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Order imbalance and liquidity supply: Evidence from the bubble burst of Nasdaq stocks

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Abstract

In this study we analyze the effect of order imbalance on the quotation behavior of Nasdaq market makers. We find that Nasdaq market makers use both price and quantity quotes when dealing with order imbalances. However, order imbalance affects only price movement, not spreads. We also find that Nasdaq market makers quote more shares and compete more intensively on bid-side (ask-side) when public sells (buys) exceed public buys (sells). These suggest that market makers increase liquidity supply when order imbalances exist. More interestingly, we show that both market conditions and price movements affect investors' trading behavior.

JEL classification: G12; G14
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1. Introduction

The microstructure literature shows that both inventory position and adverse selection risk affect the quotations of market makers. In this study, we focus on the effects of market

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wide order imbalance on the quotation behavior of the Nasdaq market makers. Intuitively, order imbalance has important influence on market makers' quotation behavior regardless whether order imbalance is driven by private information or by random events.[1] We conjecture that a market wide order imbalance is less likely due to private information, since a piece of private information about a firm only affects the trades of that particular firm, not the whole market. Hence, we investigate the effects of market wide order imbalance on market makers' quotations mainly based on inventory theories.

Specifically, we address the following questions in the current study: (1) how do the Nasdaq market makers respond to market-wide order imbalance and do they respond differently in different market conditions? Although inventory control models predict that market makers increase (decrease) bid–ask quotes to induce movements towards desired inventory levels, it is not clear how they respond to market-wide order imbalance in extended periods of Bull (up) or Bear (down) markets. Do they move away from the market to avoid undesired inventory when they face excessive buying or selling pressure or do they provide liquidity to bridge the gap between supply and demand? Do they use both quoted prices and depths to provide liquidity or do they prefer one to another? (2) Does order imbalance affect only the location of quoted prices (price movement) or the spreads of quoted prices (liquidity) or both? Does this effect differ in Bull and Bear markets and on days with different price movement (up- and down-days)?

We address these issues for two main reasons. First, compared with the numerous research efforts on the NYSE, research on Nasdaq is rather limited. Given this, the results on the NYSE studies are not fully consistent. For example, Madhavan and Smidt (1993) and Hasbrouck and Sofianos (1993) find a weak relation between the inventory level and the quotes of the NYSE specialists. Madhavan and Sofianos (1998) find that the NYSE specialists control their inventory positions by selectively timing the size and the direction of trades rather than by adjusting quotes. Similarly, Kavajecz and Odders-White (2001) find that the inventory position of the NYSE specialists has no effect on posted price schedules. In contrast, Chordia et al. (2002) find a contemporaneous negative relation between order imbalance and spreads.

Second, the quotation behavior of these two markets is quite different. The affirmative obligation requests the NYSE specialists to maintain a fair and orderly market. This becomes more important when extreme order imbalance exists. In contrast, the Nasdaq market makers do not have this obligation; although they are required to quote on both sides, they frequently quote the minimum required depth when they are not at the inside market (Chan et al., 1995; Barclay et al., 1999; Chung and Zhao, 2004). In addition, the multi-dealer feature of Nasdaq market offers Nasdaq market makers advantages in inventory risk sharing, while the sole agent-specialist on the NYSE does not have this advantage.

[1] According to the adverse selection theories (e.g., Kyle, 1985; Glosten and Milgrom, 1985), order imbalance increases the likelihood that informed traders are pre-empting their private information, and market makers revise their quotes accordingly. As suggested by inventory models of Stoll (1978), Amihud and Mendelson (1980), and Ho and Stoll (1983), even a random order imbalance could also create pressure on market makers' inventory holdings and force them to adjust their quotations.

We focus on the bubble burst of Nasdaq stocks and define October through December 1999 as a Bull market and March through May 2000 as a Bear market. Our study has the following findings: first, order imbalance affects only quoted prices, not quoted spreads. This is consistent with the theories of Stoll (1978), Ho and Stoll (1983), Hasbrouck (1988), and Madhavan and Smidt (1993).

Second, market makers adjust both prices and depths when they deal with order imbalance. More importantly, we find that market makers quote more shares and compete more intensively on bid-side when there are more public sells than public buys. They sell more aggressively and quote more shares on ask-side when public buys exceed public sells. These suggest that market makers increase liquidity supply when they face order imbalance or that they profit from information about impending order imbalance by trading on the opposite of the external orders.

Third, we also find that both market conditions and price movements affect investors' trading behavior. Average buy size is larger than sell size on up-days, while average sell size is greater than buy size on down-days. Public buying exceeds selling on up-days, while public selling exceeds buying on down-days. These results suggest that investors over-react to price movement in general. However, we also find that, on up-days, even though the frequency of excess buying is greater than 50% as a whole, the frequency of excess selling (negative order imbalance) is still higher in the Bear market than in the Bull market. On down-days, the difference between Bull and Bear markets is not significant. These results suggest that investors tend to under-react to good news (up-days) in the Bear market, consistent with the investors' behavior observed by Levy and Linden (2002, p. 4): "An upbeat market leaves the public unmindful of bad news, whereas during a down market, no one trusts good news."

Our results provide indirect evidence on the competing theories regarding the relation between inventory position and market liquidity. Amihud and Mendelson (1980) show that both the placement (location) of and the size of spread are affected by market makers' inventory. The size of spread increases in the absolute inventory level, since a larger position is associated with greater risk. In contrast, Stoll (1978) and Ho and Stoll (1983) show that only quoted bid–ask prices are related to the market maker's inventory position, because a positive (negative) inventory raises (lowers) both the reservation bid and ask prices and has no effect on the distance between the bid–ask prices (spreads). Similarly, spreads are also assumed to be independent of inventory position in Hasbrouck (1988) and Madhavan and Smidt (1993). Consistent with Stoll (1978), Ho and Stoll (1983), Hasbrouck (1988) and Madhavan and Smidt (1993), our results show that spreads are independent of order imbalance.

Our study also complements previous studies. Blume et al. (1989) find a strong positive relation between stock returns and order imbalance for the NYSE-listed stocks during the October 1987 crash. Ben-Zion et al. (1990) and Lauterbach and Ben-Zion (1993) analyze trading volume and order imbalance during the October 1987 crash. Chordia et al. (2001, 2002) examine trading volume, order imbalance, and market liquidity of the NYSE stocks over an 11-year period (1988 to 1998). Breen et al. (2002) find a strong positive relation between stock returns and order imbalance for the NYSE, Nasdaq, and Amex-listed stocks during a period from January 1993 to May 1997. However, none of these studies address how order imbalance affects the Nasdaq dealers' quotes and how these effects differ under different market conditions.

Several studies investigate the association between market makers' inventory and quotes of London Stock Exchange (LSE). Hansch et al. (1998) find a cascade effect between market makers' inventory and quotes on the LSE. Market makers who change their quotes from best bid (ask) to best ask (bid) have the larger inventory increase (decrease), and those with divergent inventory post competitive quotes and execute large trades. Naik and Yadav (2003) find that the LSE market makers' quote changes are significantly related to changes in the inventory of the stocks assigned to them, not to the inventory of the stocks of the whole dealer firm. Though these empirical studies on the LSE shed some light on the quotation behavior of a dealer market, significant differences exist between the LSE and Nasdaq.

More importantly, this is one of the few empirical studies to analyze how the Nasdaq market makers use both quoted prices and depths when dealing with order imbalance. The traditional inventory control theories assume that market makers use only quoted prices to manage their inventory, even though we know that market makers' liquidity supply schedule includes both quoted prices and depths. Asymmetric information studies of Lee et al. (1993), Seppi (1997), and Kavajecz (1999) do show that specialists and other liquidity suppliers use both quoted prices and depths strategically when they deal with informed traders. However, there is very limited evidence of how market makers use depths when they face order imbalance.

2. Sample selection, data, and methodology

2.1. Sample selection

Our test sample includes Internet related common stocks listed on Nasdaq. The main reason for this selection is that Internet sector experienced the largest ups and downs in prices around March 2000. For example, the Internet index (INTDEX) composed by Pegasus Research International was about 90 in early January of 1998, climbed to 750 in late March 2000, and then fell more than 200 points within a 30-day span during March to April 2000. This had a significant effect on the U.S. stock markets.

We collect Internet related stocks from two sources. We get a list of 400 Internet related stocks published by Morgan Stanley during the period of January 1, 1998 to February 29, 2000. Among the 400 stocks, we exclude initial public offerings (IPOs) listed after September 1999, which is the month prior to the beginning of our test period. We also identified 255 valid Nasdaq stocks from WRSN.com, which includes Internet stocks composing different indices. Almost one-third of the IPOs collected from WRSN.com are also in the Morgan Stanley list. The final sample includes 430 Internet related stocks after we exclude: (1) stocks listed after September 1, 1999; (2) those without valid listing date on Morgan Stanley list; (3) those without valid data from both the Center for Research in Security Prices (CRSP) and Nasdaq Trade and Quote (NASTRAQ®); and (4) those with a price less than \$5.

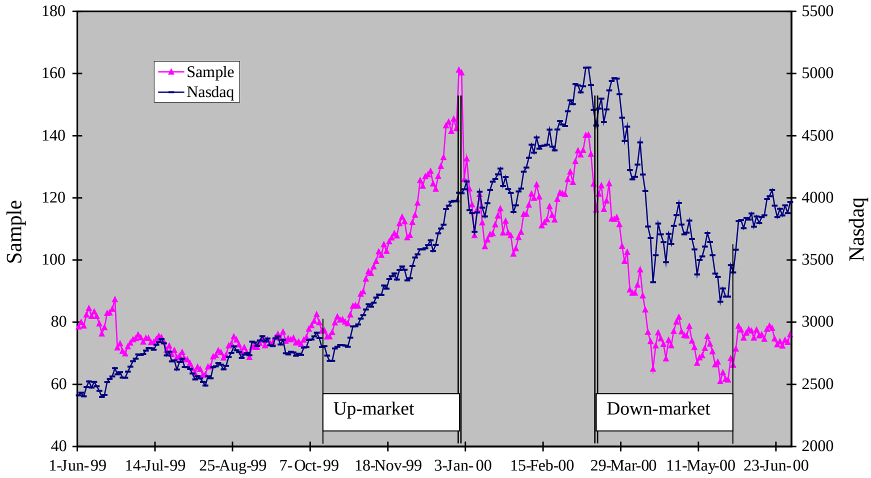

Fig. 1. Nasdaq composite index versus the average price of sample stocks.

2.2. Test periods

The U.S. stock markets experienced the largest decline in March and April 2000 and thereafter. For this reason, we use March 2000 as a turning point and classify Bull and Bear market based on market return. This method is also used in Maheu and McCurdy (2000) and Butler and Joaquin (2001). Specifically, we define the period of March 10, 2000 to May 31, 2000 as a Bear market, during which the Nasdaq composite index and the average price of our test sample declined about 31% and 51%, respectively (Fig. 1). To make the test period comparable in terms of length and the magnitude of price changes, we define October 10, 1999 to December 31, 1999 as a Bull market, where the Nasdaq composite index increased about 39% and the average price of our test sample grew about 53%.

2.3. Data and methodology for order imbalance

We retrieve intra-day trade and quote data from the NASTRAQ® database compiled by Nasdaq and firm size, SIC code, and the Nasdaq composite index data from CRSP data set. We exclude the first trade of the day if it is not preceded by a quote and drop quotes if the bid price is greater than or equal to the ask price or the ratio of the quoted spread to the quote midpoint is greater than 0.5. We determine trade direction using the algorithm of Lee and Ready (1991), except that we do not assume a five-second-quote delay. A trade with a transaction price above (below) the prevailing quote midpoint is classified as a buyer- (seller) initiated trade. A trade at the quote midpoint is classified as seller-initiated if the midpoint moved down from the previous trade (downtick) and as buyer-initiated if the midpoint moved up (uptick). If there is no price movement from the previous price, we apply the above algorithm successively to earlier trades.[2]

[2] See Easley et al. (1997) and Ellis et al. (2000) for detailed discussion on trade classification.

We follow the method in Chordia et al. (2002) and use two different ways to measure order imbalance: order imbalance in shares ($\text{IMBSH}_{i,t}$) and in dollars ($\text{IMBVOL}_{i,t}$). These measures are defined for stock i on day t as:

$$\text{IMBSH}_{i,t} = \text{Total number of shares purchased} - \text{total number of shares sold}; \tag{1}$$

$$\text{IMBVOL}_{i,t} = \text{Total dollar volume purchased} - \text{total dollar volume sold}. \tag{2}$$

An alternative measure of order imbalance is the difference between the number of trades initiated by buyers and the number of trades initiated by sellers. Since this measure ignores trade size, we do not use this measure in the current study.

Table 1 summarizes trade and order imbalance statistics. The average daily trading volume is about 1023 thousand shares or \$69.06 million during the whole test period. Both the average daily trading volume in shares and dollars are higher in a Bear market than those in a Bull market. The average daily order imbalance is about 2630 shares (more buys than sells) during the whole test period. However, the average order imbalance in a Bear

Table 1
Summary of daily trading volume and order imbalance

	Trading volume (Shares/10^3)	Trading volume (\$/10^6)	Imbalance (Shares Vol/10^3)	Imbalance (\$Vol/10^6)
Panel A: whole period				
Mean	1023.48	69.06	2.636	1.29
Median	398.43	10.56	−6.07	−0.07
Minimum	6.26	0.02	−334.54	−7.52
Maximum	534,593.13	3753.53	865.8	145.34
Panel B: Bull market (10/10/99–12/31/99)				
Mean	834.36	58.72	6.96	1.42
Median	393.14	11.69	−3.48	−0.03
Minimum	9.08	0.02	−105.03	−7.52
Maximum	19,219.03	225.06	865.56	145.34
Panel C: Bear market (03/10/00–05/31/00)				
Mean	1213.04	79.43	−1.70	1.16
Median	413.87	9.59	−9.47	−0.11
Minimum	6.26	0.02	−334.54	−6.79
Maximum	53,459.13	3753.53	492.83	60.16
Panel D: difference in mean values (Bear−Bull)				
	378.68 (3.83)	20.69 (2.97)	−8.64 (−2.59)	−0.26 (−0.78)

Trading volume is measured by the number of shares traded (*Shares*) and dollar trading volume (\$). Order imbalance in shares (*Share Vol*) is calculated as the number of shares purchased minus the number of share sold. Order imbalance in dollars is computed as the trading volume of buyer-initiated orders minus the trading volume of seller-initiated orders (*\$Vol*). The period of 10/10/99 to 12/31/99 is defined as a Bull market and the period of 03/10/00 to 05/31/00 as a Bear market. The whole sample includes 430 Internet related common stocks listed on Nasdaq. We first calculate daily values of each stock, then we average them across the whole sample. The numbers in parentheses are t-statistics.

market (−1700 shares) is significantly smaller that that in a Bull market (6900 shares). This suggests mores sells than buys in Bear markets in general. Order imbalances in dollars are not significantly different between Bull and Bear markets. This is mainly due to lower prices in the Bear market.

3. Empirical results

To analyze how price movements affect order imbalance, we classify trading days into down- and up-days. For each stock in our sample, we calculate the difference between the average quoted midpoint of bid–ask prices during the first 30 minutes after market opening (9:30–10:00) and the average quoted midpoint during the last 30 minutes before market closing (15:30–16:00) on each day and use it as daily price movement. For a stock, if the daily price movement is greater (smaller) than or equal to 2.5% (−2.5%), we define that day as an up-day (down-day). To test whether the results are sensitive to the classification method, we also calculate daily price movement as the difference between the opening and closing prices, the difference between the average quoted midpoint of current day and that of previous day, difference between the average trading price of current day and the average trading price of previous day. The results are consistent, so we report only the results based on the 30 minutes open-to-close classification.

We classify market conditions into four categories based on daily price movements (PRICE) and test periods (PERIOD) and denote them as (PRICE, PERIOD) for explanation purposes. In particular, these four categories are defined as:

(Up, Bull): daily price movement equal to or greater than 2.5% in Bull market;
(Up, Bear): daily price movement equal to or greater than 2.5% in Bear market;
(Down, Bull): daily price movement equal to or less than −2.5% in Bull market; and
(Down, Bear): daily price movement equal to or less than −2.5% in Bear market.

3.1. Order imbalance under different market conditions

To make it comparable across different market conditions, we standardize order imbalance by trading volume measures. These measures are calculated for stock i on day t as:

$$\mathrm{IMBSH}_{i,t}/\mathrm{Totsh}_{i,t} = \text{Order imbalance in shares/Total trading volume in shares;} \tag{3}$$

$$\mathrm{IMBVOL}_{i,t}/\mathrm{TotVol}_{i,t} = \text{Order imbalance in dollars/Total trading volume in dollars} \tag{4}$$

Table 2 summarizes order imbalance. For up-days, regardless of whether it is during a Bull market or a Bear market, order imbalance is always positive, i.e., there are more buys than sells on up-days (Panel A). The results on down-days are reversed. This result is as expected since up-days should have more buyer-initiated trades and down-days should

Table 2
Summary of order imbalance

	Up-days		Down-days	
	ImbSh/Totsh (%)	ImbVol/Totvol (%)	ImbSh/Totsh (%)	ImbVol/Totvol (%)
Panel A: Order imbalance/Total trading volume (N=422)				
Bull market	6.81	7.24	−12.68	−12.24
Bear market	3.94	4.52	−12.56	−12.02
Difference: Bear−Bull (*t*-stat)	−2.86 (−5.31)	−2.72 (−5.05)	0.12 (0.26)	0.22 (0.45)
Sign-test stat (*P*-value)	−45 (0.00)	−45 (0.00)	17 (0.11)	18 (0.09)
Panel B: % of time during which order imbalance is negative (N=422)				
Bull market	28.93	28.02	73.74%	72.78%
Bear market	35.56	34.38	71.23	70.32
Difference: Bear−Bull (*t*-stat)	6.63 (5.86)	6.36 (5.63)	−2.52 (−2.91)	−2.46 (−2.78)
Sign-test stat (*P*-value)	49 (0.00)	42.5 (0.00)	−23 (0.02)	−18 (0.08)

Panel A reports daily averages of order imbalance as a percentage of total trading volume. *ImbSh/Totsh*=(shares purchased− shared sold)/total trading volume (shares), and *ImbVol/TotVol*=(trading volume of buyer initialed orders−trading volume of sell initiated orders)/Total trading volume (dollars). Panel B reports the average proportion of time during which order imbalance is negative (# of days when order imbalance is negative/total number of trading days). The period of 10/10/99 to 12/31/99 is defined as a Bull market and the period of 03/10/00 to 05/31/00 as a Bear market. We define down-days when the average 30 minutes open-to-close price movement (quoted midpoint at the bid–ask prices during the first 30 minutes after market opening and the last 30 minutes before market closing) is ≤−2.5% and up-days when the average open-to-close price movement is ≥2.5%. We limit our sample to stocks (422) that have valid observations in both Bear and Bull markets and on both down- and up-days. We first calculate order imbalance for individual stocks in each periods, and then we average them across the whole sample. Both parametric and non-parametric tests are conducted to compare the Bear and Bull market differences.

have more seller-initiated trades. However, a difference exists between the Bear and Bull markets. For (Up, Bull) market conditions, order imbalance in shares (dollars) is about 6.81% (7.24%) of the total trading volume, compared with 3.94% (4.52%) for (Up, Bear) market conditions. Both parametric and non-parametric tests (sign-test) show that order imbalances in a Bull market are significantly larger than in a Bear market. This suggests that liquidity provision on up-days is important in a Bull market. In contrast, for all down-days classes, order imbalance is always negative (more sells than buys), and difference is not significant between Bull and Bear markets. This suggests that liquidity provision on down-days is important during both bullish and bearish market conditions.

The above analysis is based on the daily averages of order imbalance measures across the whole sample. It may be possible that these results are driven by extreme days. To avoid this possible measurement error, we also examine the proportion of days with negative order imbalance, which is calculated as:

$$\begin{aligned}&\text{Percentage of days with negative order imbalance}\\&\quad=\text{The number of days with negative order imbalance}\\&\qquad/\text{The total number of trading days.}\end{aligned} \tag{5}$$

Table 2 (Panel B) summarizes the results. For all up-days classes, the proportion of days with negative order imbalance is far less than 50%, suggesting more buys than sells on up-days. Whereas, for the down-days classes, it is far more than 50%, indicating more sells than buys on down-days, regardless of market conditions. These results are consistent with the results in Panel A and with the findings of Blume et al. (1989).

Interestingly, cross-market comparisons show that the proportion of days with negative order imbalance is significantly lower for (Up, Bull) than for (Up, Bear) conditions. In other words, on up-days, even though the frequency of excess buying is greater than 50% as a whole, the frequency of excess selling (negative order imbalance) is still higher in a Bear market than in a Bull market. However, on down-days, the difference between Bull and Bear markets is not economically significant. The proportion of days with negative order imbalance (ImbSh/Totsh) is about 73.74% for (Down, Bull) conditions compared to 71.23% for (Down, Bear) conditions, although both parametric and non-parametric statistics are statistically significant. These results suggest that investors' sentiment varies and investors tend to under-react to good news (up-days) in a Bear market, implying that "An upbeat market leaves the public unmindful of bad news, whereas during a down market, no one trusts good news" (see Levy and Linden, 2002).

3.2. Trade size and market conditions

Table 3 presents the results on average trade size. First, we compare buy size with sell size for a given market condition category. For up-days categories, buy size is always larger than sell size. For example, the average buy size is \$12,586 and the average sell size is \$11,421 for (Up, Bull) conditions. The difference (\$1164) is significant at 1% level ($t=12.21$). For down-days classes, in contrast, sell size is always larger than buy size. The sell size is about \$1818 larger than buy size for (Down, Bull) conditions and about \$1233 larger for (Down, Bear) conditions.

We compare the average trade size between the Bull market and the Bear market. Interestingly, the result shows that both buy size and sell size are larger in a Bull market than in a Bear market for both the up- and down-days classes. This finding suggests that investors trade more cautiously in bearish market conditions.

In addition, we compare buy and sell size for up-days and down-days. In a given market, buy size is always larger on up-days than on down-days. For example, the daily average buy size is about \$12,586 for (Up, Bull) conditions and \$10,841 for (Down, Bull) conditions. The down-day and up-day buy size difference in Bull market is −\$1745, both economically and statistically significant at 1% level (t-stat = −14.02).

In contrast, sell size is always larger on down-days than on up-days in a given market. The daily average sell size for (Down, Bull) conditions is \$1237 larger than for (Up, Bull) conditions. To see whether the above results are merely driven by price differences among different market conditions, we repeat our analysis by measuring average trade size in number of shares. The results are qualitatively similar. For brevity, these results are not reported, but available upon request.

In summary, the results in this section are as follows: (1) buy size is larger than sell size on up-days, while sell size is larger than buy size on down-days. (2) Buy size on up-days is larger than buy size on down-days, while sell size on up-days is smaller than sell size on down-days. These suggest that, in a given market, investors buy (sell) more on "good" ("bad") days. These also support the cascade model in which price increases (decreases)

Table 3
Average trade size under different market conditions

	Up-days			Down-days			Buy size difference	Sell size difference
	Buy size ($)	Sell size ($)	Buy − sell (*t*-stat)	Buy size ($)	Sell size ($)	Buy − sell (*t*-stat)	Down − up (*t*-stat)	Down − up (*t*-stat)
Bull market	12,586.13	11,421.74	1164.39 (12.21*)	10,841.31	12,658.92	− 1817.61 (− 14.92*)	− 1744.82 (− 14.02*)	1237.18 (9.67*)
Bear market	10,818.88	10,079.49	739.39 (9.77*)	9615.74	10,848.79	− 1233.05 (− 15.27*)	− 1203.14 (− 11.77*)	769.30 (7.46*)
Difference: Bear − Bull	− 1767.26	− 1342.25	–	− 1225.58	− 1810.13	–	–	–
t-stat	− 7.14*	− 5.40*	–	(− 5.08*)	(− 6.93*)	–	–	–

The average trade size is measured in dollars for both buyer-initiated and seller-initiated orders. The period of 10/10/99 to 12/31/99 is defined as a Bull market and the period of 03/10/00 to 05/31/00 as a Bear market. We define down-days when the average 30 minutes open-to-close price movement (midpoint at the bid–ask prices during the first 30 minutes after market opening and the last 30 minutes before market closing) is $\leq -2.5\%$ and up-days when the average open-to-close price movement is $\geq 2.5\%$. We limit our sample to stocks (422) that have valid observations in both Bear and Bull markets and on both down- and up-days. We first calculate daily stock-by-stock buy and sell sizes and the difference between buy and sell sizes, and then we get the averages for the whole sample. "*" indicates the 0.01 significance level.

lead to large buys (sells) and large buys (sells) further leads to price increases (decreases). (3) Trade sizes are larger in a Bull market than in a Bear market, suggesting investors' under-reaction in a Bear market.

3.3. Liquidity and market conditions

Given that a market wide order imbalance is not likely the result of private information trading, the question of how order imbalance affects market liquidity is still an empirical issue since inventory models have conflicting predictions regarding the effect on spreads. Amihud and Mendelson (1980) show that market maker's inventory position affects both the location and the size of spread. In contrast, Stoll (1978) and Ho and Stoll (1983) show that quoted bid–ask spreads are not affected by market maker's inventory position. Other models also assume that spreads are independent of inventory position (Hasbrouck, 1988; Madhavan and Smidt, 1993). Although we do not have inventory data for individual market maker, the aggregate order imbalance directly affects market makers' inventory as a whole. Thus, the results based on the effects of order imbalance on spreads shed light on the inventory literature.

Table 4 reports the results based on our empirical tests. Liquidity is measured by both quoted and effective spreads. Quoted spreads are the difference between the quoted bid–ask prices at inside market associated with prevailing trades. Effective spreads are calculated as twice the absolute value of the difference between trade price and quoted midpoint. Panel A reports quoted spreads. In a given market, the differences in quoted spreads between up- and down-days are not significant. For example, the quoted spreads

Table 4
Spreads under different market conditions

	Up-days	Down-days	Difference: down-day − up-day	t-stat
Panel A: quoted spread ($)				
Bull market	$0.2543	$0.2576	$0.0033	1.63
Bear market	0.2470	0.2505	0.0035	1.51
Difference: Bear − Bull	−0.0073	−0.0071	–	–
t-stat	−0.87	−0.81	–	–
Panel B: effective spread ($)				
Bull market	0.2398	$0.2378	−0.0020	−0.73
Bear market	0.2331	0.2356	0.0025	1.16
Difference: Bear − Bull	−0.0067	−0.0022	–	–
t-stat	−0.91	−0.29	–	–

Quoted spread is the difference between the quoted ask–bid prices at inside market corresponding to trades. The effective spread is calculated as twice the absolute value of the difference between trade price and quoted midpoint. The period of 10/10/99 to 12/31/99 is defined as a Bull market and the period of 03/10/00 to 05/31/00 as a Bear market. We define down-days when the average 30 minutes open-to-close price movement (quoted midpoint at the bid–ask prices during the first 30 minutes after market opening and the last 30 minutes before market closing) is $\leq -2.5\%$ and up-days when the average 30 minutes open-to-close price movement is $\geq 2.5\%$. We limit our sample to stocks (422) that have valid observations in both Bear and Bull markets and on both down- and up-days. We calculate daily values for each stock, and then average them across the whole sample.

are \$0.2543 and \$0.2576 for (Up, Bull) and (Down, Bull) market conditions, respectively, with a t-statistic of 1.63. The differences across other market conditions are also very marginal. On up-days, the quoted spreads are \$0.2543 in a Bull market versus \$0.2470 in a Bear market. The results based on effective spreads are similar (Panel B). Neither the cross-market, nor the cross-day differences are significant.

To further verify our results regarding the effect of order imbalance on liquidity, we run the following time-series ordinary least square (OLS) regressions for each stock:

$$\log(\mathrm{Qspread}_t) = a_0 + a_1\log(\mathrm{Risk}_t) + a_2\log(\mathrm{Price}_t) + a_3\log(\mathrm{Vol}_t) + a_4\log(|\mathrm{Imbsh}_t|) + \mu_t, \tag{6}$$

$$\log(\mathrm{EffSpread}_t) = b_0 + b_1\log(\mathrm{Risk}_t) + b_2\log(\mathrm{Price}_t) + b_3\log(\mathrm{Vol}_t) + b_4\log(|\mathrm{Imbsh}_t|) + \varepsilon_t. \tag{7}$$

where, subscript t is the tth trading day and $t=1, 2,\ldots, N$; QSpread is the quoted spread associated with prevailing trades and EffSpread is the effective spread; Price and Risk are the mean and standard deviation of quoted midpoint at bid and ask prices; Vol is trading volume in number of shares; and |Imbsh| is the absolute value of the difference between the trading volume (shares) of buyer- and seller-initiated trades.

The reason for including Risk, Price, and Volume as independent variables is that both theoretical and empirical evidences show that these variables are the main determinants of spreads. We use the logarithm of the dependent variables and independent variables in the regression, so that the estimated coefficient measures the 'elasticity' of the quoted spread (effective spread) with respect to changes in order imbalance, i.e., percentage change in the quoted spread (effective spread) given 1% change in the order imbalance. We repeat these regressions for each stock and average the regression coefficients across the whole sample. Z-statistics are the sum of the individual t-statistics divided by the square root of number of regressions ($N=430$). We use the Z-statistic to test the hypothesis that the average coefficients are not different from zero.

Table 5 summarizes the average regression coefficients. In both the quoted and effective spread regressions, all variables are significant except order imbalance. The coefficients on price and risk are all positive and significantly different from zero, while the coefficients on trading volume are always negative and significantly different from zero. These results suggest that high price and large risk stocks have wider spreads, while actively traded stocks have small spreads, consistent with previous studies. The insignificant coefficients on order imbalance suggest that the effect of imbalance on spreads is negligible, consistent with the observations in Table 4. Our results provide indirect support for the inventory models of Stoll (1978) and Ho and Stoll (1983), which suggest that spreads are independent of inventory level.

As an additional robustness test, we also run a pooled-time series regression. Specifically, we calculate the sample averages of the related variables on each trading day, and then run a time series regression for the whole sample during the Bull market, the Bear market, and during the whole test period. The results are consistent with those in Table 5 and not reported for brevity.

Table 5
Regression of spreads

	Intercept	log(Risk)	Log(Price)	log(Vol)	log(|Imbsh|)	Adj-R^2
Panel A: Bull market						
Dependent variable = log(Qspread)						
Coeff	−0.5242	0.0865	0.7335	−0.2104	0.0002	0.5160
Z-stat	−14.60	73.34	108.12	−95.18	−0.51	
P-value	0.00	0.00	0.00	0.00	0.58	
Dependent variable = log(Effspread)						
Coeff	−1.9617	0.1814	0.8272	−0.1393	−0.0030	0.4014
Z-stat	−29.68	53.67	60.87	−45.06	−1.36	
P-value	0.00	0.00	0.00	0.00	0.17	
Panel B: Bear market						
Dependent variable = log(Qspread)						
Coeff	−0.2753	0.1769	0.3718	−0.1546	−0.0001	0.4120
Z-stat	−15.05	62.40	87.08	−56.73	−0.92	
P-value	0.00	0.00	0.00	0.00	0.36	
Dependent variable = log(Effspread)						
Coeff	−1.4762	0.2025	0.3105	−0.0771	0.0009	0.3997
Z-stat	−36.72	67.69	67.38	−26.13	−0.59	
P-value	0.00	0.00	0.00	0.00	0.56	

We specify time-series ordinary least square (OLS) regressions for each stock as:

$$\log(\mathrm{QSpread}_t) = a_0 + a_1\log(\mathrm{Risk}_t) + a_2\log(\mathrm{Price}_t) + a_3\log(\mathrm{Vol}_t) + a_4\log(|\mathrm{Imbsh}_t|) + \mu_t,$$

$$\log(\mathrm{EffSpread}_t) = b_0 + b_1\log(\mathrm{Risk}_t) + b_2\log(\mathrm{Price}_t) + b_3\log(\mathrm{Vol}_t) + b_4\log(|\mathrm{Imbsh}_t|) + \varepsilon_t$$

where, subscript t is the tth trading day and $t=1, 2,\ldots, N$; QSpread is quoted spreads associated with prevailing trades; Effspread is effective spread; Price and Risk are the mean and standard deviation of the quoted midpoint at bid and ask prices; Vol is trading volume in number of shares; and |Imbsh| is the absolute value of the difference between the trading volume (shares) of buyer- and seller-initiated orders. We repeat the regression for each individual stock and average the regression coefficients for the whole sample. Z-statistics are the sum of t-statistics of individual stock regression divided by the square root of total number of observations ($N=430$).

3.4. Quoted depths and market condition

Lee et al. (1993), Seppi (1997), Kavajecz (1999), and many others show that specialists and other liquidity suppliers use both quoted prices and depths strategically to avoid the risk of trading with informed traders. We conjecture that the Nasdaq market makers also adjust both prices and depths when they manage their inventory. Although the Nasdaq market makers are required to make two-side quotes, they may quote actual depth on bid (ask) side to reflecting his buying (selling) interests as either an agent or a principal, and the required minimum depth on ask (bid) side that is priced far away from the inside market quote. Evidence shows that market makers make competitive quotes only on one side most of time (Chan et al., 1995).

To see how market makers use depths strategically under different market conditions, we classify market makers' two-sided quotes, *Quote(Bid, Ask)*, into four categories based on whether their quotes are at the inside market quotes or not. Bid (or Ask) = "I" when a market maker's quoted bid (or ask) price is at the inside market, i.e., a market maker's quoted bid (or ask) price is the highest (lowest) price among all available quotes at a given time. Bid (or Ask) = 'N' when a market maker's quoted bid (or ask) is not at the inside market. The four quote classes are summarized as:

Quote (Bid = I, Ask = N): only quoted bid price is at the inside market;
Quote (Bid = N, Ask = I): only quoted ask price is at the inside market;
Quote (Bid = I, Ask = I): both quoted bid and ask prices are at the inside market; and
Quote (Bid = N, Ask = N): neither quoted bid nor quoted ask price is at the inside market.

A quote denoted as *Quote(Bid = N, Ask = I)* suggests that the market maker is interested in selling only. Similarly, *Quote(Bid = I, Ask = N)* suggests that the market maker is interested in buying only. *Quote(Bid = I, Ask = I)* implies that the market maker makes competitive quotes on both sides and suggests interest in both buying and selling. In contrast, *Quote(Bid = N, Ask = N)* suggests that the market maker is not interested in trading on either side.[3]

Table 6 presents market makers' quoted depths under different market conditions. As expected, market makers quote larger depths when their quotes are at inside market. For example, when only one side quote is at inside market, the average quoted depths on this side is about 1.5 times of that on the opposite side. When both quotes are at inside market quote, the average quoted depth is more than 1.5 times the average depth when quoting away from the inside market. These results are consistent with the findings of Chung and Zhao (2003) and suggest that large depths at inside market quote reflect market makers' interest of trade and their liquidity supply.

More importantly, we find that quoted depths are also affected by price movements. For *Quote(Bid = N, Ask = I)* class, i.e., only the ask quote is at inside market, the quoted depths on ask side on up-days is significantly larger than that on down-days, while difference on bid side is negligible. For example, in a Bull market, the average ask-side depths are 600.89 shares on up-days and 507.87 shares on down-days (Panel A). The difference is about 93 shares on average (t-stat = −14.17). The results in a Bear market are similar. The average ask-side depths are 71 shares more on up-days than on down-days (Panel B). This suggests that market makers increase liquidity supply and provide more depths on ask side when excess buying pressure exists on up-days.

In contrast, for *Quote(Bid = I, Ask = N)* class, i.e., only bid quote is at inside market, the quoted depths on bid side are significantly larger on down-days than on up-days, while the differences on ask side are not significant. Similarly, this suggests that market makers increase liquidity supply by quoting more shares on bid-side when excess selling pressure exists on down-days.

[3] The results reported in the current section and next section exclude quotes in Electronic Communication Networks (ECNs). The reason for excluding ECN quotes is that these quotes come either from limit orders submitted by market makers or from investors, which may not reflect market makers' interest in trading. The results are essentially unchanged when we repeat our tests with quotes from both ECNs and market makers.

Table 6
Quoted depths at different quote classes

Quote classes	Down-days		Up-days		Difference (down-day – up-day)	
	Depth at bid	Depth at ask	Depth at bid	Depth at ask	Difference at bid (t-stat)	Difference at ask (t-stat)
Panel A: Bull market (10/10/99–12/31/99)						
Quote (Bid = N, Ask = I)	336.59	507.87	338.63	600.89	– 2.03 (– 0.48)	– 93.02 (– 14.17*)
Quote (Bid = I, Ask = N)	564.18	363.33	498.61	363.47	65.58 (7.23*)	– 0.14 (– 0.03)
Quote (Bid = I, Ask = I)	492.84	492.00	488.26	523.37	4.59 (0.41)	– 31.37 (– 3.30)
Quote (Bid = N, Ask = N)	310.39	325.93	311.58	341.23	– 1.20 (– 0.43)	– 15.29 (– 4.82*)
Panel B: Bear market (03/10/00–05/31/00)						
Quote (Bid = N, Ask = I)	351.19	528.73†	358.69	599.65	– 7.50 (– 0.95)	– 70.93 (– 7.50*)
Quote (Bid = I, Ask = N)	599.59†	364.65	527.98†	347.61	71.61 (6.78*)	17.05 (3.41*)
Quote (Bid = I, Ask = I)	515.74	512.55	480.44	510.58	35.30 (2.66)	1.97 (0.17)
Quote (Bid = N, Ask = N)	325.68	327.19	325.84	324.36	– 0.16 (– 0.03)	2.83 (0.86)

Market makers' quotes are classified into four classes: *Quote(Bid = N, Ask = I)*, when a market maker's quoted ask price is the lowest ask price (ask price at inside market), but the quoted bid price is not the highest bid price; *Quote(Bid = I, Ask = N)*, when a market maker's quoted bid price is the highest bid price, but the quoted ask price is not the lowest ask price; *Quote(Bid = I, Ask = I)*, when a market maker's quoted bid price is the highest bid price and the quoted ask price is the lowest ask price; *Quote(Bid = N, Ask = N)*, when a market maker's quoted bid price is not the highest bid price and the quoted ask price is not the lowest ask price. For each stock, we first calculate daily average quoted depths (shares) at each quote class under different market conditions. Then, we average the quoted depths for the whole sample. We define down-days when the average 30 minutes open-to-close price movement (midpoint at the bid–ask prices during the first 30 minutes after market opening and the last 30 minutes before market closing) is ≤ – 2.5% and up-days when the average 30 minutes open-to-close price movement is ≥ 2.5%. The period of 10/10/99 to 12/31/99 is defined as a Bull market and the period of 03/10/00 to 05/31/00 as a Bear market. We limit our sample to stocks (422) that have valid observations in both Bull and Bear markets and on both down- and up-days. "*" indicates 0.01 significance level. "†" indicates that quoted depth in a Bear market differs from that of the corresponding quote class in a Bull Market at 0.05 significance level.

When both bid and ask quotes are at inside market, i.e., *Quote (Bid = I, Ask = I)*, some differences still exists. In a Bull market, the quoted depths at ask-side on up-days are larger than that on down-days, while in a Bear market, the quoted depths at bid-side on down-days is larger than that on up-days. This is due to the difference in the buying and selling pressure, because in a Bull market, more buying pressure exists on up-days, while in a Bear market, more selling pressure exists on down-days. These results, again, show that market makers use depths to provide liquidity to handle order imbalance.

As additional evidence, we also report quote frequency at different quote classes. In a Bull market (Table 7, Panel A), for example, the daily quote frequency of *Quote(Bid = N, Ask = I)* is about 16.36% of the total quotes on down-days and about 17.35% on up-days. The relative higher frequency on up-days is consistent with the results reported in Table 2 that there are more public buy orders than sell orders on up-days and is in accordance with market makers' liquidity supply behavior. The frequency of *Quote(Bid = I, Ask = N)* is about 17.96% of the total quotes on down-days and about 17.4% on up-days. The frequency of *Quote(Bid = I, Ask = I)* ranges from 3.7% to 3.8%. In contrast, the frequency of *Quote(Bid = N, Ask = N)* is about 62% of total quotes. The results in a Bear market (Panel B) are similar to those in a Bull market. These results are consistent with the findings of Chung and Zhao (2003).

Table 7
Quote frequency at different quote classes

Quote class	Down-days	Up-days	Difference (down-day − up-day)
Panel A: Bull market (10/10/99–12/31/99)			
Quote (Bid = N, Ask = I)	0.1636	0.1735	−0.0098 (−7.07*)
Quote (Bid = I, Ask = N)	0.1796	0.1740	0.0056 (3.82*)
Quote (Bid = I, Ask = I)	0.0383	0.0371	0.0013 (1.56)
Quote (Bid = N, Ask = N)	0.6202	0.6170	0.0032 (2.30**)
Panel B: Bear market (03/10/00–05/31/00)			
Quote (Bid = N, Ask = I)	0.1607	0.1738	−0.0131 (−9.55*)
Quote (Bid = I, Ask = N)	0.1906	0.1830	0.0076 (5.06*)
Quote (Bid = I, Ask = I)	0.0431	0.0428	0.0003 (0.31)
Quote (Bid = N, Ask = N)	0.6078	0.6031	0.0048 (3.05*)

Market makers' quotes are classified into four classes: *Quote(Bid = N, Ask = I)*, when a market maker's quoted ask price is the lowest ask price (ask price at inside market), but the quoted bid price is not the highest bid price; *Quote(Bid = I, Ask = N)*, when a market maker's quoted bid price is the highest bid price, but the quoted ask price is not the lowest ask price; *Quote(Bid = I, Ask = I)*, when a market maker's quoted bid price is the highest bid price and the quoted ask is the lowest ask price; *Quote(Bid = N, Ask = N)*, when a market maker's quoted bid price is not the highest bid price and the quoted ask price is not the lowest ask price. For each stock, we first count the daily number of quotes in each class and total number of quotes. Then, we divide the number of quote in each class by the total number of quotes to compute proportion of quote frequency. Finally, we average the daily proportion of quote frequency for the whole sample under different market conditions. We define down-days when the average open-to-close price movement (midpoint at the bid–ask prices during the first 30 minutes after opening and the last 30 minutes before closing) is $\leq -2.5\%$ and up-days when the average open-to-close price movement is $\geq 2.5\%$. The period of 10/10/99 to 12/31/99 is defined as a Bull market and the period of 03/10/00 to 05/31/00 as a Bear market. We limit our sample to stocks (422) that have valid observations in both Bull and Bear markets and on both down- and up-days. Numbers in parentheses are *t*-statistics. "*" and "**" indicate 0.01 and 0.05 significance level.

3.5. Quote distance from inside market midpoint

To test how the Nasdaq market makers respond to order imbalance, we measure quote competitiveness as the quote distance from the midpoint of inside market as in Hansch et al. (1998). If inventory effect dominates market makers' quote decision, excess buying (selling) from public investors reduces (increases) market makers' inventory and forces market makers to quote more aggressively on bid (ask) side and less competitively on ask (bid) side. However, if liquidity supply dominates market makers' quote decision, they would quote less competitively on bid side and more competitively on ask side when public buying exceeds public selling. Similarly, if market makers take advantage of temporal order imbalance and trade for profit by taking on the opposite side of public orders, they would quote more competitively on ask side when public buying exceeds public selling.

Table 8 summarizes quote distance for each quote classes. For *Quote(Bid = N, Ask = I)* class, the distance on ask side is about the same under all market conditions. For example, in a Bull market, the average quote distance is \$0.1333 on down-days and \$0.1307 on up-days (Panel A); in a Bear market, it is \$0.1336 on down-days and \$0.1330 on up-days. This suggests that when market makers make competitive quotes only at inside ask, they behave in the same way across up- and down-days. However, the quote distance on bid-

Table 8
Quote distance from the inside market midpoint

	Down-days		Up-days		Difference (down-day − up-day)	
	Distance bid side	Distance ask side	Distance bid side	Distance ask side	Difference at bid (t-stat)	Difference at ask (t-stat)
Panel A: Bull market (10/10/99–12/31/99)						
Quote (Bid = N, Ask = I)	\$1.0331	\$0.1333	\$1.2071	\$0.1307	−\$0.1741 (−12.81*)	0.0026 (2.27)
Quote (Bid = I, Ask = N)	0.1343	1.2348	0.1314	1.1007	0.0029 (2.46)	0.1340 (7.40*)
Quote (Bid = I, Ask = I)	0.1533	0.1533	0.1484	0.1484	0.0049 (2.91*)	0.0049 (2.91*)
Quote (Bid = N, Ask = N)	1.0259	1.2681	1.2048	1.0635	−0.1789 (−16.07*)	0.2046 (17.42*)
Panel B: Bear market (03/10/00–05/31/00)						
Quote (Bid = N, Ask = I)	1.2447	0.1336	1.4245	0.1330	−0.1798 (−12.39*)	0.0006 (0.45)
Quote (Bid = I, Ask = N)	0.1370	1.5475	0.1349	1.3840	0.0021 (1.32)	0.1635 (9.63*)
Quote (Bid = I, Ask = I)	0.1573	0.1573	0.1565	0.1565	0.0008 (0.32)	0.0008 (0.32)
Quote (Bid = N, Ask = N)	1.2944	1.6671	1.5118	1.4299	−0.2174 (−15.71*)	0.2372 (15.96*)

Market makers' quotes are classified into four classes: *Quote(Bid = N, Ask = I)*, when a market maker's quoted ask price is the lowest ask price (ask price at inside market), but the quoted bid price is not the highest bid price; *Quote(Bid = I, Ask = N)*, when a market maker's quoted bid price is the highest bid price, but the quoted ask price is not the lowest ask price; *Quote(Bid = I, Ask = I)*, when a market maker's quoted bid price is the highest bid price and the quoted ask is the lowest ask price; *Quote(Bid = N, Ask = N)*, when a market maker's quoted bid price is not the highest bid price and the quoted ask price is not the lowest ask price. For each stock, we first calculate average bid and ask distances from the inside market midpoint. Then, we average the quote distances for the whole sample. We define down-days when the average 30 minutes open-to-close price movement (midpoint at the bid–ask prices during the first 30 minutes after market opening and the last 30 minutes before market closing) is ≤ −2.5% and up-days when the average 30 minutes open-to-close price movement is ≥ 2.5%. The period of 10/10/99 to 12/31/99 is defined as a Bull market and the period of 03/10/00 to 05/31/00 as a Bear market. We limit our sample to stocks (422) that have valid observations in both Bear and Bull markets and on both down- and up-days. "*" indicates 0.01 significance level.

side is quite different across up- and down-days. In both Bull and Bear markets, the distance is about \$0.17 to \$0.18 less on down-days than that on up-days (also see Fig. 2, Panel A for the whole period). Although the quotes at bid may not be meaningful when market makers only quote ask price at inside market, the significant difference in the bid-side quote distance may reveal additional information. We will discuss this issue in detail in Section 3.6.

For *Quote(Bid = I, Ask = N)* class, the situation reverses. The bid-side distance is about the same (\$0.13) under all conditions, while the difference on ask-side becomes significant. In a Bull market, the ask-side quote distance is about \$1.23 on down-days and \$1.10 on up-days. The difference is about \$0.13 and significant at 0.01 level. The difference is even greater (\$0.16) in a Bear market. Again, the quotes at ask price may not be meaningful when market makers only quote bid price at inside market. However, the large difference in ask-side distance across up- and down-days is worth additional attention. We will further explore this issue in the following section.

When both ask and bid quotes are at inside market, i.e., *Quote(Bid = I, Ask = I)*, the quote distance is about \$0.15 on both sides and does not have significant variation across market conditions. This is consistent with our findings in Section 3.3, which shows that spreads are not affected by market conditions.

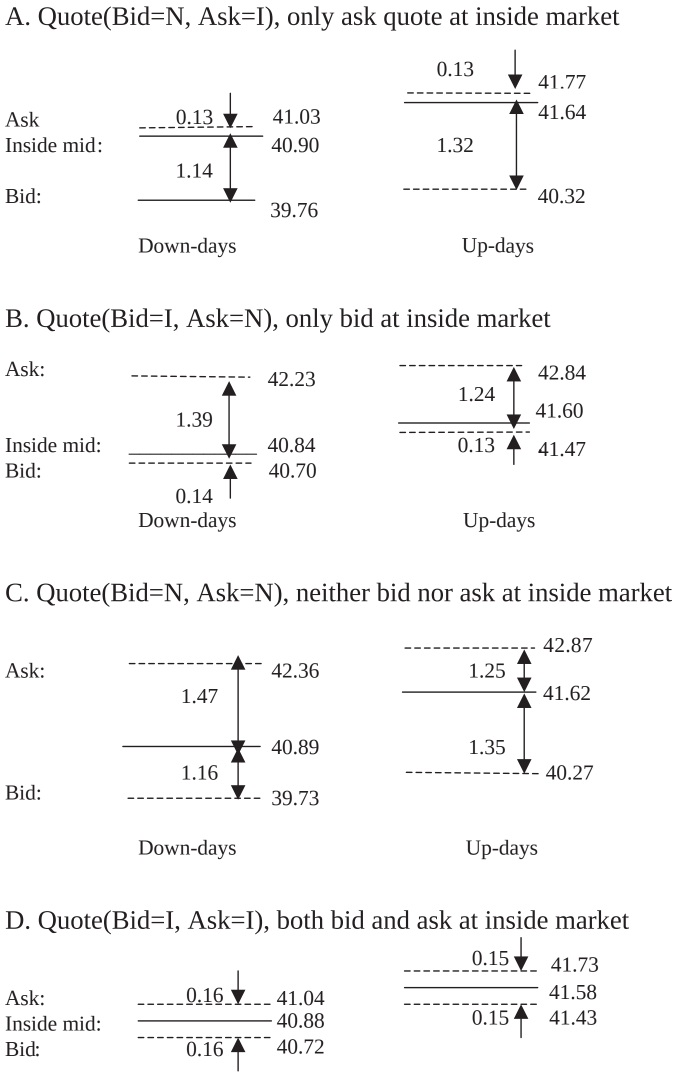

Fig. 2. Quote distance from inside market midpoint during the whole test period. Note: these figures are not in exact scale.

3.6. Quote frequency and market makers' competition at inside bid and inside ask

Theoretically, when market makers quote at one side of the inside market, they are interested in trading on that side only, and the quote on the other side may not be meaningful. However, the special institutional feature of Nasdaq enables market markers to obtain orders without quoting at inside market. The literature shows that brokers and dealers on Nasdaq frequently send their customers' orders to any dealer who agrees to execute the order at the best quoted price even though the dealer who received the order may not quote the best price at the time of order receipt. Brokers and dealers also routinely direct orders to an affiliated dealer.[4]

Hence, we conjecture that the quote distance on the opposite of the inside market may reveal additional information that is not captured by the inside quote. When market makers quote only at inside ask, the smaller distance on bid-side during down-days possibly suggests that they are more competitive on bid-side during down-days than during up-days. In other words, even though market makers do not quote at inside bid, they still compete to buy when public selling exceeds public buying during down-days. Similarly, the smaller distance on ask-side during up-days when market makers quote only at inside bid may suggest that market makers are more competitive on ask side during up-days.

To test this possibility, we conduct the following tests. First, we compare the daily frequency of *Quote(Bid=I, Ask=N)* with that of *Quote(Bid=N, Ask=I)*. *Quote(Bid=I, Ask=N)* occurs more frequently than *Quote(Bid=N, Ask=I*) does on down-days, suggesting that market makers are more competitive on bid-side during down-days. For example, in a Bull market (Panel A of Table 9), the average daily frequency of *Quote(Bid=I, Ask=N)* is 193.87 on down-days, while the frequency of *Quote(Bid=N, Ask=I)* is only 164.50. The difference is significant at the 1% level (with a t-statistic of -10.15). To reduce the effect of extreme numbers, we also adopt Wilcoxon signed rank non-parametric test, which compares the ranks instead of the actual values. The related Wilcoxon Z-statistic is -6.70, which also suggests that quote frequency at inside bid is higher than quote frequency at inside ask during down-days. The result is reversed on up-days.

Second, we compare the proportion of market makers quoting *(Bid=I, Ask=N)* to the proportion of market makers quoting *(Bid=N, Ask=I)*. In a Bull market, for example, there are 63.38% of market makers quoting *(Bid=I, Ask=N)* at least once a day during down-days, while only 60.54% of them quoting *(Bid=N, Ask=I)* during the same period. Both the t-statistic (-11.69) and Wilcoxon Z-statistic (-12.22) reject the null hypothesis that the proportion of market makers who quote at inside bid and at inside ask is the same. However, during up-days, more than 68.61% of market makers quote *(Bid=N, Ask=I)*, while only 66.59% quote *(Bid=I, Ask=N)*. The results in a Bear market (Panel B) are similar to the results in a Bull market.

Third, comparing the proportion of market makers who quote *(Bid=I, Ask=N)* and *(Bid=N, Ask=I)* may not accurately reflect the quoting competition, since it ignores a market maker's quote frequency at a given quote class. For example, Market Maker A may quote 100 times with *(Bid=I, Ask=N)* during a day, while Market Maker B may quote *(Bid=I, Ask=N)* only once during the given day. However, these two market makers are considered equally competitive using the above comparison method. To avoid this measurement weakness, we also compare the proportion of market makers who make more *(Bid=I, Ask=N)* quotes than *(Bid=N, Ask=I)* quotes with the proportion of market makers who make fewer *(Bid=I, Ask=N)* quotes than *(Bid=N, Ask=I)*. We find that the

[4] See Christie and Schultz (1994), Chordia and Subrahmanyam (1995), Battalio et al. (1997), Chung et al. (2004), among others, for detailed discussions.

Table 9
Quote frequency and proportion of market makers quoting at inside bid and inside ask

Panel A: Bull market (10/10/99–12/31/99)

	Quote frequency (Bid=I, Ask=N)	Quote frequency (Bid=N, Ask=I)	Paired *t*-test (*t*-stat)	Wilcoxon signed rank test (*Z*-stat)
Down-day	193.87	164.50	−10.15*	−6.70*
Up-day	240.99	259.86	7.30*	1.95**
	% of MMs quoting (Bid=I, Ask=N)	% of MMs quoting (Bid=N, Ask=I)	Paired *t*-test (*t*-stat)	Wilcoxon signed rank test (*Z*-stat)
Down-day	63.38	60.54	−11.69*	−12.22*
Up-day	66.59	68.61	7.09*	9.20*
	% of MMs quoting (Bid=I>Ask=I)	% of MMs quoting (Bid=I<Ask=I)	Paired *t*-test (*t*-stat)	Wilcoxon signed rank test (*Z*-stat)
Down-day	38.42	32.27	−14.83*	−30.67*
Up-day	35.65	39.78	8.42*	19.38*

Panel B: Bear market (03/10/00–05/31/00)

	Quote Frequency (Bid=I, Ask=N)	Quote frequency (Bid=N, Ask=I)	Paired *t*-test (*t*-stat)	Wilcoxon signed rank test (*Z*-stat)
Down-day	236.61	187.24	−9.06*	−10.12*
Up-day	232.79	240.97	3.29*	−0.30
	% of MMs quoting (Bid=I, Ask=N)	% of MMs quoting (Bid=N, Ask=I)	Paired *t*-test (*t*-stat)	Wilcoxon signed rank test (*Z*-stat)
Down-day	62.22	57.54	−18.66*	−21.30*
Up-day	63.05	63.16	0.33	2.07**
	% of MMs quoting (Bid=I>Ask=I)	% of MMs quoting (Bid=I<Ask=I)	Paired *t*-test (*t*-stat)	Wilcoxon signed rank test (*Z*-stat)
Down-day	40.00	29.38	−23.15*	−53.74*
Up-day	35.83	36.06	0.44	3.06*

To compare quotation competition, we first calculate the daily *quote frequency* of *Quote(Bid=I, Ask=N)* and *Quote(Bid=N, Ask=I)* for each stock under different market conditions. Then, we compute the averages across the whole sample. We conduct paired comparison to investigate the difference in the quote frequency of these two quote classes and report *t*-statistics. To avoid the effect of extreme numbers, we also use Wilcoxon signed rank test, which compares ranks instead of raw numbers. Similarly, we compare the proportion of market makers having at least one (Bid=I, Ask=N) quote (*% of MM quoting (Bid=I, Ask=N)*) with that of having at least one (Bid=N, Ask=I) quote (*% of MM quoting (Bid=N, Ask=I)*) on daily basis. In addition, we also compare the proportion of market makers having more (Bid=I, Ask=N) quotes than (Bid=N, Ask=I) quotes (*% of MMs quoting Bid=I>Ask=I*) with the proportion of market makers having fewer (Bid=I, Ask=N) quotes than (Bid=N, Ask=I) quotes (*% of MMs quoting Bid=I<Ask=I*). We define down-days when the average open-to-close price movement (midpoint at the bid–ask prices during the first 30 minutes after opening and the last 30 minutes before closing) is ≤ −2.5% and up-days when the average open-to-close price movement is ≥ 2.5%. The period of 10/10/99 to 12/31/99 is defined as a Bull market and the period of 03/10/00 to 05/31/00 as a Bear market. We limit our sample to stocks (422) that have valid observations on both down- and up-days. Numbers in parentheses are *t*-statistics. "*" and "**" indicate 0.01 and 0.05 significance level.

proportion of market makers who make more *(Bid=I, Ask=N)* quotes than *(Bid=N, Ask=I)* quotes is significantly larger than the proportion of market makers who make fewer *(Bid=I, Ask=N)* quotes than *(Bid=N, Ask=I)* during down-days. The result is reversed during up-days. Again, this suggests that market makers are more competitive on bid-side during down-days, and on ask-side during up-days.[5]

These results may have other explanations. For instance, it may simply reveal the difference in institutional buy and sell interests during these times. In other words, small investors' buy interest during down-days has been eaten up and all that remains is the institutional (and market maker) buy interest. A market maker who is working an institutional buy order wants to be far away from the ask price as possible, because he does not want to sell any shares. If this were the case, the ask-side distance on down-days would be greater. A similar explanation applies to the larger bid-side distance on up-days.

To test this possibility, we separate market makers with large institutional base (classified as either institutional or bulge bracket firms) from others and repeat our tests. The results show that even though the ask-side distance on down-days and the bid-side distance on up-days are slighter larger for market makers with large institutional base, the differences are very marginal and economically insignificant. In other words, institutional interest could not explain the observed results. The results are not included for brevity.

3.7. Robustness tests

To test whether the observed results are unique for the Internet sector, we also select a control sample by matching each stock in our sample with non-Internet related Nasdaq stocks based on average price, volatility (standard deviation of price), firm size, and trading volume in September 1999. We chose these matching variables because empirical evidence suggests that they have important effects on trades and quotes. We replicate all the analyses and the results for the Internet related and non-Internet stocks are qualitatively similar. For brevity, we do not report the results based on the control sample, but they are available upon request.

4. Conclusions and discussions

Although the question of how order imbalance affects the Nasdaq market makers' quotation is an important issue, it has not been well addressed in the literature to date. Market wide order imbalance affects market makers' quotations largely from inventory considerations. However, inventory models provide an incomplete explanation of market makers' liquidity supply because predictions on how order imbalance affects market liquidity conflict, and because most inventory models do not incorporate quoted depths in market makers' liquidity supply schedule. In this study, we provide empirical evidence on this important issue. Our main findings based on a sample of 430 Internet related Nasdaq stocks are as follows.

[5] We thank the anonymous referee for this suggestion.

First, order imbalance does not have significant effects on spreads. The results are robust and consistent after controlling for other variables. Second, market makers use both quoted prices and depths when they deal with order imbalance. They quote more shares on ask side when public buying pressure is more intense during up-days in a Bull market. They also quote more shares on bid-side when public selling exceeds public buying during down-days in a Bear market. Third, market makers are more competitive on bid-side during down-days, and on ask-side during up-days. These suggest that market makers compete to buy when public sells exceed public buys on down-days and compete to sell when public buys exceed sells on up-days. More importantly, we find that investors trading behavior also varies. They tend to under-react to good news (up-days) in a Bear market.

Although we analyze how order imbalance affects market makers' liquidity supply in the current study, we have no direct evidence on how individual market maker's inventory is related to his quotation behavior due to the lack of inventory data. Also, we are not able to analyze when market makers engage in inter-dealer trades and how they share their inventory risks during market-wide price movements. These are interesting issues and addressing them would contribute more to the inventory control literature.

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