errors in italic.

Table 6 Post-IPO intraday bid-ask spreads (continued)

Day	*Non-dot.com IPOs (698 observations)*		*Dot.com IPOs (281 observations)*	
	Percentage	*S.E.*	*Percentage*	*S.E.*
1	0.42	*0.021*	0.527	*0.020*
2	0.65	*0.029*	0.725	*0.030*
3	0.88	*0.033*	0.790	*0.042*
4	0.76	*0.031*	0.783	*0.033*
5	0.65	*0.030*	0.908	*0.039*
6	0.60	*0.026*	0.903	*0.031*
7	0.55	*0.025*	0.959	*0.036*
8	0.57	*0.027*	0.987	*0.035*
9	0.71	*0.032*	1.007	*0.038*
10	0.90	*0.039*	0.976	*0.051*
11	0.87	*0.039*	1.023	*0.049*
12	0.78	*0.035*	1.063	*0.048*
13	0.66	*0.031*	1.022	*0.037*
14	0.62	*0.027*	1.050	*0.033*
15	0.61	*0.028*	1.048	*0.036*
16	0.75	*0.032*	1.047	*0.042*
17	0.88	*0.040*	1.117	*0.060*
18	0.90	*0.042*	1.133	*0.048*
19	0.82	*0.038*	1.096	*0.047*
20	0.67	*0.029*	1.047	*0.039*
21	0.60	*0.028*	1.094	*0.039*
22	0.62	*0.026*	1.085	*0.040*
23	0.76	*0.035*	1.082	*0.044*
24	1.03	*0.047*	1.033	*0.055*
25	0.96	*0.046*	1.121	*0.064*
26	0.83	*0.035*	1.031	*0.050*
27	0.70	*0.030*	0.921	*0.030*
28	0.65	*0.029*	0.988	*0.034*
29	0.63	*0.029*	1.031	*0.036*
30	0.75	*0.033*	1.070	*0.047*

Notes: Our intraday sample consists of 979 US IPOs from 1993 to 2000. IPOs are denoted ‘dot.coms’ if their business name ended in .com or the SDC business description contained ‘e-commerce’, ‘online’, ‘internet’ or ‘web’. For the first 30 calendar days of public trading the bid and ask quotes at 10:01, 10:02, …, 15:29 and 15:30 are extracted from TAQ. With these, we compute 329 intraday absolute ($) and relative bid-ask spreads, the latter expressed as a percentage of the midpoint. These spreads are averaged for each stock-day and averaged again to arrive at the average percentage spread for each event day. Standard errors in italic.

Table 7 Intraday bid-ask spreads during the first trading day

Event-time (minutes)	*Full sample of IPOs with TAQ data (979 observations)*		
	$-cent	*Percentage*	*S.E.*
0:00–0:01	16.91	0.68	0.031
0:01–0:05	12.59	0.47	0.019
0:05–0:30	11.96	0.43	0.016
0:30–1:00	12.47	0.45	0.018
1:00–2:00	13.11	0.47	0.015
2:00–3:00	14.16	0.54	0.032
3:00–4:00	14.32	0.61	0.024
4:00–5:00	18.68	1.27	0.051

Event-time (minutes)	*Non-dot.com IPOs (698 observations)*		*Dot.com IPOs (281 observations)*	
	Percentage	*S.E.*	*Percentage*	*S.E.*
0:00–0:01	0.69	0.042	0.654	0.034
0:01–0:05	0.45	0.026	0.507	0.022
0:05–0:30	0.42	0.022	0.456	0.017
0:30–1:00	0.44	0.025	0.478	0.018
1:00–2:00	0.46	0.020	0.480	0.019
2:00–3:00	0.55	0.045	0.542	0.030
3:00–4:00	0.60	0.027	0.625	0.047
4:00–5:00	1.39	0.060	0.733	0.071

Notes: Our intraday sample consists of 979 US IPOs from 1993 to 2000. IPOs are denoted ‘dot.coms’ if their business name ended in .com or the SDC business description contained ‘e-commerce’, ‘online’, ‘internet’ or ‘web’. All bid and ask quotes are taken from TAQ. For each event time interval of the first trading day, spreads are time-weighted (time measured in seconds) for each stock then averaged over the full sample and subsamples. The percentage spreads are calculated with respect to the midprice.

Also, our analysis of the intraday bid-ask spreads, reported in Table 6, is supportive of our earlier analysis on closing bid-ask spreads. The development of intraday bid-ask spreads over the event-window closely mirrors the pattern reported in Table 4. Still, we again have significant differences in magnitude. The average intraday bid-ask spreads is significantly lower than the average closing bid-ask spreads. We put forward two explanations for this difference. First, it is well-known that intraday, bid-ask spreads follow a U-shaped pattern and may widen excessively during the last four to signal the end of the trading day.[12] Second, the TAQ data is biased toward more recent years, a period of increasing trading turnover and narrowing bid-ask spreads. To see whether the increasing pattern is continued on a smaller scale, we also looked at the intraday bid-ask spreads over the first five hours of public trading. Table 7 shows that the bid-ask spread reached its minimum at approximately half an hour after the first trade. Interestingly, during the first minutes, spreads decrease. Even so, the average bid-ask spread on the first day is lower than the average bid-ask spread on the second day.

Our daily and intraday analysis on volatility reveals that IPO-information is aggregated into prices within approximately one week of listing. The speedy aggregation of information coincides with extraordinarily high initial liquidity as gauged by trading turnover and the inverse of bid-ask spreads. We conjecture that the pattern of widening of bid-ask spreads can be explained by the proportion of informed and uninformed traders in the aftermath of the IPO and the scalability of inventory holding and transaction costs exceeding adverse selection costs. The results suggest that any adverse selection in the first week of trading is more than offset by the economies of scale obtained through the exceptional trading turnover.

5 Decomposition of the bid-ask spread

Having established that post-IPO spreads are low and increasing, we now turn to the question of what can explain this at first sight puzzling phenomenon. As mentioned earlier, it is generally accepted that bid-ask spreads are driven by three factors. First, market makers require positive bid-ask spreads to meet their fixed costs (administration, licence, livelihood, etc.). It is generally accepted that due to scalability, the transaction cost component of the spread should decrease in trading volume. Second, market makers tend to be underdiversified agents or firms who hold significant inventories of the securities in which they make a market (Ho and Stoll, 1981; Bollen et al., 2004). In equilibrium, market makers will post quotes so as to recompense themselves for the cost and risk of holding inventory. Finally, positive bid-ask spreads compensate market makers against adverse selection. A security's expected value if a buy-order arrives is higher than the expected value contingent on a sell-order, because non-market makers may know more about the underlying security (see Glosten and Milgrom, 1985). Hence, the adverse selection component will be higher in a market with a greater proportion of informed traders. Because our post-IPO analysis on daily and intraday data unveils

1 high and decreasing volatility

2 high and decreasing trading volume

3 low and increasing bid-ask spreads, we conjecture that economies of scale due to high volume outweigh adverse selection effects.

To investigate this interplay further, we extract intraday data from the TAQ database for our sample IPOs over the first 30 days of public trading and decompose the bid-ask spread into an adverse information component and a fixed cost component. We use the technique suggested by Madhavan et al. (1997) to decompose the bid-ask spread for 979 IPOs over the period 1993 through 2000.

5.1 Methodology

Several models have been suggested to decompose the quoted bid-ask into different components. Early studies (Glosten and Harris, 1988; Huang and Stoll, 1997) used closing bid-ask spreads and looked at the autocorrelation of traded prices to make conjectures about transaction cost, inventory holding costs and adverse selection cots components. Several recent studies have suggested alternative models to decompose the bid-ask spread. For our study, we choose the method described by Madhavan et al. (1997) who use a trade indicator model.[13] Their model postulates the existence of a consensus asset value u_t that changes in response to surprises in the trade indicator x_t (which takes a value of one for a buy and –1 for a sell order) and news ε_t:

$$u_t = u_{t-1} + \eta(x_t - E(x_t \mid x_{t-1})) + \varepsilon_t \tag{4}$$

The parameter η is then gauges the informational content of the order flow surprises. A larger η will cause higher price revision for a given order flow surprise. The non-information component of the spread affects the transaction price p_t in the following way:

$$p_t = u_t + \phi x_t + \xi_t. \tag{5}$$

The parameter ϕ represents the transaction cost component of the half-spread while ξ_t captures the rounding error due to price discreetness. With the assumption that order flow follows a Markov process with a probability of price continuation γ and an unconditional probability of mid-quoted-spread transaction λ (i.e., Prob(x_t = 0) = λ), the conditionally expected order flow becomes:

$$E\left(x_t \middle| x_{t-1}\right) = \rho x_{t-1} = \left(2\gamma - 1 + \lambda\right) x_{t-1} \tag{6}$$

Where ρ is the first-order autocorrelation of the trade indicator.

To eliminate the unobserved consensus value, the asset equations (4)–(6) are combined to express the intraday price process as follows:

$$p_t - p_{t-1} = \left(\eta + \phi\right) x_t - \left(\phi - \rho\eta\right) x_{t-1} + v_t \tag{7}$$

Here, v_t is the error caused by the information shocks for the stock prices and the rounding errors. The traded spread is $2(\eta + \phi)$ and the proportion of adverse selection component in the spread is $\eta / (\eta + \phi)$. Following Madhavan et al. (1997), we estimate the model using the generalised method of moments (GMM).[14] The moment conditions implied by this model are:

$$E\begin{pmatrix} x_t x_{t-1} - x_t \rho \\ \mid x_t \mid -(1-\lambda) \\ v_t - \alpha \\ (v_t - \alpha) x_t \\ (v_t - \alpha) x_{t-1} \end{pmatrix} = 0 \tag{8}$$

Where α is a constant drift parameter. The first two equations specify the first order autocorrelation of the order flow and the probability of trades at the mid-point of the spread. The last three equations specify the expectation of the pricing error and its orthogonal conditions. To estimate the model, the parameters of interest, [ρ, α, λ, η, ϕ], are chosen so that the sample moments best meet the moment conditions specified above. The model is exact identified and the GMM estimates are consistent and asymptotically normally distributed (Hansen, 1982).

5.2 Empirical results

Before running the GMM estimation, we cleaned the data in accordance with the literature. From the TAQ database we compiled all regular trades and quotes from 9:30 AM to 4:00 PM and purged these of all out of sequence trades. Following Hasbrouck (2003), we exclude:

1 quotes with zero or negative spreads

2 quotes with spreads greater than one dollar

3 outliers with bid or ask prices that differ by more than 50 cents from a centred moving average over the nearest ten prices.

We also remove quotes in which the ask price is greater than 1.5 times of the bid price and all firms with fewer than 25 eligible trades in any day of the first month after IPO. These screening procedures reduce our sample to 979 IPOs, of which 698 are identified as non-dot.com and 281 as dot.com companies.

To establish the direction of trade initiation in our sample, we match trades with best bid-offer (BBO) quotes at least one second earlier within the same trading day.[15] To avoid the call auction based on the orders accumulated overnight, we delete all opening trades that are not preceded by regular quotes. If the trade price is higher (lower) than the mid-point of the BBO quote, we classify the trade as a buyer (seller) initiated trade. If the trade price coincides with BBO mid-point, we use the algorithm suggested by Lee and Ready (1991) to determine the sign on the trade; that is, if the last price change is positive (negative) then it is a public buy (sell). If the last price change is zero, then the trade is considered a mid-quote spread transaction ($\underline{x}_t = 0$).

The results on the spread decomposition into an adverse selection and fixed cost component for our sample IPOs over a 30-day post-listing period are presented in Table 8. Daily estimates on the adverse selection cost per share in cents (η) and the fixed cost per share in cents (ϕ) are statistically significant at the 5% level or less in the first month after the IPO. The results in Table 8 show that η is 0.82¢ on the listing date and quickly increases to approximately 3¢ after some three weeks of trading. This implies that adverse selection is initially low but increases over time, which is consistent with our conjecture that the IPO aftermarket attracts a large number of uninformed traders who provide liquidity in the stock and lure in informed investors to trade more aggressively (Admati and Pfleiderer, 1988). This story receives additional support when we examine the proportion of the spread explained by adverse selection, which increases from 8.96% at the IPO date to a steady average of approximately 27% by the tenth day of trading.

Nonetheless, for our story of catalystic liquidity trading to be valid, we must establish that both informed and uninformed trading to be high and decreasing after the IPO. To test this conjecture, we estimate the *number* of informed and uninformed trades by multiplying the proportion of adverse selection cost and its complement by the total number of trades. The results are presented in the last columns of Table 8. The data clearly shows that, although, the proportion of informed trading is low and increasing, the total number of informed trades is initially high and decreasing, giving credence to our story that extraordinary volume of uninformed trading acts as a catalyst for information aggregation.

Table 8 Post-IPO spread decomposition

Day	*Number of trades*	*Number of stocks*	*Adverse selection cost* $\hat{\eta}$ *(cent)*	*Fixed cost* $\hat{\phi}$ *(cent)*
1	6,289,428	979	0.8	8.5
2	1,361,897	631	1.4	8.4
3	413,238	402	2.0	8.4
4	688,697	531	1.9	8.8
5	489,435	539	2.2	8.9
6	572,665	754	2.3	8.9
7	624,297	941	2.6	8.7
8	558,087	960	2.7	8.6
9	328,221	627	2.7	8.3
10	177,713	409	2.9	7.9
11	226,621	510	3.7	8.4
12	256,086	543	3.4	8.5
13	326,653	759	3.2	8.4
14	412,331	945	3.2	8.2
15	415,061	953	3.1	8.3
16	245,306	626	3.0	8.0
17	126,014	399	3.7	8.0
18	152,575	489	4.2	7.9
19	225,112	551	3.9	8.3
20	303,166	759	3.5	8.7
21	375,335	948	3.3	8.2
22	374,195	969	3.5	8.0
23	298,137	627	2.9	7.5
24	185,531	413	3.1	7.5
25	257,948	499	3.5	7.8
26	366,878	545	2.9	8.5
27	436,410	747	2.8	8.1
28	581,418	942	2.5	8.1
29	578,158	961	2.4	8.3
30	300,387	628	2.7	8.1
Average			2.9	8.3

Notes: Our intraday sample consists of 979 US IPOs from 1993 to 2000. IPOs are denoted 'dot.coms' if their business name ended in .com or the SDC business description contained 'e-commerce', 'online', 'internet' or 'web'. We decompose the bid-ask spread into an adverse selection component $\hat{\eta}$ and a fixed cost component $\hat{\phi}$ using the methodology described by Madhavan et al. (1997) for the first 30 calendar days after the IPO. The standard errors of both parameters lie between 0.01¢ and 0.07¢, depending on the event-day. The implied traded spread (not reported) is $2(\hat{\eta}+\hat{\phi})$. The proportion of the bid-ask spread that is attributed to adverse selection is $\hat{\eta}/(\hat{\eta}+\hat{\phi})$.

Table 8 Post-IPO spread decomposition (continued)

Day	*Proportion of adverse selection cost (%)*	*Proportion of fixed cost (%)*	*Number of informed trades per stock*	*Number of informed trades per stock*
1	9.0	91.0	576	5,849
2	14.2	85.8	307	1,851
3	19.4	80.6	199	829
4	17.7	82.3	229	1,068
5	20.0	80.0	181	727
6	20.5	79.5	156	604
7	22.7	77.3	150	513
8	24.2	75.8	141	441
9	24.4	75.6	128	396
10	26.8	73.2	116	318
11	30.3	69.7	135	310
12	28.6	71.4	135	337
13	27.7	72.3	119	311
14	28.2	71.8	123	313
15	27.1	72.9	118	318
16	27.4	72.6	107	284
17	31.5	68.5	99	216
18	34.7	65.3	108	204
19	31.9	68.1	130	278
20	28.6	71.4	114	285
21	28.6	71.4	113	283
22	30.3	69.7	117	269
23	28.0	72.0	133	342
24	29.4	70.6	132	317
25	30.8	69.2	159	358
26	25.7	74.3	173	500
27	25.9	74.1	151	433
28	23.4	76.6	145	473
29	22.4	77.6	135	467
30	24.7	75.3	118	360
Average	25.5	74.5	158	642

Notes: Our intraday sample consists of 979 US IPOs from 1993 to 2000. IPOs are denoted 'dot.coms' if their business name ended in .com or the SDC business description contained 'e-commerce', 'online', 'internet' or 'web'. We decompose the bid-ask spread into an adverse selection component $\hat{\eta}$ and a fixed cost component $\hat{\phi}$ using the methodology described by Madhavan et al. (1997) for the first 30 calendar days after the IPO. The standard errors of both parameters lie between 0.01¢ and 0.07¢, depending on the event-day. The implied traded spread (not reported) is $2(\hat{\eta}+\hat{\phi})$. The proportion of the bid-ask spread that is attributed to adverse selection is $\hat{\eta}/(\hat{\eta}+\hat{\phi})$.

Table 8 also reveals that the fixed cost component is relatively constant over the event horizon. We find that the average fixed cost per share traded during the first event week is 8.62¢, which is slightly and marginally significantly, higher than the 7.91¢ cost during the fourth week (Days 22 through 28). This pattern is somewhat surprising because one would expect high turnover to be associated with economies of scale. Although the fixed costs over the first week are only marginally different from the 30-day average, we attribute this minor increase in fixed costs to:

1 diseconomies of scale during the first trading day

2 the market maker's market power, which increases with demand for trading and/or

3 increased inventory risk.

Clearly, with higher volume, market makers are forced to hold greater inventory (Ellis et al., 2000).

6 Conclusions

It has been long assumed that secondary market trading enables profit-maximising traders to quickly incorporate all IPO-related information into the market clearing price. Thus, it has been taken for granted that the speed of information aggregation is instantaneous, once secondary market trading for an IPO is underway. However, a number of recent studies indicate that market learning may not be immediate: trading volumes and order imbalances display post-IPO drifts that can last for several weeks (Hegde and Miller, 1989; Barry and Jennings, 1993; Ellis et al., 2000; Corwin et al., 2004). Results of Ellul and Pagano (2006) indicate that information aggregation for IPO stocks listed on the London Stock Exchange may take several months.

In this study, we show that, for a sample of 2,040 US IPOs between 1993 and 2000, it takes around a week until IPO-related information is aggregated into secondary market prices. We reveal that post-IPO volatility converges to a constant level within one week of the IPO, that volumes are very high and continuously over the first 20 weeks of trading and that bid-ask spreads are initially low and increasing over the first two weeks after which they stabilise. These findings collectively suggest that post-IPO trading is liquidity driven and that uninformed trading is a catalyst for quick information aggregation.

Our findings contrast starkly with those reported by Ellul and Pagano (2006), who study a sample of 227 British IPOs and find initially high bid-ask spreads that decrease for several months until they become stationary. We attribute the relatively quick aggregation of IPO-related information in our sample to the bookbuilding method employed by US. IPOs. Incumbent research has found convincing arguments and evidence that the bookbuilding method, which is gradually adopted throughout the world, is superior in teasing out information from the many identifiable sources in the market.

As a second explanation for the rapid convergence of the pricing error, we point at the extraordinary liquidity in the IPO-aftermarket. It is well documented that in the US, IPO stocks receive widespread media coverage during their first weeks of trading. We believe that the impresario behaviour of the securities markets industry attracts scores of unsophisticated retail investors looking for excitement (Barber and Odean, 2008; Taffler and Tuckett, 2005) and a small chance to make it rich (Kumar, 2005). During the first week of trading, we find an average daily turnover of 32.52%, the median being 23.21%, much higher than the 4.19% and 0.91% reported by Ellul and Pagano (2006). Perhaps, it is the lack of sports betting opportunities (widely available to British citizens) that makes the US stock market a focal meeting point for fortune and excitement seeking punters. In any case, the unusual liquidity in the IPO aftermarket enables informed investors to aggressively trade on their information thereby imputing their private signals quickly in the stock price.

This latter story is supported by a decomposition of the bid-ask spread of fresh IPO stocks. We find that the small and increasing bid-ask spreads, can be attributed to a small and increasing adverse selection component and a relatively constant fixed price component. Whereas the percentage of the spread attributed to adverse selection is initially small, the total number of informed traders is large, yet swamped by an even larger activity of uninformed trading.

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Notes

1 See the equilibrium models of Grossman (1976), Hellwig (1980) and Milgrom and Stokey (1982).

2 Biais et al. look at how the volatility develops in the pre-opening mock trading at the Paris Bourse. Corwin and Lipson study the price dynamics around trading halts.

3 Corwin et al. (2004) also report a high and decreasing limit-order book depth, yet a low and increasing volume-weighted depth. This is because there are relatively few limit orders, compared to market orders.

4 Ellul and Pagano (2006) report an average turnover of 4.1% of the total shares outstanding. We divide this by the reported average percentage issue size of 31%, to arrive at 13%. The turnover as percentage total shares decreases from 4.15% in the first week to 1.17% in the fourth week.

5 Underwriters offer to buy back stock at the issue price to cover their over allocation enabled by the Green Shoe option. Simultaneously, the stabilising bid prevents the newly issued stocks from falling. For discussions on underwriter stabilisation, see Weiss-Hanley et al. (1993), Ruud (1993), Schultz and Zaman (1994), Benveniste et al. (1996), Chowdhry and Nanda (1996), Asquith et al. (1998), Aggarwal (2000) and Boehmer and Fishe (2004).

6 Because we collate time series in event-time, we do not need to worry about stochastic or autocorrelated heteroskedasticity in asset returns (see Engle, 1982; Bollerslev, 1986).

7 Because we considered the first 140 calendar days after the IPO, the total number of return observations used to estimate the volatility process was approximately $2{,}040 \times 140 \times 5/7 = 204{,}000$ (total number of firms × calendar days × weekdays/calendar day).

8 With a kurtosis of 19.42, the distribution of abnormal returns is extremely leptokurtic. We find that the high volatility multiplier of event Day 14 can be attributed solely to the IPO of Internet America, a dot.com that floated in December 1998 at an offer price of $13. The first day close was $147/8, but at the second trading day it fell back to $13 where it hovered for a week, until it jumped to $31 on 23 December for an abnormal return of 109% in a single day, the largest in our sample. To reduce the effect of extreme cases, we also carried out our analysis with the five largest and smallest abnormal returns for each event day removed. The spike in volatility on Day 14 disappears, the significant negative abnormal return on Day 5 remains. The other results are very similar.

9 Miller and Reilly find that overpriced issues experience a significant additional drop of –3.2% over the first four weeks of trading, Weiss-Hanley et al. report a day 10-to-20 return of –3.05%, of IPOs classified as stabilised based on the first ten trading days. Aggarwal reports a ten day CAR of –3% for a sample of 61 supported IPOs of 1997.

10 The kink exists because the Day 3 average is computed using the third trading day of IPOs that went public on Mondays, Tuesdays and Wednesdays, while the Day 4 average is computed using the fourth trading day of IPOs that went public on Monday or Tuesday and the second trading day of Friday-IPOs. The kink is pronounced because: relatively few firms went public on a Monday and trading volume decreases exponentially over time.

11 We based our closing did/ask spreads on CRSP's variables nmsbid and nmsask.

12 See, among others, McInish and Wood (1992) or Lee et al. (1993).

13 This method closely resembles to those of Huang and Stoll (1997), who further decomposes the non-information component into an inventory holding and transaction cost component. Easley et al. (1996) offer an alternative trade indicator decomposition model that is qualitatively similar to the structural MRR method that we chose for its intuitiveness and simplicity.

14 GMM is more appropriate than maximum likelihood estimation as it does not require distributional assumptions regarding the return generating process. GMM is also used by Huang and Stoll (1997).

15 Early studies take five second differences in recording trades and quotes. Henker and Wang (2006) show that a five second delay in recording a trade is inappropriate for data after 1997 and recommend using a one second delay. We also estimated our model using three and five second differences to match trades with BBO quotes and find qualitatively similar results.