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Limit orders and the bid–ask spread[☆]

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Abstract

We examine the role of limit-order traders and specialists in the market-making process. We find that a large portion of posted bid–ask quotes originates from the limit-order book without direct participation by specialists, and that competition between traders and specialists has a significant impact on the bid–ask spread. Specialists' spreads are widest at the open, narrow until late morning, and then level off. The *U*-shaped intraday pattern of spreads largely reflects the intraday variation in spreads established by limit-order traders. Lastly, the intraday variation in limit-order spreads is significantly related to the intraday variation in limit-order placements and executions. © 1999 Elsevier Science S.A. All rights reserved.

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1. Introduction

In a quote-driven market, such as the Nasdaq system, market makers quote the ask and bid prices at which investors can buy or sell shares. In an order-driven market, such as the Tokyo Stock Exchange, investors buy and sell at the ask and bid prices established through previously placed limit orders. The NYSE and Amex are hybrid markets in which both specialists and limit-order traders establish prices. The NYSE/Amex specialists must reflect in their quotes the highest bid price and the lowest ask price posted in the limit-order book when these limit prices better their own quotes. Harris and Hasbrouck (1996) report that limit orders account for about 54% of all orders submitted through SuperDOT. Hence, limit orders are expected to exert a significant influence on the bid–ask quotes on the NYSE and Amex. In this study, we perform an empirical analysis of the impact of limit orders on the posted bid–ask spread.

Much of the theoretical work on market microstructure focuses on the optimal quote behavior of one or more dealers under different information environments and/or demand and supply processes.[1] While some of these studies recognize that the specialist can face competition from limit-order traders, none of them explicitly consider the role of limit-order traders. O'Hara and Oldfield (1986) analyze the dynamic pricing policy of a risk-averse market maker who receives both limit and market orders. However, O'Hara and Oldfield assume that both market and limit orders are executed against only the market maker's quotes.

A number of studies analyze cross-sectional and/or time-series variations in quoted spreads on the NYSE as an attempt to test specialist models of spreads.[2] However, the NYSE specialist participates in fewer than 20% of trades with over 80% of the liquidity provided by other traders (New York Stock Exchange, Fact Book, 1992). The analytical framework that focuses on specialist behavior, therefore, might not be suitable for predicting price-setting behavior in a hybrid market such as the NYSE.

Only recently have researchers begun to study the various aspects of limit-order trading. Glosten (1994) considers an equilibrium model in which limit-order traders gain from liquidity-driven price changes but lose from information-driven price changes. Glosten considers two distinct types of traders, those who trade by limit orders and those who trade by market orders, but does not endogenize the trader's decision to use a limit or market order. Handa and

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[1] See Stoll (1978), Amihud and Mendelson (1980), Copeland and Galai (1983), Ho and Stoll (1980,1981,1983) Glosten and Milgrom (1985), Glosten (1989), and Easley and O'Hara (1992)

[2] See Glosten and Harris (1988), Chiang and Venkatesh (1988), McInish and Wood (1992), Affleck-Graves et al. (1994), Chan et al. (1995b), and Huang and Stoll (1997).

Schwartz (1996) extend Glosten's analysis by examining the investor's optimal choice between market and limit orders.

Harris and Hasbrouck (1996) conduct an empirical investigation of the relative performance of market and limit orders. They find that limit orders placed at, or better than, the prevailing quote perform better compared to market orders. Greene (1997) develops a methodology for inferring limit-order executions from transactions and quote data, and finds that trading costs are about three to four cents less per share on a round-trip transaction when purchases and sales are executed against the limit-order book. Kavajecz (1999) compares the limit-order book spread with the quoted spread of specialists. His study suggests that specialists play an important role in narrowing the spread, especially for smaller and less frequently traded stocks. Kavajecz's study is similar to ours in that it also examines whether quoted spreads reflect the trading interest of specialists or limit-order traders. However, Kavajecz neither analyzes intraday variations in spreads nor tests theoretical models of specialist behavior.

In this paper, we perform an empirical analysis of the effect of limit orders on NYSE spreads. Our analysis helps explain why the NYSE exhibits lower execution costs (i.e., lower spreads) than does the purely quote-driven Nasdaq market.[3] Our study also provides additional insight on the intraday pattern of spreads. To test the specialist models of spreads, previous studies (e.g., McInish and Wood, 1992; Brock and Kleidon, 1992; Lee et al., 1993; Chan et al., 1995a,b) use data on quoted spreads for NYSE stocks. However, the available NYSE quotes can reflect specialist or limit-order interest. In this study, we determine for a sample of NYSE stocks whether each spread quote is from the specialist, the limit-order book, or both. Then, to test the specialist models of spreads, we examine the intraday pattern of spreads that originate from specialists. In addition, we trace the intraday pattern of spreads that originate from the limit-order book.

We find that the majority of bid–ask quotes reflect the interest of limit-order traders. Specialists tend to quote more actively for low-volume stocks and during early hours of trading when there are fewer limit orders submitted. Spreads are widest when both the bid and ask prices are quoted by specialists

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[3] See Huang and Stoll (1996) and Bessembinder (1997) for recent findings on differential execution costs between NYSE and Nasdaq stocks. Recent Securities and Exchange Commission (SEC) rules introduce competition from limit orders into the Nasdaq market. The first SEC rule, known as the limit order display rule, requires that market makers display investors' limit orders in their quotes when they are priced better than the market maker quote. The second SEC rule, known as the quote rule, requires market makers to publicly display their most competitive quotes. Previously, market makers placed orders on proprietary systems that may have been priced more favorably than their public quotes. Private system prices were only available to financial professionals.

alone, and narrowest when both sides of the quote originate from the limit-order book. We find that specialist spreads are widest at the open, narrow until late morning, and then level off for the rest of the day. Our results suggest that the *U*-shaped intraday pattern of spreads (i.e., spreads falling sharply in the first few minutes of trading and rising in the last few minutes of the trading) largely reflects the intraday variation in spreads established by limit-order traders. We also find that the intraday variation in spreads is significantly associated with the intraday variation in competition among limit-order traders.

The paper is organized as follows. Section 2 discusses data and methodology. Section 3 presents our empirical findings on the relation between the posted bid–ask spread and the quote class. Section 4 offers a test of specialist models of spreads using only those quotes that reflect the trading interest of specialists. Section 5 examines the intraday variation in spreads originating from the limit-order book. Section 6 offers our conjecture on the underlying determinants of the intraday variation in spreads, and Section 7 concludes the paper.

2. Data and quote classification

2.1. Data source

The data for this study are obtained from the NYSE's TORQ (Trades, Orders, Reports, and Quotes) database. This database contains detailed information on consolidated transactions, quotes, the NYSE audit trail, and NYSE orders that are handled by the automated SuperDOT system. For a detailed description of the database, see Hasbrouck (1992) and Hasbrouck et al. (1993). The data cover 144 randomly selected stocks traded on the NYSE from November 1990 through January 1991. The data are restricted to standard (non-tick-sensitive) market and limit orders, and to day orders, i.e., orders that are marked on submission to expire at the close of the day. For this study, we use data from the quote and order files.

Although the TORQ database is the best database available for the task at hand, we note its limitations. First, it covers only 144 stocks and includes only orders submitted to the NYSE. Second, it includes only orders submitted through the electronic routing systems. Orders that are hand-carried to the specialist's post are not captured. Considering the large number and size of orders submitted by floor traders, our data might not be representative of the whole population. We also recognize that the TORQ database is seven years old, and that there have been some changes in the market. For example, the trading activity on stock markets has risen significantly in recent years. Also, on June 24, 1997, the tick size was reduced from \$1/8 to \$1/16 for NYSE stocks selling at or above \$1. The findings of this study, therefore, need to be interpreted with some caution.

2.2. Quote classification procedure

We classify all bid (ask) quotes in our sample into one of three categories according to whether the quote reflects the trading interest of the specialist, limit-order traders, or both. To determine whose interest is reflected in the quote, we partition each quoted depth into the depth provided by the specialist and the depth provided by limit-order traders. To determine the limit-order depth for each quote, we compile all outstanding limit orders at the same bid (ask) price (i.e., matching orders). We compile the matching orders from order, execution, and cancellation records in the TORQ database. Each order record contains information on the date and time of submission, the order type and quantity, and the limit price. Execution and cancellation records provide similar information about the underlying order as well as the execution (cancellation) time and quantity executed (cancelled). We obtain matching limit orders at any point in time by netting all prior executions and cancellations from the orders placed prior to the time in question. Matching orders are residual orders placed prior to the time in question and neither executed nor cancelled in their entirety as of the time in question.

If a bid (ask) quote has no matching limit orders, we categorize the quote as a specialist quote which we denote by quote class (S). Quote class (S) reflects cases in which either the specialist alone has posted the bid (ask) or all limit orders are at prices inferior to the specialist bid (ask) price. If a bid (ask) quote has one or more matching limit orders, we compare the quoted depth (i.e., size) at the bid (ask) with the depth of the matching limit order(s). If the former is equal to the latter, we categorize the bid (ask) quote as a limit-order bid (ask) quote which we denote by quote class (L). If the quoted depth is greater than the depth of the matching limit order(s), then we categorize it as a mixed quote by both the specialist and limit-order trader(s) and denote it by quote class (M); in this case the specialist adds depth to the limit order(s) at the limit-order price.

By following this procedure, we classify each quoted spread into quote class (x, y) where $x\,(x = \mathrm{S, L, M})$ represents the quote class for the bid price and $y\,(y = \mathrm{S, L, M})$ represents the quote class for the ask price. For example, (S, S) represents the quote class when both the bid and ask prices are quotes by the specialist alone. Similarly, (L, M) represents the quote class when the bid price is from the limit-order book and the ask price is a mixed quote by the specialist and limit-order trader(s).

2.3. Distribution of quoted spreads by quote class

To examine the distribution of spreads by quote class, we use the following procedure. For each stock, we cluster posted bid–ask quotes into six groups according to their respective quote class. The first group includes all quotes that belong to quote class (S, S). The second group includes all quotes that belong to either quote class (S, L) or (L, S); the third, all those in (S, M) or (M, S); the fourth, all those in (L,L); the fifth, all those in (L, M) or (M, L); and the last group includes all quotes in (M, M). Because we make no distinction between quote classes (x, y) and (y, x) in our empirical analysis, we merge them into a single class and label it simply as quote class (x, y). Hence, we label the second, third, and fifth quote groups above simply as (S, L), (S, M), and (L, M), respectively. In addition, we define (S, A) as the quote class that includes all spread quotes in which at least one side of the quote is from the specialist alone, with A denoting 'all' since it includes all three (S, L, and M) quote classes. Similarly, quote class (L, A) includes all spread quotes in which at least one side of the quote is exclusively from the limit-order book, and quote class (M, A) includes all spread quotes in which at least one side of the quote is the mixed quote. For each stock, we count the number of quotes in each of these quote groups. Finally, the number of quotes in each group is summed across our sample of stocks.

Table 1 shows the number of quotes in each quote class for our entire sample of stocks and for each trading volume quartile. The total number of sample quotes is 338,078. Of these, 92,867 (27.5%) quotes originate solely from limit-order traders on both sides of the quote. The number of quotes in which at least one side of the quote originates exclusively from limit-order traders [i.e., quote class (L, A)] is 253,256 (74.9%). On the other hand, the number of posted spreads quoted exclusively by the specialist [i.e., quote class (S,S)] is only 19,796 (5.9%). The number of quotes in which at least one side of the quote originates exclusively from the specialist [i.e., quote class (S, A)] is 98,940 (29.3%).

In many instances, the specialist quotes for his own trading interest, but does so at the same price as the limit-order price. The number of quotes in which the specialist adds depth to limit orders on both sides of the quote [i.e., quote class (M, M)] is 35,752 (10.6%). The number of quotes in which the specialist adds depth (in number of shares) to that of limit-order traders on at least one side of the quote [i.e., quote class (M, A)] is 175,545 (51.9%).

To examine whether the distribution of quotes varies among stocks with different trading volumes, we cluster our sample of stocks into four groups according to the average daily trading volume, and tabulate the number of quotes for each quote class within each volume quartile. The results (see Table 1) show that the proportion of quotes that belong to quote class (S, S) is 9.2% among stocks with the least volume, while the corresponding figure is only 3% for stocks with the largest volume. We obtain similar results for quote classes (S, L) and (S, M). On the whole, spread quotes in which as least one side of the quote is exclusively from the specialist [i.e., quote class (S, A)] account for 40.1% of posted spreads in the smallest volume quartile, while the corresponding figure is only 20.5% in the largest volume quartile. These results suggest that specialists frequently provide liquidity to low-volume stocks when there are no limit orders or when limit orders submitted by outsiders are too wide. However, for high-volume stocks, the specialist's role as the sole provider of liquidity is less

Table 1
The number of quotes in each quote class for the whole sample of stocks and for stocks with differing trading volumes. We classify every bid (ask) quote in our sample into one of the following three classes: (1) the quoted bid (ask) price reflects the trading interest of the specialist alone, denoted by quote class (S); (2) the quoted bid (ask) price originates from the limit-order book without the specialist's direct participation, denoted by quote class (L); and (3) the quoted bid (ask) price reflects the trading interest of both the specialist and limit-order traders, denoted by quote class (M). We classify each quoted spread into quote class (x, y) where x ($x =$ S, L, M) represents the quote class for the bid price and y ($y =$ S, L, M) represents the quote class for the ask price. For each stock, we cluster posted bid–ask quotes into six groups according to their respective quote class. The first group includes all quotes that belong to quote class (S, S). The second group includes all quotes that belong to either quote class (S, L) or (L, S); the third, all those in (S, M) or (M, S); the fourth, all those in (L, L); the fifth, all those in (L, M) or (M, L); and the last group includes all quotes in (M, M). Because we make no distinction between quote classes (x, y) and (y, x) in our empirical analysis, we merge them into a single class and label it simply as quote class (x, y). In addition, we define (S, A) as the quote class that includes all spread quotes in which at least one side of the quote is from the specialist alone. Similarly, quote class (L, A) includes all spread quotes in which at least one side of the quote is exclusively from the limit order book, and quote class (M, A) includes all spread quotes in which at least one side of the quote is the joint quote

Quote class	Whole sample	Trading volume quartile			
		Smallest	2nd Quartile	3rd Quartile	Largest
(S, S)	19,796 (5.9%)	2,089 (9.2%)	3,076 (7.5%)	8,365 (13.1%)	6,266 (3.0%)
(S, L)	49,870 (14.8%)	4,661 (20.6%)	7,609 (18.5%)	15,259 (23.9%)	22,341 (10.6%)
(S, M)	29,274 (8.7%)	2,324 (10.3%)	4,036 (9.8%)	8,459 (13.2%)	14,455 (6.9%)
(L, L)	92,867 (27.5%)	5,474 (24.2%)	9,407 (22.8%)	12,639 (19.8%)	65,347 (31.1%)
(L, M)	110,519 (32.7%)	6,295 (27.8%)	12,780 (31.0%)	14,809 (23.1%)	76,635 (36.5%)
(M, M)	35,752 (10.6%)	1,776 (7.9%)	4,291 (10.4%)	4,455 (7.0%)	25,230 (12.0%)
Total	338,078 (100%)	22,619 (100%)	41,199 (100%)	63,986 (100%)	210,274 (100%)
(S, A)	98,940 (29.3%)	9,074 (40.1%)	14,721 (35.7%)	32,083 (50.1%)	43,062 (20.5%)
(L, A)	253,256 (74.9%)	16,430 (72.6%)	29,796 (72.3%)	42,707 (66.7%)	164,323 (78.1%)
(M, A)	175,545 (51.9%)	10,395 (46.0%)	21,107 (51.2%)	27,723 (43.3%)	116,320 (55.3%)

Table 2
The number of quotes within each quote class during each of 13 30-min intervals. We classify every bid (ask) quote in our sample into one of the following three classes: (1) the quoted bid (ask) price reflects the trading interest of the specialist alone, denoted by quote class (S); (2) the quoted bid (ask) price originates from the limit-order book without the specialist's direct participation, denoted by quote class (L); and (3) the quoted bid (ask) price reflects the trading interest of both the specialist and limit-order traders, denoted by quote class (M). We classify each quoted spread into quote class (x, y) where x ($x =$ S, L, M) represents the quote class for the bid price and y ($y =$ S, L, M) represents the quote class for the ask price. For each stock, we cluster posted bid–ask quotes into six groups according to their respective quote class. The first group includes all quotes that belong to quote class (S, S). The second group includes all quotes that belong to either quote class (S, L) or (L, S); the third, all those in (S, M) or (M, S); the fourth, all those in (L, L); the fifth, all those in (L, M) or (M, L); and the last group includes all quotes in (M, M). Because we make no distinction between quote classes (x, y) and (y, x) in our empirical analysis, we merge them into a single class and label it simply as quote class (x, y). In addition, we define (S, A) as the quote class that includes all spread quotes in which at least one side of the quote is from the specialist alone. Similarly, quote class (L, A) includes all spread quotes in which at least one side of the quote is exclusively from the limit order book, and quote class (M, A) includes all spread quotes in which at least one side of the quote is the joint quote

Time interval	Whole sample	Quote class								
		(S, S)	(S, L)	(S, M)	(L, L)	(L, M)	(M, M)	(S, A)	(L, A)	(M, A)
9:30–10:00	43,927	6,281	8,104	6,808	4,842	11,136	6,754	21,193	24,082	24,698
10:01–10:30	32,018	2,371	4,960	3,797	4,936	10,810	5,144	11,128	20,706	19,751
10:31–11:00	27,234	1,669	4,098	2,699	5,637	9,406	3,725	8,466	19,141	15,830
11:01–11:30	27,196	1,594	4,028	2,496	6,402	9,379	3,297	8,118	19,809	15,172
11:31–12:00	24,950	1,238	3,685	2,060	6,630	8,712	2,625	6,983	19,027	13,397
12:01–12:30	22,761	1,040	3,338	1,724	6,544	7,913	2,202	6,102	17,795	11,839
12:31–13:00	20,114	854	2,892	1,459	6,221	6,807	1,881	5,205	15,920	10,147
13:01–13:30	18,580	669	2,389	1,255	6,265	6,262	1,740	4,313	14,916	9,257
13:31–14:00	20,503	648	2,851	1,250	7,212	6,907	1,635	4,749	16,970	9,792
14:01–14:30	22,052	781	3,041	1,245	8,003	7,318	1,664	5,067	18,362	10,227
14:31–15:00	23,919	815	3,072	1,452	8,811	8,110	1,659	5,339	19,993	11,221
15:01–15:30	25,293	809	3,281	1,384	10,018	8,159	1,642	5,474	21,458	11,185
15:31–16:00	29,531	1,027	4,131	1,645	11,346	9,600	1,782	6,803	25,077	13,027

prominent. This is perhaps because traders place more limit orders for high-volume stocks since the probability of order execution increases with trading volume (Cohen et al., 1981).

Table 2 reports the number of quotes within each quote class during each of the 13 successive 30-min intervals of the trading day (see also Fig. 1). Several patterns can be noted. First, among those quote classes in which the specialist posts his own trading interest on at least one side of the quote, the number of quotes is greatest during the first 30-min interval, declines steadily until early

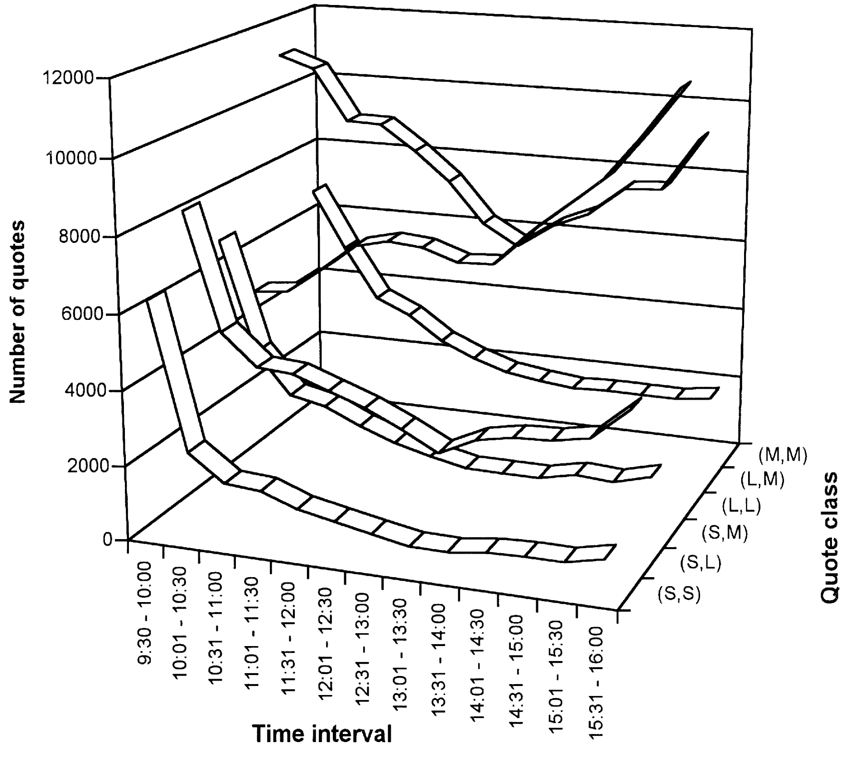

Fig. 1. The number of quotes within each quote class during each of 30-min intervals. We classfiy every bid (ask) quote in our sample into one of the following three classes: (1) the quoted bid (ask) price reflects the trading interest of the specialist alone, denoted by quote class (S); (2) the quoted bid (ask) price originates from the limit-order book without direct participation of the specialist, denoted by quote class (L); and (3) the quote bid (ask) price reflects the trading interest of the specialist and limit-order traders, i.e., the specialist adds depth to limit orders at the limit-order price, denoted by quote class (M). Each posted spread is classified into quote class (x, y), where x ($x =$ S, L, M) represents the quote class for the bid price and y ($y =$ S, L, M) represents the quote class for the ask price. Because we make no distinction between quote classes (x, y) and (y, x) in our empirical analysis, we merge them into a single class and label it simply as quote class (x, y).

afternoon hours, and then increases slightly during the last hour of trading. These quote classes include (S, S), (S, L), (S, M), and (M, M), or alternatively, (S, A) and (M, M). In contrast, the number of quotes that originate exclusively from the limit-order book [i.e., quote class (L, L)] is smallest during the first 30-min interval and then increases almost monotonically until the close of the market. For quote class (L, M) in which both specialists and limit-order traders post their trading interests, the number of quotes is largest at the beginning of the day, generally declines until early afternoon, and then increases sharply thereafter. These results indicate that specialists tend to quote more actively during the early hours of trading when there are fewer limit orders submitted. However, as the number of limit-order quotes rises, specialist participation diminishes, perhaps because the spread established through limit orders narrows. But during the final hour of trading, the specialist participation rate rises slightly. This might reflect the specialists' wish to make changes in their inventories before the market close. On the whole, our findings suggest that specialists step up to provide liquidity for certain stocks and at times when the level of liquidity supplied by limit-order traders is low.

3. The effect of quote type on the bid–ask spread

To examine the effect of limit orders on quoted spreads, we compare the mean spread across different quote classes. First, we calculate both the dollar and percentage spreads for every quote in the TORQ database. We obtain the percentage spread by dividing the dollar spread (i.e., the difference between the ask and bid prices) by the midpoint of the bid and ask prices. We then calculate the mean values of both the dollar and percentage spreads across our sample of stocks for each of the quote classes discussed above. The results are reported in Table 3.

The descriptive data presented in Tables 1 and 2 show that whether a quote represents the specialist's or limit-order traders' interest varies systematically by firm type and the time of day. Note also that some stocks exhibit large spreads due to their inherent characteristics, e.g., high risks, low volumes, or large adverse selection costs. These facts imply that any meaningful comparison of the width of specialist spreads to the width of limit-order spreads requires controls for both firm type and time of day. Hence, we calculate the standardized spread ($\mathrm{STSPRD}_{k,i}$) by subtracting the mean spread of each stock during a 30-min interval from each quoted spread, and then dividing the difference by the standard deviation of the spread during the same 30-min time interval, i.e.,

$$\mathrm{STSPRD}_{k,i} = (\mathrm{s}_{k,i,t} - m_{i,t})/sd_{i,t}, \tag{1}$$

where $s_{k,i,t}$ denotes the posted spread of quote k for stock i during time interval t, and $m_{i,t}$ and $sd_{i,t}$, respectively, are the mean and standard deviation of $s_{k,i,t}$ during the same time interval. It is important to note that the standardization purges all variation across stocks and across the time of day, but retains variation across quote types. Table 3 (Panel A) reports the mean values of the standardized dollar and percentage spreads for each quote class.

To test the effect of quote type on the posted bid–ask spread, we estimate the following regression model for each of the 144 stocks in our sample:

$$\mathrm{STSPRD}_k = \alpha_0 + \alpha_1 D_{\mathrm{S,L}} + \alpha_2 D_{\mathrm{S,M}} + \alpha_3 D_{\mathrm{L,L}} + \alpha_4 D_{\mathrm{L,M}} + \alpha_5 D_{\mathrm{M,M}} + \varepsilon_k, \quad (2)$$

where STSPRD_k is the standardized spread of quote k, $D_{x,y}$ equals one if the quote class is (x, y) and zero otherwise, and ε_k is an error term. To the extent that the spread is correlated across stocks, estimating Eq. (2) simultaneously for all 144 stocks (by exploiting cross-correlations in the error terms) would produce more efficient estimates. We are unable to estimate Eq. (2) as a multivariate system across all stocks, however, because no two stocks have an identical

Table 3

Mean spread for each quote class. We report four different measures of the spread. The dollar spread is the difference between the ask price and bid price. We obtain the percentage spread by dividing the dollar spread by the midpoint of the bid and ask prices. We calculate the standardized spread ($\mathrm{STSPRD}_{k,i}$) by subtracting the mean spread of each stock during a 30-min interval from each quoted spread, and then dividing the difference by the standard deviation of the spread during the same time interval, i.e., $\mathrm{STSPRD}_{k,i} = (s_{k,i,t} - m_{i,t})/s_{di,t}$, where $s_{k,i,t}$ denotes the posted spread of quote k for stock i during time interval t, and $m_{i,t}$ and $sd_{i,t}$, respectively, are the mean and standard deviation of $s_{k,i,t}$ during the same time interval. Panel A shows the mean spread for each quote class. Panel B reports the results of the following regression model: $\mathrm{STSPRD}_k = \alpha_0 + \alpha_1 D_{\mathrm{S,L}} + \alpha_2 D_{\mathrm{S,M}} + \alpha_3 D_{\mathrm{L,L}} + \alpha_4 D_{\mathrm{L,M}} + \alpha_5 D_{\mathrm{M,M}} + \varepsilon_k$, where STSPRD_k is the standardized spread of quote k, $D_{x,y}$ equals one if the quote class is (x, y) and zero otherwise, and ϵ_k is an error term. The intercept measures the average percentage spread of quote class (S, S) (i.e., specialist's quotes only on both sides). The coefficients for dummy variables, α_1 through α_5, measure the differences between the average spread for quote class (S, S) and the average spread for other quote classes. For each dummy variable, we report the average coefficient value from the individual time-series regressions, the percentage of stocks with negative coefficients, the aggregated p-value from the chi-square test using the procedure outlined in Gibbons and Shanken (1987), Z-statistic, and the p-value from Z-statistic

(*A*) *Mean spread for each quote class*

Quote class	Raw spread		Standardized spread	
	(in \$)	(% of price)	(in \$)	(% of price)
(S, S)	0.2781	0.0278	0.1868	0.1856
(S, L)	0.2270	0.0174	– 0.0049	– 0.0050
(S, M)	0.2151	0.0174	– 0.0105	– 0.0058
(L, L)	0.1858	0.0097	– 0.0197	– 0.0226
(L, M)	0.1847	0.0149	– 0.0213	– 0.0209
(M, M)	0.1821	0.0120	0.0289	0.0325
(S, A)	0.2337	0.0195	0.0318	0.0329
(L, A)	0.1934	0.0115	– 0.0175	– 0.0184
(M, A)	0.1893	0.0119	– 0.0092	– 0.0075

Table 3. Continued.

(*B*) *Regression results*

		STSPRD ($)	STSPRD (%)
$D_{S,L}$	Average coefficient	– 0.2148	– 0.2222
	Negative coefficients (%)	79.9%	78.5%
	Aggregated p-value (χ^2 test)	0.0000	0.0000
	Z-statistic	– 19.51	– 19.22
	p-value from Z-statistic	0.0000	0.0000
$D_{S,M}$	Average coefficient	– 0.1179	– 0.1243
	Negative coefficients (%)	74.3%	68.8%
	Aggregated p-value (χ^2 test)	0.0000	0.0000
	Z-statistic	– 10.80	– 10.59
	p-value from Z-statistic	0.0000	0.0000
$D_{L,L}$	Average coefficient	– 0.4160	– 0.4053
	Negative coefficients (%)	78.5%	76.4%
	Aggregated p-value (χ^2 test)	0.0000	0.0000
	Z-statistic	– 30.17	– 28.59
	p-value from Z-statistic	0.0000	0.0000
$D_{L,M}$	Average coefficient	– 0.3103	– 0.3121
	Negative coefficients (%)	76.4%	74.3%
	Aggregated p-value (χ^2 test)	0.0000	0.0000
	Z-statistic	– 24.08	– 22.07
	p-value from Z-statistic	0.0000	0.0000
$D_{M,M}$	Average coefficient	– 0.0834	– 0.1156
	Negative coefficients(%)	57.6%	63.2%
	Aggregated p-value (χ^2 test)	0.0000	0.0000
	Z-statistic	– 8.42	– 6.51
	p-value from Z-statistic	0.0000	0.0000

timing of quotes during the study period. Hence, we estimate Eq. (2) using time-series data for each individual stock. For the same reason, Foster and Viswanathan (1993) also run regressions using time-series data for each individual stock in their intraday analysis of trading costs.

The intercept measures the average standardized spread of quote class (S, S). The coefficients for the dummy variables, α_1–α_5, measure the differences between the average standardized spread for quote class (S, S) and the average standardized spread for other quote classes. For instance, α_4 measures the difference between the average spread for quote class (S, S) and the average spread for quote class (L, M). We estimate Eq. (2) for each stock using Hansen's (1982) generalized method of moments (GMM) with the Newey and West (1987) correction for serial correlation. We define the maximum lag length as $l = cn^e$, where l is the maximum lag length, n is the sample size, and c and e are constants. We report the results with $c = 1$ and $e = 0.25$. The results using other values of c and e are similar to those presented here.

The regression results based on the standardized dollar and percentage spreads are reported in Panel B of Table 3. For each dummy variable, we report the average coefficient estimate from the individual time-series regressions as well as the percentage of stocks with negative coefficients. To test whether each dummy variable coefficient is significantly less than zero (we perform one-sided tests because we have priors on the sign of the coefficients), we calculate the aggregated p-value from the chi-square test using the procedure outlined in Gibbons and Shanken (1987). For any continuous random variable, the product of negative two and the natural logarithm of the p-value is distributed as chi-square with two degrees of freedom. To obtain the aggregated p-value, we first calculate the p-value for each coefficient estimate using the t-statistic from the individual time-series regression. We then sum the $-2(\log_e)$ of the individual stock p-values across our sample of stocks. Because the sum of these transformed p-values follows a chi-square distribution with twice the number of stocks as its degrees of freedom, we then calculate an overall or aggregated p-value from this statistic. Note that this procedure ignores cross-correlations in the error terms. Hasbrouck (1991a,b) and Foster and Viswanathan (1993) also aggregate test statistics across firms without an explicit correction for cross-correlations.

To assess the sensitivity of our results to different aggregation methods, we also employ an alternative approach outlined in Meulbroek (1992). Dodd and Warner (1983) and Warner et al. (1988) provide a detailed discussion of the methodology. Specifically, we calculate the Z-statistic and its p-value for each dummy variable coefficient to test whether the mean regression coefficient for each dummy variable differs from zero. We obtain the Z-statistic by adding individual regression t-statistics across stocks and then dividing the sum by the square root of the number of regression coefficients. This procedure assumes that the individual regression t-statistics follow asymptotically a unit normal distribution.

The results show that the mean value of each and every dummy variable coefficient is less than zero, indicating that the average spread of quote class (S, S) is greater than the average spread of the other quote classes. The p-values from both the chi-square test and Z-statistics suggest that the results are statistically significant. Note also that the estimated coefficients for quote classes (L, L) and (L, M) are smaller than the corresponding figures for other quote classes. Hence, our results indicate that the spread is widest when both the bid and the ask prices reflect the trading interest of the specialist alone, and that the spread narrows when the quoted spread reflects the limit-order prices. On the whole, our results suggest that limit-order traders play a significant role in reducing the width of spreads.[4]

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[4] Using the TORQ database, Kavajecz (1999) finds that the proportion of bid (ask) quotes in which the specialist posts an inferior price relative to the best limit price is 8.76% (7.77%). Using the same database, McInish and Wood (1995) report that 51% of limit orders that would better the

We note that aggregating individual test-statistics across stocks relies on the assumption of independence across the tests being aggregated. To the extent this assumption does not hold, our econometric specification remains imperfect. To examine the sensitivity of our results to different econometric specifications, we estimate one set of coefficients for Eq. (2) using our panel data of time-series and cross-sectional observations; Chan et al. (1995a,b) provide a detailed discussion of this method. In the estimation, we allow for arbitrary patterns of cross-sectional correlation, autocorrelation, and heteroskedasticity. The results of this regression are similar to those based on stock-by-stock regressions. Hence, we conclude that our results are not sensitive to different econometric specifications.

Huang and Stoll (1996) find that the average spread of a sample of Nasdaq stocks is about twice as large as the average spread of a matched sample of NYSE stocks. They attribute this difference, at least in part, to the different treatment of limit orders between the two markets. Similarly, Bessembinder and Kaufman (1997) report that various measures of execution cost (i.e., quoted spreads, effective spreads, and realized spreads) are larger for Nasdaq-listed than for NYSE-listed stocks. Demsetz (1997) suggests that different methods used by the NYSE and Nasdaq to accommodate limit orders account for at least part of the excess of Nasdaq spreads over NYSE spreads. Considering the spread-reducing function of limit orders for NYSE stocks documented in our study, we concur with these authors.

Until 1997, incoming Nasdaq market orders were executed against the inside dealer quote (the best bid and the best ask among all the dealers), while limit orders were neither exposed to the rest of the market nor executed against incoming market orders. Limit orders, like market orders, execute against the dealer's quote and must wait until the quote reaches the limit price. Hence, limit-order traders on the Nasdaq system did not compete with market makers as they do on the NYSE. As noted earlier, new SEC rules that expose limit orders as part of the best quotes on the Nasdaq system were implemented on January 20, 1997. According to a preliminary analysis by the National Association of Securities Dealers, quoted spreads have fallen by about 33% and effective spreads have fallen by about 24% for the stocks for which investor limit orders are included as part of the inside quotes (NASD Economic Research Department, 1997). These results are consistent with our findings.

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standing quotes on the NYSE are not displayed as quotes. These results suggest that the extent of *potential* liquidity enhancement provided by limit-order traders may actually be greater than the magnitude we document in this study. The large disparity in the results of these studies appears to stem from differences in their algorithms to identify hidden limit orders.

4. Intraday pattern of the spread

In this section, we first present a brief description of microstructure models of specialist behavior and their testable implications. We then examine intraday variations in spreads based on those quotes that reflect the trading interest of specialists, and determine which models of specialist behavior are most consistent with the empirical evidence.

4.1. The microstructure models of intraday variations in the bid–ask spread

Microstructure models that deal with order arrival and quote revision fall into the three general categories: inventory, market power, and asymmetric information (adverse selection) models. In the inventory models (see Stoll, 1978; Amihud and Mendelson, 1980,1982; Ho and Stoll, 1981), the spread compensates the specialist for bearing the risk of holding undesired inventory. Amihud and Mendelson (1982) develop a model in which specialists respond to inventory imbalances by widening their spreads. If inventory imbalances accumulate during the course of trading, they can become particularly severe near the close of the market. Based on these observations, Amihud and Mendelson predict a wider spread at or near the close.

Market-power models link intraday variations in spreads to the possible monopoly power of specialists. In determining the opening price for NYSE stocks, the Opening Automated Report Service automatically matches buy and sell orders, and specialists offset any order imbalance from their inventories. Thus, specialists use their knowledge of market and limit orders in setting the opening price. Specialists also have privileged knowledge on the market's desire to trade through the market-on-close orders (i.e., orders that are to be executed as close to 4:00 as possible). Stoll and Whaley (1990) suggest that the specialist's ability to profit from privileged knowledge of order imbalances implies wider spreads at the open and close than during the rest of the day. Brock and Kleidon (1992) suggest that specialists' market power could be enhanced by the fact that investors' trading demand is less elastic at the open and close.

Information models (see, e.g., Copeland and Galai, 1983; Glosten and Milgrom, 1985; Easley and O'Hara, 1987; Madhavan, 1992; Foster and Viswanathan, 1994) focus on the adverse selection problem faced by specialists, who are at an informational disadvantage relative to informed traders. Madhavan (1992) considers a model in which information asymmetry is gradually resolved during the trading day. Madhavan's model predicts that the bid–ask spread will decline throughout the day. Foster and Viswanathan (1994) develop an information model in which competition between two informed traders leads to high volume, return variances, and spreads at the start of trading.

4.2. Intraday variation in specialist spreads

To test the specialist models of spreads, we examine the intraday variation in spreads using only those quotes that reflect specialist interest in both the bid and the ask, i.e., quote classes (S, S), (S, M), and (M, M). We exclude spread quotes that belong to quote class (L, L), because these quotes reflect the interest of limit-order traders. We also exclude quotes that belong to quote classes (S, L) and (L, M) because they are hybrid quotes in which only one side of the quote reflects the specialist's interest. This sample of specialist quotes includes 84,822 quotes.

An ideal analysis of the specialist's quote behavior would require data from a market without limit-order traders, as the presence of limit orders effectively censors the specialist quotation data. We do not observe the quote that the specialist would have posted when limit orders constitute the best quote. For example, we do not know what specialists would have posted in those quotes that belong to our quote class (L, L) if there were no limit orders. Bid–ask quotes that belong to quote classes (S, M) and (M, M) represent cases in which specialists match limit-order quotes on at least one side of the quote. Although we do not know what specialists would have quoted in these cases if there were no corresponding limit orders, we treat these quotes as the specialist quotes. And for these reasons, our tests are imperfect tests of the specialist models of spreads. To assess the sensitivity of our results, we examine the intraday variation of spreads using only those quotes that belong to quote class (S, S); the results are similar to those presented here.

We partition each day into 13 successive 30-min intervals and then calculate the average standardized spread for each stock during each of the 30-min intervals. We obtain the standardized spread by subtracting the stock's mean spread for the day from the quoted spread and dividing the difference by the standard deviation of that stock's spread for the day. Note that this procedure differs from that used in Eq. (1) since it retains variations in spreads across the time of day. We then stack the time-series data for individual stocks and calculate the mean spread during each of the 13 intervals.

Table 4 (see also Fig. 2) shows the intraday variation in the specialist spread. (When we replicate Fig. 2 using the standardized dollar spread, the result is almost identical to Fig. 2. Hence, for brevity, we report only the results based on the standardized percentage spread.) The results indicate that the specialist spread is widest at the open, narrows until late morning, and then levels off for the rest of the day. In Table 4, we also report the intraday variation in the standardized spread calculated from our entire sample of quotes. We find that the spread is widest at the beginning of the day, narrows during the day, and then rises steadily prior to the close. These full-sample results are consistent with the findings of McInish and Wood (1992), Brock and Kleidon (1992), and Chan et al. (1995b), which suggests that our data are comparable to data used in other

Table 4
The average standardized spread for each 30-min interval of the trading day. We define the standardized spread as $(s-m)/sd$, where s is the quoted spread, m is the mean of s for the day, and sd is the standard deviation of s for the day. We calculate the standardized spread by using both the dollar and percentage spreads. The dollar spread is the difference between the ask and bid prices. We obtain the percentage spread by dividing the dollar spread by the midpoint of the bid and ask prices. The specialist quote comprises all posted spreads that reflect the trading interest of the specialist on at least one side of the quote. Hence, according to our quote classification scheme, the specialist quote includes all those quotes that belong to quote classes (S, S), (S, M), and (M, M). Similarly, the limit-order quote comprises all posted spreads that reflect the trading interest of limit-order traders on at least one side of the quote, i.e., quote classes (L, L), (L, M), and (M, M). The first two columns show the intraday variation in the standardized dollar and percentage spread based on our entire sample data (i.e., all quote classes).

Time interval	Whole sample		Specialist quote		Limit-order quote	
	Spread (in $)	Spread (% of price)	Spread (in $)	Spread (% of price)	Spread (in $)	Spread (% of price)
9:30–10:00	0.2089	0.2127	0.2577	0.2610	0.1775	0.1731
10:01–10:30	0.0197	0.0232	0.0513	0.0546	0.0158	0.0133
10:31–11:00	– 0.0319	– 0.0286	0.0183	0.0223	– 0.0267	– 0.0299
11:01–11:30	– 0.0411	– 0.0393	0.0050	0.0079	– 0.0289	– 0.0309
11:31–12:00	– 0.0533	– 0.0527	– 0.0262	– 0.0238	– 0.0493	– 0.0493
12:01–12:30	– 0.0542	– 0.0555	– 0.0205	– 0.0209	– 0.0350	– 0.0344
12:31–13:00	– 0.0540	– 0.0555	– 0.0391	– 0.0386	– 0.0398	– 0.0384
13:01–13:30	– 0.0622	– 0.0649	– 0.0373	– 0.0400	– 0.0610	– 0.0584
13:31–14:00	– 0.0289	– 0.0329	0.0246	0.0181	– 0.0259	– 0.0226
14:01–14:30	– 0.0564	– 0.0599	– 0.0118	– 0.0160	– 0.0475	– 0.0427
14:31–15:00	– 0.0401	– 0.0419	– 0.0005	– 0.0053	– 0.0274	– 0.0250
15:01–15:30	– 0.0185	– 0.0207	– 0.0216	– 0.0229	– 0.0100	– 0.0073
15:31–16:00	0.0151	0.0114	– 0.0156	– 0.0205	0.0265	0.0302

studies, and that the findings presented below are not likely to be unique to our sample.

For a formal examination of the intraday variation in spreads, we use the following model:

$$\mathrm{STSPRD}_k = \alpha_0 + \alpha_1 D_1 + \alpha_2 D_2 + \alpha_3 D_3 + \alpha_4 D_4 + \alpha_5 D_5 + \alpha_6 D_6 + \varepsilon_k, \quad (3)$$

where STSPRD_k is the standardized spread of quote k, and D_1–D_6 are dummy variables each of which represents a 30-min time interval. Dummy variables D_1, D_2, and D_3 represent, respectively, the first three 30-min intervals of the trading day: 9:30–10:00 a.m., 10:01–10:30 a.m., and 10:31–11:00 a.m. Similarly, dummy variables D_4, D_5, and D_6 represent, respectively, the last three 30-min intervals of the trading day: 2:31–3:00 p.m., 3:01–3:30 p.m., and 3:31–4:00 p.m. The intercept term measures the average spread during the time period from 11:01 a.m. to 2:30 p.m. The coefficients for the dummy variables, α_1–α_6, measure

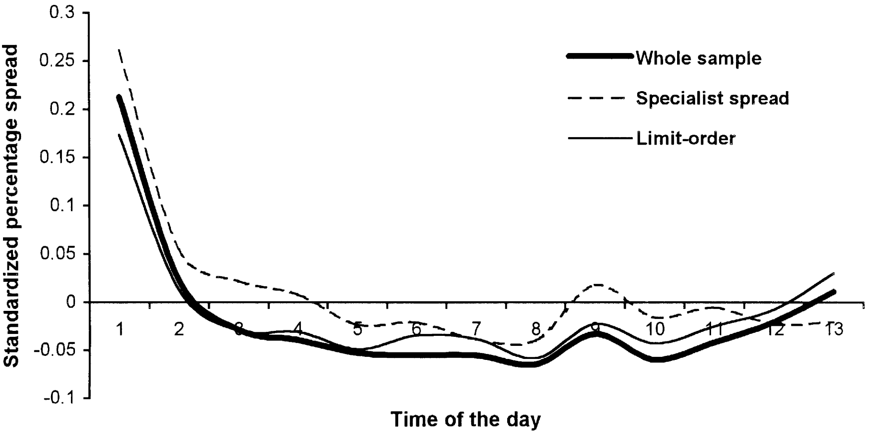


Fig. 2. The intraday variation in the standardized percentage spreads. We define the standardized spread as $(s - m)/sd$, where s is the quoted spread, m is the mean of s for the day, and sd is the standard deviation of s for the day. The percentage spread is the ratio of the dollar spread to the midpoint of the bid and ask prices. The specialist quote comprises all posted spreads that reflect the trading interest of the specalist on at least one side of the quote. The limit-order quote comprises all posted spreads that reflect the trading interest of limit-order traders on at least one side of the quote.

the differences between the mean spreads during the respective 30-min interval and the mean spread during 11:01 a.m. to 2:30 p.m.

As in Section 3, we estimate Eq. (3) for each stock using GMM with the Newey and West correction for serial correlation. We determine the maximum lag length (l) by $l = n^{1/4}$, where n is the sample size. The results based on other values of l, such as $(1/2)n^{1/3}$ and $2n^{1/5}$, are similar to those presented here. We report the regression results in Table 5. The first two columns show the results when we estimate the regression model using our entire sample of quotes. For each time-interval dummy variable, we report the average coefficient estimate from the individual time-series regressions as well as the percentage of stocks with positive coefficients. To determine whether each dummy variable coefficient is significantly greater than zero, we also report the p-values from both the chi-square test and Z-statistic. The results confirm the observation that spreads are widest at the open, narrow during the day, and rise during the final hour of trading. Columns 3 and 4 report the regression results when we estimate the model using specialist quotes. The results show that the specialist spreads during the first three 30-min intervals are significantly greater than the average spread during midday. We find, however, that the specialist spreads during the last three 30-min intervals are not greater than the average spread during midday.

On the whole, our empirical results are consistent with the prediction of Madhavan (1992) and Foster and Viswanathan (1994). As trading continues, private information is impounded into prices, and specialists narrow their spreads as their informational handicap declines. According to our results, the resolution of informational uncertainty appears to be completed mostly by late morning or early afternoon. Our results are only partially consistent with the prediction of market-power models of Stoll and Whaley (1990) and Brock and Kleidon (1992). Consistent with these models, we find wider spreads at the open. Contrary to these models, our results do not show any rise in spreads at the close. One possible interpretation of these results is that although there are significant order imbalances at the open, order imbalances at the close are not great enough to cause significant changes in spreads.

Our empirical results are not compatible with the prediction of the Amihud and Mendelson (1982) inventory model of spreads, which predicts a wider spread at or near the close of trading than during the rest of the day. This is perhaps, as suggested by Hasbrouck and Sofianos (1993) and Madhavan and Smidt (1993), due to the fact that inventory imbalances are reversed over a number of trading days rather than within each day. Thus, specialists appear to require more than a single trading day to control inventory through prices. One possible reason for the slow reversal of inventory positions is that specialists are required to maintain an orderly market by accepting trades on both sides of the spread.

5. Intraday pattern of the limit-order spread

Because a significant portion of bid–ask quotes posted by specialists reflects the interest of limit-order traders, we also examine intraday variation in spreads that originate from the limit-order book. Given our finding that the well-known *U*-shaped pattern of spreads cannot be explained by specialist quotes, we conjecture that an intraday analysis of limit-order quotes will increase our understanding of the forces behind the observed pattern.

We note that limit-order traders resemble specialists in providing liquidity and immediacy to the market but differ because they have the freedom to post *either* a bid *or* an ask quote, while the primary objective of specialists is to provide an orderly and smooth market by continuously posting *both* bid *and* ask quotes. Also, it is important to note that the intraday variation in specialist spreads for a stock is determined by successive decisions of a single specialist, while the intraday variation in limit-order spreads is determined by many different traders.

To examine the intraday variation in limit-order spreads, we include in our study subsample only those quotes that reflect the interest of limit-order traders in both the bid and the ask, i.e., quote classes (L, L), (M, M), and (L, M). We exclude quotes that belong to quote class (S, S) because they are the specialist's quotes. We also exclude from our study sample all those quotes that belong to

Table 5

Results of the regression model $\mathrm{STSPRD}_k = \alpha_0 + \alpha_1 D_1 + \alpha_2 D_2 + \alpha_3 D_3 + \alpha_4 D_4 + \alpha_5 D_5 + \alpha_6 D_6 + \varepsilon_k$, where STSPRD_k is the standardized spread of quote k, and D_1 through D_6 are dummy variables, each representing a 30-min time interval. D_1 represents the time interval 9:30–10:00 a.m., D_2 represents the time interval 10:01–10:30 a.m., and D_3 represents the time interval 10:31–11:00 a.m. Similarly, dummy variables D_4, D_5, and D_6 represent, respectively, the last three 30-min intervals of the trading day: 2:31–3:00 p.m., 3:01–3:30 p.m., and 3:31–4:00 p.m. The intercept term measures the average spread during the time period from 11:01 a.m. to 2:30 p.m. The coefficients for the dummy variables, α_1 through α_6, measure the differences between the mean spreads during the respective 30-min interval and the mean spread during 11:01 a.m. to 2:30 p.m. We define the standardized spread as $(s - m)/sd$, where s is the quoted spread, m is the mean of s for the day, and sd is the standard deviation of s for the day. We calculate the standardized spread by using both the dollar and percentage spreads. The dollar spread is the difference between the ask and bid prices. We obtain the percentage spread by dividing the dollar spread by the midpoint of the bid and ask prices. The specialist quote comprises all posted spreads that reflect the trading interest of the specialist on at least one side of the quote. Hence, according to our quote classification scheme, the specialist quote includes all those quotes that belong to quote classes (S, S), (S, M), and (M, M). Similarly, the limit-order quote comprises all posted spreads that reflect the trading interest of limit-order traders on at least one side of the quote, i.e., quote classes (L, L), (L, M), and (M, M). For each dummy variable, we report the average coefficient value from the individual time-series regressions, the percentage of stocks with positive coefficients, the aggregated p-value from the chi-square test using the procedure outlined in Gibbons and Shanken (1987), Z-statistic, and p-value from Z-statistic

		Whole sample		Specialist quote		Limit-order quote	
		Spread (in $)	Spread (% of price)	Spread (in $)	Spread (% of price)	Spread (in $)	spread (% of price)
D_1	Average coefficient	0.3067	0.3105	0.3183	0.3222	0.2118	0.2331
	Positive coefficients (%)	95.8%	96.5%	93.1%	90.3%	83.7%	85.8%
	Aggregated p-value (χ^2 test)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Z-statistic	37.803	38.49	27.04	27.81	19.33	20.15
	p-value from Z-statistic	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
D_2	Average coefficient	0.0728	0.0843	0.1107	0.1173	0.0312	0.0349
	Positive coefficients (%)	69.4%	70.8%	68.8%	70.1%	63.1%	62.4%
	Aggregated p-value (χ^2 test)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Z-statistic	9.22	9.57	7.67	8.35	4.25	4.83
	p-value from Z-statistic	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

D_3	Average coefficient	0.0196	0.0296	0.0307	0.0442	0.0136	0.0110
	Positive coefficients (%)	54.9%	59.0%	59.7%	59.7%	53.2%	52.5%
	Aggregated *p*-value (χ^2 test)	0.0004	0.0001	0.0003	0.0000	0.0061	0.0023
	Z-statistic	2.11	3.38	2.46	4.94	1.51	1.87
	p-value from Z-statistic	0.0173	0.0004	0.0069	0.0000	0.649	0.304
D_4	Average coefficient	– 0.0105	– 0.0138	– 0.0378	– 0.0367	– 0.0119	– 0.0131
	Positive coefficients (%)	48.6%	47.9%	44.4%	40.3%	48.8%	50.4%
	Aggregated *p*-value (χ^2 test)	0.1019	0.1331	0.1479	0.3346	0.1075	0.1617
	Z-statistic	– 0.78	– 1.04	– 1.56	– 1.86	– 0.19	– 0.27
	p-value from Z-statistic	0.7832	0.8517	0.9404	0.9688	0.5736	0.6068
D_5	Average coefficient	0.0024	0.0092	– 0.0610	– 0.0611	0.0090	0.0120
	Positive coefficients (%)	52.1%	51.4%	43.1%	43.1%	51.1%	51.8%
	Aggregated *p*-value (χ^2 test)	0.0491	0.0213	0.9324	0.9321	0.0415	0.0291
	Z-statistic	1.35	1.52	– 4.76	– 4.06	1.37	1.58
	p-value from Z-statistic	0.0885	0.0643	1.0000	0.9688	0.0853	0.0571
D_6	Average coefficient	0.0378	0.0309	– 0.0936	– 0.0975	0.0652	0.0671
	Positive coefficients (%)	61.8%	61.1%	40.3%	40.3%	66.7%	67.4%
	Aggregated *p*-value (χ^2 test)	0.0000	0.0000	0.9585	0.6331	0.0000	0.0000
	Z-statistic	5.34	4.81	– 5.28	– 7.22	4.97	5.75
	p-value from Z-statistic	0.0000	0.0000	1.0000	0.9999	0.0000	0.0000

quote classes (S, L) and (S, M) since they represent hybrid quotes in which only one side of the quote reflects the limit-order quote. The intraday variation in spreads for limit-order quotes is shown in Fig. 2 as well as in Table 4. Notice the remarkable similarity between the intraday variation in limit-order spreads and the intraday variation in spreads based on our entire sample of quotes. In particular, the limit-order spread is widest during the first 30-min interval, narrow during midday, and rises during the last hour.

We formally examine the intraday variation in limit-order spreads by estimating the regression model in Eq. (3) using limit-order quotes. The results, reported in Table 5, show that the average spreads during the first three 30-min intervals and during the last hour of trading are significantly greater than the average spread during the middle of the day. Overall, our results show that the intraday variation in limit-order spreads is similar to the intraday variation in spreads based on our entire sample of quotes. Hence, the *U*-shaped pattern of spreads reported in Jaffe and Patel (undated), Porter (1988), McInish and Wood (1992), and Brock and Kleidon (1992) appears to be driven by the limit-order quotes.

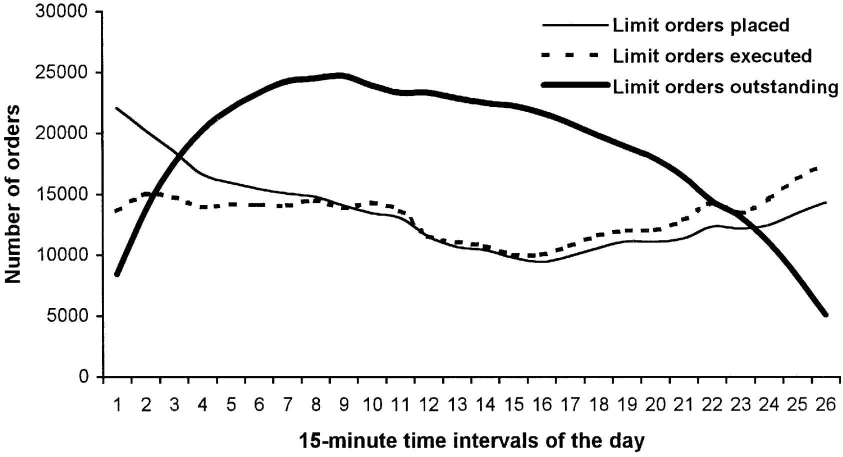
Our empirical analysis uses bid–ask quote data for all 144 stocks in the TORQ database. A close inspection of these stocks shows that some are low-volume stocks that have only a few quotes during the entire three-month study period. These low-volume stocks frequently exhibit the same bid–ask quote over time and consequently do not show any intraday variation in quoted spreads. To assess the robustness of our findings, we replicate our analyses using only those stocks with at least 1,600 posted quotes during the study period, or an average of at least two quotes during every 30-min interval of the study period. The results based on the reduced sample data are similar to those presented here.

6. Determinants of the intraday variation in spreads

6.1. Limit-order spreads

Since the intraday pattern of limit-order spreads is determined by different traders submitting limit orders throughout the day, it is reasonable to suspect that the best way to explain the intraday pattern of limit-order spreads is to look closely at the intraday variation in limit-order placements and executions. We conjecture that varying levels of competition among limit-order traders at different times of the day determine the intraday variation in limit-order spreads. We expect spreads to be wider when there are only a few limit orders outstanding and narrower when there are many limit orders in the book.

Fig. 3 shows the intraday variation in the number of limit orders placed, executed, and outstanding for our sample of stocks. We obtain the number of



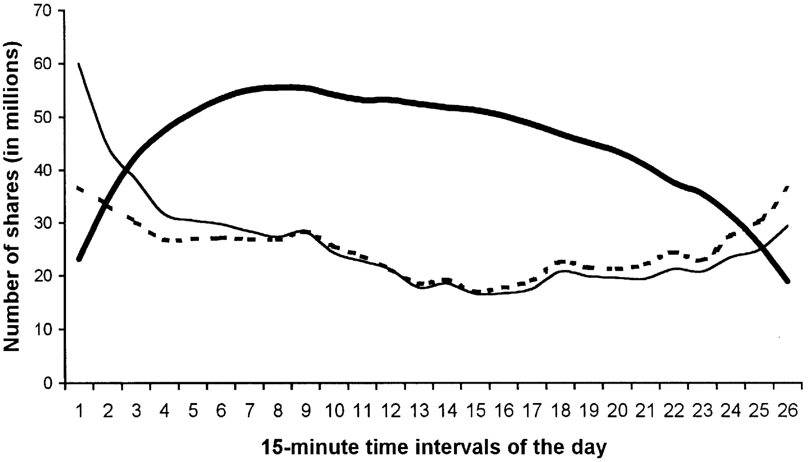


Fig. 3. The intraday variation in the number of limit orders placed, limit orders executued, and limit orders outstanding. The first figure is based on the number of orders and the second is based on the number of limit orde shares.

outstanding limit orders at the end of time interval t (NOLO$_t$) by adding the number of newly placed limit orders during time interval t (NOLP$_t$) to the number of outstanding limit orders at the end of time interval $t-1$ (NOLO$_{t-1}$), and then subtracting the number of limit orders that are executed during time interval t (NOLE$_t$). We note that the number of outstanding limit orders is smallest at the open, increases sharply during the first two hours after the open, and then declines steadily during the afternoon hours until the market close. We obtain similar results when we use the *number of shares*, instead of the number of orders, in the limit-order book. If we look at Fig. 2 in conjunction with Fig. 3, we see that the intraday variation in limit-order spreads is indeed strongly and negatively correlated with the intraday variation in the number of outstanding limit orders.

While we maintain that the quantity of limit orders has an impact on the limit-order spread, the quantity of limit orders is also endogenously determined. This is because we expect the rate of limit-order execution (and, by implication, the quantity of limit orders) to be positively related to the limit-order spread. The limit-order execution rate is defined as the ratio of the number of limit orders executed during time interval *t* to the number of limit orders available for execution during the same period. A higher limit-order execution rate implies a smaller quantity of unexecuted limit orders. We expect a positive relation between the limit-order execution rate and the limit-order spread because a high execution rate means that the inside limit orders are being hit, which implies, ceteris paribus, a wider spread.

The number of newly placed limit orders is also an endogenous variable. Handa and Schwartz (1996) compare returns between the market- and limit-order strategies. In the market-order strategy, traders buy and sell at market at the start of a trading session. In the limit-order strategy, traders place limit orders that are subsequently converted to market orders if they do not execute within a specified period of time. Handa and Schwartz find that the returns to the limit-order strategy, conditional on order execution, are greater than unconditional market-order returns. They also find that the returns to the limit-order strategy, conditional on non-execution of order, are lower than unconditional market-order returns. These results suggest that rational investors would prefer to place limit orders when the probability of order execution is high. Cohen et al. (1981) suggest that since a market order always executes, while the probability of a limit order executing is less than one, there is a jump in the probability as the limit price approaches the ask (or bid) price. They show that the probability jump is larger in inactive (thin) markets and, as a result, the probability of order execution is also lower in such markets. Because the probability of order execution is an increasing function of the intensity of trading activity, we expect that the number of limit orders is an increasing function of trading volume (VOL).

We also expect that the number of newly placed limit orders during an interval of time is an increasing function of the average posted spread (ASPRD) during the interval. If the spread is wide, then a trader has much to gain from submitting a limit order, because if it executes, the trader will have transacted at a better price. To the extent that order execution probability increases with stock price volatility (RISK), we expect the number of limit orders to be positively associated with price volatility. Lastly, a close inspection of plots between LSPRD and NOLO, between LOER and LSPRD, and between NOLP and VOL, ASPRD, and RISK suggests that the functional form between these variables is approximately linear. Hence, we assume a linear functional form. We check both the rank and order condition of identification and find that all three equations are identified.

Based on these considerations, we employ the following structural model as an empirical representation of the relations between the limit-order spread, the limit-order execution rate, and the number of limit-order placements:

$$\mathrm{LSPRD}_t = \alpha_0 + \alpha_1 \mathrm{NOLO}_t + \varepsilon_{1t}, \tag{4}$$

$$\mathrm{LOER}_t = \beta_0 + \beta_1 \mathrm{LSPRD}_t + \varepsilon_{2t}, \tag{5}$$

$$\mathrm{NOLP}_t = \gamma_0 + \gamma_1 \mathrm{VOL}_{t-1} + \gamma_2 \mathrm{ASPRD}_{t-1} + \gamma_3 \mathrm{RISK}_{t-1} + \varepsilon_{3t}, \tag{6}$$

where LSPRD_t is the average standardized limit-order spread during time interval t, NOLO_t is the number of outstanding limit orders (or shares) at the end of time interval t, LOER_t is the limit-order execution rate during time interval t [i.e., $\mathrm{NOLE}_t/(\mathrm{NOLO}_{t-1} + \mathrm{NOLP}_t)$], NOLP_t is the number of newly placed limit orders (or shares) during time interval t, VOL_{t-1} is the average standardized trading volume during time interval $t-1$, ASPRD_{t-1} is the average standardized posted spread during time interval $t-1$, RISK_{t-1} is the average standardized stock price volatility during time interval $t-1$, and $\varepsilon_t s$ are error terms. We measure price volatility by the standard deviation of the midpoint of the bid and ask prices. Because the main purpose of this section is to examine whether the intraday variation in limit-order spreads can be explained by the intraday variation in limit-order placements and executions in the aggregate, we use minute-to-minute mean values of the variables across our sample of stocks in the regressions. We report the results when LSPRD and ASPRD are measured as a percentage of stock prices. The results based on the dollar spread are qualitatively identical.

We estimate the system of Eqs. (4)–(6) using GMM. To assess the sensitivity of our results to different estimation methods, we also estimate the system using the two- and three-stage least squares, full information maximum likelihood, and seemingly unrelated regression methods. The results from these methods are similar to those from GMM. Hence we report, for brevity, the results from GMM. In the GMM estimation, we use lagged values of NOLO, VOL, ASPRD, and RISK as instruments. We also perform the GMM estimation with the partial derivatives of the equations with respect to the parameter (i.e., the columns of the Jacobian matrix associated with the parameter) as additional instruments, but the results are similar to those presented here. We use lagged values of VOL, ASPRD, and RISK as instruments because contemporaneous values of these variables could be endogenously determined within the system, although using lagged instruments might not completely solve the simultaneity problem to the extent that the orders we observe are part of a trading program.

We report the regression results in Panel A of Table 6. The first half of Panel A reports the results when we measure NOLO, LOER, and NOLP by the

Table 6

A structural model of spreads, limit-order executions, and limit-order placements. Panel A reports parameter estimates of the following system of equations using minute-to-minute data:

$$\mathrm{LSPRD}_t = \alpha_0 + \alpha_1 \mathrm{NOLO}_t + \varepsilon_{1t}, \tag{4}$$

$$\mathrm{LOER}_t = \beta_0 + \beta_1 \mathrm{LSPRD}_t + \varepsilon_{2t}, \tag{5}$$

$$\mathrm{NOLP}_t = \gamma_0 + \gamma_1 \mathrm{VOL}_{t-1} + \gamma_2 \mathrm{ASPRD}_{t-1} + \gamma_3 \mathrm{RISK}_{t-1} + \varepsilon_{3t}; \tag{6}$$

where LSPRD_t is the average standardized limit-order spread during time interval t, NOLO_t is the number of outstanding limit orders (or shares) at the end of time interval t (i.e., $\mathrm{NOLO}_t = \mathrm{NOLO}_{t-1} + \mathrm{NOLP}_t - \mathrm{NOLE}_t$),$\mathrm{LOER}_t$ is the limit-order execution rate during time interval t [i.e., $\mathrm{LOER}_t = \mathrm{NOLE}_t/(\mathrm{NOLO}_{t-1} + \mathrm{NOLP}_t)$],$\mathrm{NOLP}_t$ is the number of newly-placed limit orders (or shares) during time interval t, VOL_{t-1} is the average standardized trading volume during time interval $t-1$, ASPRD_{t-1} is the average standardized posted spread during time interval $t-1$, RISK_{t-1} is the average standardized stock price volatility during time interval $t-1$, and ε_ts are error terms. We estimate the system by using the GMM. Panel B reports parameter estimates of the structural model of Eqs. (4)–(6), after LSPRD_t in Eq. (4) is replaced by the specialist spread (SSPRD_t). We use LSPRD in Eq. (5) because the limit-order execution rate is related to the limit-order spread, not to the specialist spread. Because LSPRD is no longer endogenous in the system, however, we use the lagged value of LSPRD in Eq. (5) and treat it as an instrument in the GMM estimation. Panel C reports parameter estimates of the structural model of Eqs. (4)–(6), after LSPRD_t in Eq. (4) is replaced by the time-series data of the standardized spread across all quote classes (ASPRD_t). Because ASPRD is endogenous in this case, we replace ASPRD_{t-1} in Eq. (6) by ASPRD_t. We use LSPRD_{t-1} in Eq. (5) and treat it as an instrument in the GMM estimation. Minute-to-minute mean values of the variables across our sample of stocks are used in the regressions. Absolute values of the t-statistics are reported in parentheses

Endogenous variable	α_0 (t value)	α_1 (t value)	β_0 (t value)	β_1 (t value)	γ_0 (t value)	γ_1 (t value)	γ_2 (t value)	γ_3(t value)
(*A*) *Limit-order spread*								
1. When NOLO, LOER, and NOLP are measured in the number of orders								
LSPRD_t	0.1183 (11.05^b)	− 0.0011 (14.26^b)						
LOER_t			0.0599 (30.12^b)	0.5506 (15.56^b)				
NOLP_t					6.4838 (77.52^b)	4.2916 (6.75^b)	9.4863 (7.72^b)	1.3499 (2.44^a)

2. When NOLO, LOER, and NOLP are measured in the number of shares								
LSPRD_t	0.1429 (10.67^b)	– 0.0005 (13.08^b)						
LOER_t			0.0476 (28.38^b)	0.4589 (11.84^b)				
NOLP_t					12.7949 (65.54^b)	17.2939 (10.46^b)	29.0044 (9.50^b)	3.6961 (2.20^a)
(*B*) *Specialist spread*								
1. When NOLO, LOER, and NOLP are measured in the number of orders								
SSPRD_t	0.1215 (5.83^b)	– 0.0009 (6.13^b)						
LOER_t			0.0534 (35.06^b)	0.2565 (8.99^b)				
NOLP_t					6.4865 (84.33^b)	4.0146 (6.36^b)	10.0172 (8.35^b)	1.3714 (2.65^b)
2. When NOLO, LOER, and NOLP are measured in the number of shares								
SSPRD_t	0.1914 (7.47^b)	– 0.0006 (7.63^b)						
LOER_t			0.0421 (36.50^b)	0.2235 (7.98^b)				
NOLP_t					12.8902 (66.54^b)	15.4128 (9.40^b)	32.4219 (11.00^b)	3.1376 (1.99^a)

Table 6. Continued.

Endogenous variable	α_0 (t value)	α_1 (t value)	β_0 (t value)	β_1 (t value)	γ_0 (t value)	γ_1 (t value)	γ_2 (t value)	γ_3 (t value)
(*C*) *Spread based on whole sample*								
1. When NOLO, LOER, and NOLP are measured in the number of orders								
ASPRD_t	0.1233 (9.81^b)	$-$ 0.0011 (13.57^b)						
LOER_t			0.0516 (31.51^b)	0.2609 (9.20^b)				
NOLP_t					6.5132 (84.18^b)	3.7188 (3.89^b)	11.2014 (5.55^b)	1.7936 (3.11^b)
2. When NOLO, LOER, and NOLP are measured in the number of shares								
ASPRD_t	0.1988 (12.23^b)	$-$ 0.0007 (15.07^b)						
LOER_t			0.0404 (33.23^b)	0.2141 (7.30^b)				
NOLP_t					12.9717 (66.62^b)	13.4898 (5.37^b)	38.9058 (7.64^b)	3.6847 (2.11^a)

[a] Significant at the 5% level.

[b] Significant at the 1% level.

number of limit orders. The second half reports the results when we measure these variables by the number of limit-order shares. The results show that the limit order spread is strongly related to the number of outstanding limit orders. The estimated coefficient (α_1) for the limit-order variable is negative and highly significant. We obtain similar results when we use the number of shares in the limit-order book. These results are consistent with the view that competition among limit-order traders has a significant impact on limit-order spreads.

We find a significant and positive correlation between the limit-order execution rate and the limit-order spread. With the influx of market orders, some of the outstanding limit orders are executed. As a result, the limit-order spread becomes wider, resulting in a positive correlation between limit-order execution and the spread. We also find that the number of newly placed limit orders is positively associated with both spread and volume. This result is consistent with the view that limit-order placement is driven by both the prospect of price improvement and the probability of execution. Our results also suggest that traders tend to place more limit orders when stock price volatility is higher.

Overall, our results show that intraday variation in limit-order spreads is strongly related to intraday variations in limit-order placements and executions. Our results also suggest that the width of spreads depends on the movement of traders between limit and market orders, and this depends partly on the execution probability of the limit order. When spreads are wide, more traders find it optimal to enter limit orders [i.e., $\gamma_2 > 0$ in Eq. (6)] and thereby increase the liquidity available to the market, which in turn results in narrow spreads [i.e., $\alpha_1 < 0$ in Eq. (4)]. As spreads narrow, the gains to such trading strategies decrease, and traders switch to demanding liquidity via market orders. This, in turn, results in increased execution of limit orders and wider spreads [i.e., $\beta_1 > 0$ in Eq. (5)]. On the whole, our results suggest that there exists a dynamic and interactive linkage between the spread and order placement strategy.

6.2. Specialist spreads

We conjecture that limit orders influence the specialist's spread, too. Consider, for example, bid–ask quotes that belong to quote class (S, S). In these quotes, the specialist is offering *better* prices (both bid and ask) than those offered by limit-order traders. Hence, given our earlier finding that the limit-order spread is negatively related to the quantity of limit orders, the average spread for quote class (S, S) when there are few outstanding limit orders is expected to be wider than the average spread when there are many outstanding limit orders. We expect similar patterns in the intraday variations in spreads for quote classes (S, M) and (M, M).

To formally test this conjecture, we reestimate the structural model of Eqs. (4)–(6) after LSPRD_t in Eq. (4) is replaced by the specialist spread (SSPRD_t). We continue to use LSPRD in Eq. (5) because the limit-order execution rate is related to the limit-order spread, rather than to the specialist spread. (One can easily imagine a situation in which the specialists update their quotes without triggering limit order executions.) Because LSPRD is no longer endogenous in the system, however, we use the lagged value of LSPRD in Eq. (5) and treat it as an instrument in GMM estimation. Hence, in this case, we use lagged values of NOLO, LSPRD, VOL, ASPRD, and RISK as instruments in the GMM estimation.

The results, reported in Panel B of Table 6, show that the specialist's spread is, indeed, strongly related to the quantity of limit orders. The regression coefficient for the number of outstanding limit orders is negative and significant. (Because the circumstances that lead to few limit orders also lead to wide spreads, these results are also subject to the simultaneity problem discussed earlier.) We find a similar result using the number of unexecuted shares in the limit-order book. As in Panel A, we find a significant, positive correlation between the limit-order execution rate and the limit-order spread. These results also confirm our earlier findings that limit-order placement is positively related to spread, trading volume, and price volatility.

6.3. *Spreads based on whole sample*

Given our finding that both limit-order spreads and specialist spreads are significantly related to the quantity of limit orders, we expect the quoted spread to be significantly related to the quantity of limit orders as well. To assess the effect of limit orders on the intraday variation in the average spread based on our entire sample data (i.e., all quote classes), we reestimate the structural model of Eqs. (4)–(6) after LSPRD_t in Eq. (4) is replaced by the time-series data of the standardized spread across all quote classes (ASPRD_t). Because ASPRD is endogenous in this case, we replace ASPRD_{t-1} in Eq. (6) by ASPRD_t. We continue to use LSPRD_{t-1} in Eq. (5) and treat it as an instrument in the GMM estimation. Hence, we use NOLO_{t-1}, LSPRD_{t-1}, VOL_{t-1}, and RISK_{t-1} as instruments in the GMM estimation.

The results (see Panel C, Table 6) show that the spread is significantly and negatively related to the number of outstanding limit orders. The results also suggest that more investors enter limit orders (rather than hit the quotes) when the spread is wide. Conversely, more investors hit the quotes when the spread is tight. These results suggest that the investors provide liquidity when it is valuable to the marketplace and consume liquidity when it is plentiful. They do this for their own benefit, and this self-motivated trading behavior seems to result in an ecological balance between the suppliers and demanders of immediacy. This behavior helps explain why the nontrivial bid–ask spread is an equilibrium property of an order-driven market, even when the market has a large number of active participants.

7. Summary and conclusion

This study shows that limit-order traders play a significant role in the market-making process. We find that the majority of bid–ask quotes on the NYSE reflect the trading interest of limit-order traders. We also find that specialists tend to quote more actively for low-volume stocks and during early hours of trading when there are fewer limit orders submitted, suggesting that specialists step up to provide liquidity when the level of liquidity supplied by limit-order traders is low. We find that the spread is widest when both the bid and ask prices are quoted by specialists alone, and narrowest when both sides of the quote originate from the limit-order book, suggesting that competition from limit-order traders has a significant effect on spreads.

Our study also presents a finer test of specialist models of spreads by using only those quotes that reflect the trading interest of specialists. Our empirical results suggest that information models of spreads are the ones that are most consistent with the observed intraday pattern of spreads. We also offer an alternative explanation for the observed intraday variation in spreads. Specifically, we argue that the intraday variation in spreads could be driven by the intraday variation in competition among limit-order traders. Indeed, we find a significant, dynamic relation among spreads, limit-order placements, and limit-order executions.

Some caveats are in order. Although our findings are consistent with the view that the intraday variation in spreads is driven by the intraday variation in the quantity of limit orders, it is conceivable that the correlation between the two series can be explained by other reasons. In particular, we cannot rule out the possibility that both specialist quotes and limit order submissions are driven by unobserved exogenous variables. For example, perhaps the specialist and limit-order traders all respond to informed trading and/or uncertainty in ways that are consistent with the observed intraday variations in spreads and limit orders. Further investigations into these issues are a fruitful area for future research.

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