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Order handling rules, tick size, and the intraday pattern of bid–ask spreads for Nasdaq stocks[☆]

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Abstract

In this study we perform a before-and-after analysis of intraday variation in bid–ask spreads surrounding two recent Nasdaq market reforms. We find that spreads declined significantly after the order handling rule changes and the magnitude of the decline is largest during midday. The results are consistent with our conjecture that, like on the NYSE, limit-order traders on Nasdaq play a significant role in the quote-setting process. Our empirical results also show that the magnitude of the spread reduction associated with the tick-size change is largest (smallest) during the last (first) hour of trading. We interpret these results using inventory and information models of the spread. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

Numerous studies examine intraday variation in the bid–ask spread of NYSE-listed stocks. McInish and Wood (1992), Brock and Kleidon (1992), Lee et al. (1993), and Chan, et al. (1995b) find that the spread is widest at the beginning of the trading day, narrows during the day, and then widens near the close. These studies attribute the observed U-shaped intraday pattern of spreads to specialists' attempt to exploit their market power and/or to deal with the inventory and information asymmetry problems.[1] Chan et al. (1995a) examine the intraday pattern of spreads for Nasdaq-traded stocks. They show that Nasdaq spreads decline throughout the day and the magnitude of the decline is largest during the last 30-minutes. They attribute the difference in intraday spreads between NYSE and Nasdaq stocks to structural differences between specialist and dealer markets.

The Securities and Exchange Commission (SEC) enacted major changes in the order handling rules (OHR) on Nasdaq in 1997. The Limit Order Display Rule was phased-in for all Nasdaq National Market System (NMS) issues from January 20, 1997 to October 13, 1997. The rule requires that limit orders be displayed in the Nasdaq BBO (i.e., best bid and offer) when they are better than quotes posted by market makers. The new rule allows the general public to compete directly with Nasdaq market makers in the quote-setting process. The second SEC rule, known as the "Quote Rule," requires market makers to publicly display their most competitive quotes. This rule gives the public access to quotes posted by market makers in Electronic Communication Networks (ECN). Under the new rule, if a dealer places a limit order into Instinet or another ECN, the price and quantity are incorporated in the ECN quote displayed on Nasdaq if it represents the best bid or offer in ECN.

The "Actual Size Rule," reduces the minimum quote size (depth) of market makers from 1000 shares to 100 shares and thereby allows greater flexibility in their quote decisions. This rule was enacted in the belief that the smaller minimum depth requirement reduces the risks that Nasdaq dealers must take and thereby encourages market makers to maintain competitive quotes. The final feature of the OHR changes involves an amendment in the "Excess Spread

[1] Microstructure models that deal with order arrival and quote revision fall into the three general categories: inventory, market power, and asymmetric information models. In the inventory models (see Stoll, 1978; Amihud and Mendelson, 1980, 1982; Ho and Stoll, 1981), the spread compensates market makers for bearing the risk of holding undesired inventory. Market-power models link intraday variations in spreads to the monopoly power of specialists. Stoll and Whaley (1990) suggest that the specialist's ability to profit from privileged knowledge of order imbalances implies wide spreads 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 market makers.

Rule (ESR)." Prior to January 20, 1997, the ESR required Nasdaq dealers to maintain their spreads within 125% of the average of the three narrowest spreads for each stock. The amended ESR requires that each dealer's average spread during each month be smaller than 150% of the average of the three narrowest spreads over the month. The new ESR defines compliance on a monthly basis rather than continuously and thus poses less restriction on dealers' ability to change their spreads. In addition to the OHR changes, on June 2, 1997, the tick size on Nasdaq changed from $1/8 to $1/16 for stocks with a price greater than $10.

This study examines how these rule changes affect intraday variation in the spread and depth of Nasdaq-traded stocks. Because the new order handing rules allow limit-order traders to become direct participants in the quote-setting process, the results of the present study shed further light on the role of limit-order traders in the price-discovery process. In addition, our analysis of the effect of the tick-size change on intraday spreads and depths helps understand how market makers and limit-order traders deal with the inventory and adverse selection problems.

Barclay et al. (1999) examine the effect of the OHR changes on Nasdaq trading costs for the first 100 stocks phased-in under the new rules. The authors find that quoted and effective spreads declined by 30%, with the largest decline observed for stocks with relatively wide spreads prior to the rule changes. While Barclay et al. report the intraday pattern of spreads before and after the OHR changes and note a shift in the pattern, the study does not fully explain how and why the rule changes have altered the intraday pattern of spreads. The authors also find that while the average quoted depth of the first 50 stocks phased in under the new OHR remained the same after the rule changes, the average depth of the second 50 stocks rose significantly after the rule changes. The study, however, does not examine the intraday pattern of depth changes associated with the OHR changes.

Simaan et al. (1998) analyze the quotation behavior of Nasdaq dealers following the tick-size change. They find that Nasdaq dealers continue to avoid odd ticks, but traders entering orders on ECN do not exhibit such a behavior. Their findings show that ECN frequently establish the inside market quote and reduce trading costs for the public about 19% of the time. Neither Barclay et al. (1999) nor Simaan et al. (1998), however, examined the impact of the tick-size change on intraday variation in spreads. Similarly, while Goldstein and Kavajectz (2000) find a decrease in quoted depths after the tick-size change, they do not examine the intraday pattern of the changes in quoted depths.

In this study, we perform an empirical analysis of the effect of the OHR changes on spreads by comparing the intraday pattern of spreads immediately after the OHR changes with the pattern immediately before the rule changes. Similarly, we analyze the effect of the tick-size change on intraday variation in spreads by comparing the intraday pattern of spreads after the tick-size change with the pattern before the change. In addition, we examine the effects of these rule changes on quoted depths of Nasdaq stocks.

Our empirical results indicate that there has been a significant decline in spreads after the introduction of the new OHR and the magnitude of the decline is largest during midday. This result is consistent with Chung et al. (1999)'s finding that the NYSE spread is narrowest during midday when competition among limit-order traders is highest. In contrast, we find a significant increase in quoted depths after the OHR changes and the magnitude of the increase is smallest during the early hour of trading. Hence, it appears that market makers and limit-order traders start to show their trading interests (i.e., desired trade sizes) more frequently after the OHR changes.

We find that the tick-size reduction led to a significant decline in spreads and the magnitude of the decline is largest (smallest) during the last (first) hour of trading. We also find a significant decrease in quoted depths after the tick-size reduction and the magnitude of the decline is smallest during the first hour of trading. We interpret these results using inventory and information models.

In the following section, we present our hypotheses on the effects of the OHR and tick-size changes on intraday variation in spreads. Section 3 describes data sources and the measurement of the variables. Section 4 presents our empirical findings, and Section 5 concludes.

2. Effects of the OHR and tick-size changes on spreads

The Limit Order Display Rule requires that limit orders be displayed in the Nasdaq BBO when they better dealer quotes. The new rule allows limit-order traders to play a critical role in the quote-setting process. Under the Quote Rule, if a Nasdaq dealer places a limit order into an ECN which betters existing quotes, its price and quantity are incorporated in the ECN quote. Chung et al. (1999) show that limit-order traders play a significant role in shaping the intraday pattern of spreads for NYSE stocks. They find that the spread is widest when both the bid and ask prices reflect the trading interest of the specialist alone and the spread narrows when the spread reflects the limit-order prices. The authors show that limit-order quotes help reduce spreads throughout the day and the extent of the reduction is particularly large during midday.

To the extent that the new order handling rules make the role of limit-order traders on Nasdaq similar to that on the NYSE, limit-order traders are expected to play an important role in shaping the intraday pattern of spreads for Nasdaq stocks as well. Hence, we expect the OHR changes to induce a larger reduction in spreads during midday, relative to the reduction during early and late trading hours. We note that inferring the effect of limit orders on Nasdaq spreads based on the corresponding effect on the NYSE has a limitation because there are structural differences between the NYSE and Nasdaq. Whether the fragmented limit-order book on Nasdaq exerts a similar effect on spreads as the consolidated limit-order book on the NYSE is, therefore, an empirical question. This leads to our first hypothesis:

Hypothesis 1. *The magnitude of spread reductions associated with changes in the order handling rules is larger during midday than other times of the day.*

We conjecture that the tick-size change will lead to a larger reduction in spreads during the last hour of trading for two reasons. Chan et al. (1995a) show that Nasdaq dealers usually post quotes that place them on only one side of the inside spread. Nasdaq dealers who wish to avoid the risk of holding unwanted inventory overnight may post quotes that improve the inside spread near the close to influence order flow. Because the smaller tick size makes it less costly for dealers to jump in front of the existing BBO (see Harris, 1997), we expect that Nasdaq dealers' ability to manage inventory through their quotes increases with the smaller tick size. These considerations suggest that the effect of the tick-size change on Nasdaq spreads will be largest when dealers' need to control their inventory is greatest, i.e., the last hour of the trading day. Similarly, limit-order traders (e.g., mutual fund managers) who wish to transact at the close may also narrow spreads during the last hour.

The larger effect of the tick-size change on spreads near the close can also be posited from the prediction in Harris (1994). Prior to the tick-size reduction, the minimum tick size was more likely to be binding at the close relative to the middle of the day. Consequently, the decline in spreads is expected to be greatest during the last hour of trading once the tick-size constraint is reduced. This is analogous to the cross-sectional prediction of Harris (1994), which was subsequently tested by Ahn et al. (1996) and Bacidore (1997).

In contrast, we posit that the effect of the tick-size change on spreads is smallest near the open. Although the smaller tick size makes it less costly for liquidity providers to jump in front of the existing BBO, they are less likely to do so during the early hour of trading. This is because the extent of information asymmetry between informed traders and liquidity providers is likely to be greater during this time period. These considerations lead to our second hypothesis:

Hypothesis 2. *The impact of the tick-size change on spreads is smallest during the early hour of trading and largest during the last hour of trading.*

3. Data and the measurement of the variables

We obtain data for this study from the NYSE's Trade and Quote (TAQ) database. We begin our sample selection by identifying Nasdaq stocks for which the new SEC rules were in effect as of February 24, 1997. This initial sample comprises 150 stocks included in the first three batches of stocks phased-in under the new SEC rules.[2] Of these 150 stocks, we obtain data on 134 stocks from the TAQ database for our study period from October 1, 1996 to September 30, 1997. We select this period to ensure that we have three distinct subperiods: a three-month period before the OHR changes (October 1, 1996 – December 31, 1996)–time period 1; a three-month period after the OHR changes but before the tick-size change (March 1, 1997 – May 31, 1997)-time period 2; a three-month period after the tick-size change (July 1, 1997 - September 30, 1997)–time period 3.

To minimize errors, we apply several error filters to our data. We omit trades and quotes if the TAQ database indicates that they are out of time sequence, involve an error, or involve a correction. We omit quotes if either the ask price or the bid price is less than or equal to zero. We omit trades if the price or volume is less than or equal to zero. In addition, as in Huang and Stoll (1996), we omit the following to further minimize data errors: quotes when the spread is greater than \$4 or less than zero; before-the-open and after-the-close trades and quotes; trade price, p_t, when $|(p_t - p_{t-1})/p_{t-1}| > 0.10$; ask quote, a_t, when $|(a_t - a_{t-1})/a_{t-1}| > 0.10$; and bid quote, b_t, when $|(b_t - b_{t-1})/b_{t-1}| > 0.10$.

We use both the absolute (\$) and proportional (%) spreads as our measures of trading costs. The absolute spread is the difference between the posted ask price and the posted bid price. The proportional spread is calculated as

$$\text{Proportional spread}_{i,t} = (A_{i,t} - B_{i,t})/M_{i,t}, \qquad (1)$$

where $A_{i,t}$ is the posted ask price for stock i at time t, $B_{i,t}$ is the posted bid price for stock i at time t, and $M_{i,t}$ is the mean of $A_{i,t}$ and $B_{i,t}$.[3]

Because our analysis involves aggregation of data across stocks, we also calculate the *standardized* spread to neutralize the inter-stock difference in spreads. We obtain the standardized spread ($\text{STSPRD}_{i,t}$) 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 quoted spread for the day:

$$\text{STSPRD}_{i,t} = (s_{i,t} - m_i)/sd_i, \qquad (2)$$

where $s_{i,t}$ denotes the quoted spread for stock i at time t, and m_i and sd_i, respectively, are the mean and standard deviation of $s_{i,t}$ for the day. This

[2] The dates on which the new SEC rules became effective for our three batches of 50 stocks are January 20, February 10, and February 24.

[3] Huang and Stoll (1996) find that a large portion of trades on Nasdaq occur at prices inside the posted bid and ask quotes. To reflect inside-the-quotes trades in the measurement of trading cost, we replicate our analysis with the effective spreads. The results are similar to those presented here.

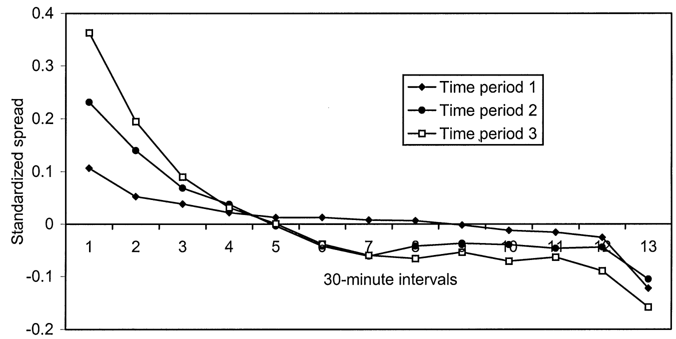

Fig. 1. Intraday variation in standardized proportional spreads.

procedure purges the inter-stock difference in spreads but retains variation in spreads across the time of day.

We partition the trading day into 13 successive 30-minute intervals and calculate the time-weighted spread for each stock during each 30-minute interval. We then stack the time-series data for individual stock across stocks and calculate the mean spread during each interval. Table 1 shows intraday variation in spreads during each of the three time periods. Fig. 1 shows intraday variation in the standardized proportional spread. When we replicate Fig. 1 using the standardized absolute spread, the results are similar to those presented here.

Consistent with the finding of Chan et al. (1995b), our results show that the spread during time period 1 is widest near the open, declines steadily throughout the day, and drops sharply during the last 30-minutes. Chan, Christie, and Schultz suggest that the gradual decline in Nasdaq spreads after the open (relative to the very abrupt drop in NYSE spreads) may reflect that Nasdaq dealers have less market power than NYSE specialists. The authors also suggest that the narrower Nasdaq spread near the close may be attributed to inventory control considerations.

Although the Nasdaq spread declined throughout the day after the OHR changes, we observe a notable difference in intraday spreads between time period 1 and time period 2. Specifically, we find that the rate of decline in intraday spreads during time period 2 is greater than the corresponding rate during time period 1 (see Fig. 1). The difference is particularly large during the first three 30-minute intervals. Fig. 1 also shows that the rate of decline in intraday spreads during time period 3 is even greater than the corresponding rate during time period 2.

These results indicate that the SEC rule changes magnify intraday variation in spreads for Nasdaq stocks. The greater intraday variation in spreads may be

Table 1
Intraday variation in spread

The absolute ($) spread is the difference between the posted ask price and the posted bid price. The proportional (%) spread is the ratio of the absolute spread to the midpoint of the bid and ask prices. 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 quoted spread for the day. This table shows time-weighted average spreads during each 30-minute interval of the trading day. Time period 1 covers a three-month period after the OHR changes (October 1, 1996–December 31, 1996). Time period 2 covers a three-month period after the OHR changes but before the tick-size change (March 1, 1997–May 31, 1997). Time period 3 covers a three month period after the tick-size change (July 1, 1997–September 30, 1997).

	Time period 1		Time period 2		Time period 3	
Time intervals	$ Spread	% Spread	$ Spread	% Spread	$ Spread	% Spread
A *Raw*						
9:30–10:00	0.3995	0.0144	0.2493	0.0110	0.2215	0.0089
10:01–10:30	0.3952	0.0142	0.2440	0.0108	0.2123	0.0085
10:31–11:00	0.3941	0.0142	0.2380	0.0105	0.2058	0.0083
11:01–11:30	0.3921	0.0141	0.2365	0.0104	0.2019	0.0081
11:31–12:00	0.3910	0.0140	0.2334	0.0103	0.1994	0.0080
12:01–12:30	0.3900	0.0140	0.2310	0.0101	0.1966	0.0079
12:31–13:00	0.3890	0.0140	0.2294	0.0100	0.1948	0.0078
13:01–13:30	0.3888	0.0140	0.2296	0.0101	0.1943	0.0078
13:31–14:00	0.3879	0.0139	0.2298	0.0101	0.1946	0.0078
14:01–14:30	0.3864	0.0138	0.2283	0.0100	0.1925	0.0077
14:31–15:00	0.3848	0.0138	0.2276	0.0100	0.1928	0.0077
15:01–15:30	0.3830	0.0137	0.2265	0.0100	0.1903	0.0076
15:31–16:00	0.3737	0.0135	0.2220	0.0098	0.1846	0.0075
B. Standardized						
9:30–10:00	0.1064	0.1065	0.2320	0.2309	0.3624	0.3632
10:01–10:30	0.0534	0.0525	0.1397	0.1399	0.1934	0.1948
10:31–11:00	0.0404	0.0382	0.0681	0.0686	0.0879	0.0897
11:01–11:30	0.0239	0.0219	0.0385	0.0375	0.0298	0.0315
11:31–12:00	0.0135	0.0126	− 0.0026	− 0.0037	− 0.0002	0.0007
12:01–12:30	0.0126	0.0126	− 0.0409	− 0.0423	− 0.0385	− 0.0383
12:31–13:00	0.0072	0.0076	− 0.0601	− 0.0614	− 0.0596	− 0.0599
13:01–13:30	0.0058	0.0062	− 0.0421	− 0.0422	− 0.0657	− 0.0659
13:31–14:00	− 0.0023	− 0.0019	− 0.0377	− 0.0371	− 0.0533	− 0.0538
14:01–14:30	− 0.0126	− 0.0122	− 0.0406	− 0.0397	− 0.0702	− 0.0709
14:31–15:00	− 0.0165	− 0.0159	− 0.0478	− 0.0466	− 0.0623	− 0.0633
15:01–15:30	− 0.0265	− 0.0257	− 0.0456	− 0.0443	− 0.0878	− 0.0896
15:31–16:00	− 0.1252	− 0.1226	− 0.1063	− 0.1053	− 0.1561	− 0.1581

attributed at least in part to the amended Excess Spread Rule (ESR), which puts less restriction on dealers' ability to change their quotes. This added freedom in setting their quotes may allow them to take more defensive positions during the early hours of trading when the level of information asymmetry is high and compete more aggressively (for order flow) during the last hour of trading as they are not forced into competing continuously throughout the day.

4. Empirical results

4.1. Effects of the OHR changes on intraday variation in spreads and depths

To examine the effects of the OHR changes on the intraday pattern of spreads, we calculate the difference in the time-weighted spreads between time period 1 and time period 2 during each 30-minute interval of the day. Because time period 1 covers a three-month period immediately before the OHR changes and time period 2 covers a three-month period after the rule changes, we expect the difference to capture the impact of the rule changes on spreads. We show the results in Table 2 (Panel A). Consistent with the finding of Barclay et al. (1999), our results show that the OHR changes prompt a significant reduction in Nasdaq spreads. The decline in the percentage spread ranges from 0.34% to 0.39% across the day. Similarly, we find a reduction of about 15 cents in the dollar spread.

Although the figures in Table 2 show the approximate magnitude of the difference in spreads between the two periods, they are not likely to accurately reveal the impact of the OHR changes on the intraday pattern of spreads because they are measured without controlling for inter-stock differences in spreads. To accurately measure the impact of the rule changes on the intraday pattern of spreads, we calculate the standardized differential spread (STDS):

$$\mathrm{STDS}_{i,t} = (ds_{i,t} - md_i)/sdd_i, \tag{3}$$

where $ds_{i,t}$ is the mean differential spread (between time period 1 and 2) for stock i during 30-minute interval t, and md_{i} and sdd_{i}, respectively, are the mean and standard deviation of $ds_{\mathrm{i,t}}$ for the day. This procedure purges the inter-stock difference in differential spreads but retains variation in differential spreads across the time of day.

We show intraday variation in the standardized differential spread in panel B of Table 2 and in Fig. 2. The results show that there is a distinct inverse U-shaped variation in the intraday pattern of differential spreads. The standardized differential spread is smallest during the first 30-minute interval, increases steadily until the early afternoon hours, and then decreases sharply during the last 30-minutes of trading. The results indicate that the OHR changes led to the largest reduction in spreads during midday.[4]

[4] To examine whether trading volume has any effect on differential spreads, we replicate Figs. 2 and 3 using the 25 least active stocks in our sample. The results are similar to those from the whole sample.

Table 2
Intraday variation in differential spreads

This table shows the difference in the time-weighted average spreads between time period 1 and time period 2 and the difference in the time-weighted average spreads between time period 2 and time period 3 during each 30-minute interval of the day. The absolute ($) spread is the difference between the posted ask price and the posted bid price. The proportional (%) spread is the ratio of the absolute spread to the midpoint of the bid and ask prices. We obtain the standardized differential spread by subtracting the stock's mean differential spread for the day from the differential spread and dividing the difference by the standard deviation of that stock's differential spread for the day.

	Change (decrease) in spread between time period 1 and time period 2		Change (decrease) in spread between time period 2 and time period 3	
Time intervals	$ Spread	% Spread	$ Spread	% Spread
A. *Raw*				
9:30–10:00	0.1503	0.0034	0.0278	0.0021
10:01–10:30	0.1513	0.0034	0.0317	0.0023
10:31–11:00	0.1561	0.0037	0.0323	0.0022
11:01–11:30	0.1556	0.0036	0.0346	0.0023
11:31–12:00	0.1575	0.0038	0.0341	0.0023
12:01–12:30	0.1590	0.0039	0.0344	0.0023
12:31–13:00	0.1596	0.0039	0.0346	0.0023
13:01–13:30	0.1592	0.0039	0.0352	0.0023
13:31–14:00	0.1581	0.0038	0.0352	0.0023
14:01–14:30	0.1581	0.0038	0.0359	0.0023
14:31–15:00	0.1571	0.0038	0.0348	0.0023
15:01–15:30	0.1566	0.0038	0.0362	0.0023
15:31–16:00	0.1516	0.0037	0.0374	0.0023
B. Standardized				
9:30–10:00	− 0.1256	− 0.1245	− 0.1304	− 0.1323
10:01–10:30	− 0.0864	− 0.0874	− 0.0536	− 0.0549
10:31–11:00	− 0.0277	− 0.0304	− 0.0198	− 0.0210
11:01–11:30	− 0.0146	− 0.0156	0.0087	0.0060
11:31–12:00	0.0162	0.0163	− 0.0024	− 0.0044
12:01–12:30	0.0535	0.0549	− 0.0024	− 0.0040
12:31–13:00	0.0674	0.0690	− 0.0006	− 0.0015
13:01–13:30	0.0479	0.0484	0.0236	0.0238
13:31–14:00	0.0354	0.0353	0.0156	0.0167
14:01–14:30	0.0281	0.0276	0.0296	0.0312
14:31–15:00	0.0313	0.0307	0.0145	0.0167
15:01–15:30	0.0191	0.0186	0.0422	0.0453
15:31–16:00	− 0.0189	− 0.0174	0.0498	0.0528

To test whether the observed variation is statistically significant, we estimate the following regression model:

$$\mathrm{STDS}_{i,t} = \alpha_0 + \alpha_1 D_1 + \alpha_2 D_2 + \alpha_3 D_3 + \alpha_4 D_4 + \alpha_5 D_5 + \alpha_6 D_6 + \varepsilon_{i,t}, \quad (4)$$

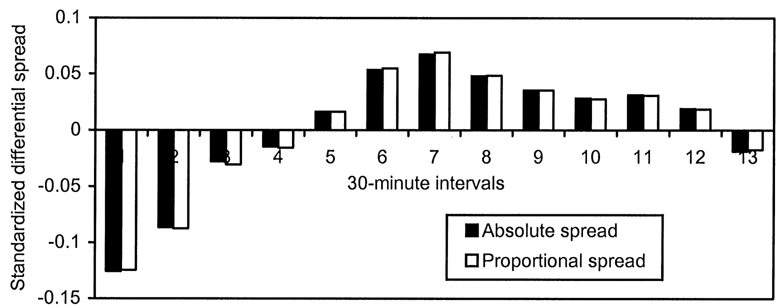

Fig. 2. Intraday variation in the standardized differential spread between time period 1 and time period 2.

where $STDS_{i,t}$ is the standardized differential spread of stock i during 30-minute interval t, and D_1 through D_6 are dummy variables each of which represents a 30-minute time interval. Dummy variables D_1, D_2, and D_3 represent, respectively, the first three 30-minute intervals of the trading day. Similarly, dummy variables D_4, D_5, and D_6 represent, respectively, the last three 30-minute intervals of the trading day. The intercept term measures the standardized differential spread during the time interval 11:01 a.m. – 2:30 p.m. The coefficients for the dummy variables, α_1 through α_6, measure the difference between the standardized differential spread during each respective 30-minute interval and the standardized differential spread during 11:01 a.m. – 2:30 p.m.

We estimate Eq. (4) for each stock using Hansen's (1982) generalized method of moments (GMM) with the Newey and West (1987) correction for serial correlation. We report the regression results in Table 3. For each dummy variable, we report the average coefficient estimate from the individual time-series regressions. To test whether each dummy variable coefficient is significantly different from zero, we calculate the aggregated p-value from the chi-square test using the procedure outlined in Gibbons and Shanken (1987). We also calculate the Z-statistic and its p-value for each dummy variable coefficient following the procedure in Meulbroek (1992).

We find that the regression coefficients for the first two 30-minute intervals are significantly negative according to both the chi-square test and Z-test. The results show that the coefficient for the last 30-minute interval is also significantly negative. These results suggest that the OHR changes have a significant impact on intraday variation in spreads for Nasdaq stocks. The rule changes reduce Nasdaq spreads throughout the day and the magnitude of the reduction is particularly large during midday. These results are supportive of our hypothesis 1 and suggest that the new order handling rules indeed allow limit-order traders to play a significant role in the quote-setting process.

Table 3
Test of intraday variation in differential spreads

This table reports the results of the regression model: $STDS_{i,t} = \alpha_0 + \alpha_1 D_1 + \alpha_2 D_2 + \alpha_3 D_3 + \alpha_4 D_4 + \alpha_5 D_5 + \alpha_6 D_6 + \varepsilon_{i,t}$; where $STDS_{i,t}$ is the standarized differential spread of stock i during time interval t, and D_1 through D_6 are dummy variables each of which represents a 30-minute time interval. We report, for each dummy variable, the average coefficient estimate from the individual time-series regressions, the aggregated p-value from the chi-square test, the Z-statistic and its p-value.

		Differential spreads between time period 1 and time period 2		Differential spreads between time period 2 and time period 3	
		$ Spread	% Spread	$ Spread	% Spread
D_1	Average coefficient	− 0.2538	− 0.4139	− 0.6709	− 0.4799
	P-value from χ^2 test	0.0001	0.0001	0.0001	0.0001
	Z-statistic	− 9.84	− 17.25	− 23.01	− 16.11
	P-value from Z-stat	0.0001	0.0001	0.0001	0.0001
D_2	Average coefficient	− 0.2240	− 0.3333	− 0.3416	− 0.2718
	P-value from χ^2 test	0.0001	0.0001	0.0001	0.0001
	Z-statistic	− 8.64	− 13.81	− 12.12	− 9.29
	P-value from Z-stat	0.0001	0.0001	0.0001	0.0001
D_3	Average coefficient	− 0.2286	− 0.1123	− 0.1722	− 0.1248
	P-value from χ^2 test	0.0065	0.0001	0.0001	0.0001
	Z-statistic	− 1.26	− 4.92	− 6.42	− 4.51
	P-value from Z-stat	0.2083	0.0001	0.0001	0.0001
D_4	Average coefficient	− 0.113	0.0020	− 0.0227	− 0.0340
	P-value from χ^2 test	0.0070	0.0765	0.0174	0.0015
	Z-statistic	− 1.13	0.41	− 0.98	− 1.42
	P-value from Z-stat	0.2574	0.6797	0.3283	0.1564
D_5	Average coefficient	0.0049	0.0378	0.0976	0.0810
	P-value from χ^2 test	0.0623	0.0032	0.0004	0.0001
	Z-statistic	− 0.72	0.92	3.12	2.38
	P-value from Z-stat	0.4710	0.3559	0.0018	0.0172
D_6	Average coefficient	− 0.3054	− 0.2010	0.2027	0.1203
	P-value from χ^2 test	0.0001	0.0001	0.0001	0.0001
	Z-statistic	− 10.54	− 6.82	6.23	3.55
	P-value from Z-stat	0.0001	0.0001	0.0001	0.0004

Although the new OHR led to a significant change in Nasdaq spreads, the intraday pattern of Nasdaq spreads after the rule changes is similar to the pattern before the rule changes in one fundamental way: Nasdaq spreads are widest at the open and decline throughout the trading day. Hence, even after the OHR changes, the intraday pattern of Nasdaq spreads remains different from that of NYSE spreads. This may indicate that the role of limit-order traders on Nasdaq is less prominent than their role on the NYSE. The difference may also be due to structural differences between specialist and dealer markets.

While the observed intraday variation in differential spreads is consistent with our conjecture that competition among liquidity providers is highest during midday, it is possible that the observed pattern could have been driven by other factors. It is likely that the new OHR have an impact on both the spread and depth. Considering the finding of Lee et al. (1993) that market makers utilize both the spread and depth for their liquidity management, the analysis of intraday variation in differential depths may help better understand the forces behind the observed intraday variation in differential spreads.

The smaller minimum required depth (the Actual Size Rule) is likely to reduce the quoted depth of market makers. According to the Limit Order Display Rule and the Quote Rule, however, the displayed depth after the rule changes reflects not only the trading interest of market makers but also the aggregate depth of outstanding limit orders at the BBO. Frequently, market makers may quote only the interest of limit-order traders without adding their own trading interests. Hence, depending on the relative frequencies of these cases, the quoted depth after the introduction of the new OHR can be greater or less than that before the rule changes.

In Table 4 we show intraday variation in differential depths (i.e., the time-weighted depth after the OHR changes minus the corresponding figure before the OHR changes) during each 30-minute interval. The results show that the average depth increased after the OHR changes throughout the trading day and the magnitude of the increase is smallest (largest) during the early (last) hour of trading. The larger depth after the OHR changes may indicate that market makers and limit-order traders start to show their trading interests (i.e., desired trade sizes) more frequently, whereas most market makers posted only the mandatory minimum depth (2,000 shares) during the pre OHR change period. [Indeed, our data show that Nasdaq dealers rarely post larger than 2,000 shares before the OHR changes.] The increase in depths after the rule changes may also indicate that large limit orders started to set the inside spread.[5]

To test whether the observed intraday variation in differential depths is statistically significant, we estimate Eq. (4) using the standardized differential depth (STDD) as the dependent variable. The results (see Table 5) show that the regression coefficients for the first three 30-minute intervals are significantly negative according to both the chi-square test and *Z*-test and the coefficient for the last 30-minute interval is significantly positive. The small increase in depths

[5] As noted earlier, Barclay et al. (1999) report mixed results on the effect of the OHR changes on depth. It should be noted, however, that our results are not directly comparable to Barclay et al.'s because the TAQ database reports only the largest, not the aggregate, depth at the inside market for Nasdaq issues.

Table 4
Intraday variation in differential depths.

This table shows the difference in the time-weighted average depths between time period 1 and time period 2 and the difference in the time-weighted average depths between time period 2 and time period 3 during each 30-minute interval of the day. We obtain the standardized differential depth by subtracting the stock's mean differential depth for the day from the differential depth and dividing the difference by the standard deviation of that stock's differential depth for the day

Time intervals	Change (increase) in depth between time period 1 and time period 2	Change (decrease) in depth between time period 2 and time period 3
A. *Raw depth*		
9:30–10:00	9.6512	2.7964
10:01–10:30	11.6474	3.8060
10:31–11:00	12.2435	4.0221
11:01–11:30	12.8970	4.3241
11:31–12:00	12.7215	4.2322
12:01–12:30	13.6524	4.6887
12:31–13:00	13.7809	4.8960
13:01–13:30	14.0324	5.0326
13:31–14:00	14.1627	5.1144
14:01–14:30	14.2809	5.2341
14:31–15:00	13.7054	4.5129
15:01–15:30	14.3560	5.3756
15:31–16:00	14.1532	4.1565
B. Standardized depth		
9:30–10:00	− 0.1565	− 0.0526
10:01–10:30	− 0.2973	− 0.0247
10:31–11:00	− 0.1123	− 0.0081
11:01–11:30	0.1720	0.0044
11:31–12:00	− 0.0158	− 0.0001
12:01–12:30	0.0283	0.0192
12:31–13:00	0.0709	0.0205
13:31–14:00	− 0.0287	0.0231
13:01–14:00	0.1065	0.0196
14:01–14:30	0.0978	0.0134
14:31–15:00	0.1074	− 0.0036
15:01–15:30	0.1342	0.0308
15:31–16:00	0.1702	− 0.0184

during the early hour of trading may indicate that liquidity providers are less willing to post large depths when the extent of information asymmetry is greater. This result is in line with our finding that the reduction in spreads after the OHR changes is smallest during the early hour of trading–liquidity providers are less willing to reduce their spreads at times of greater information asymmetry. The large increase in depths during the last hour of trading may reflect greater trading desires of limit-order traders and/or market makers. For example, some

Table 5
Test of intraday variation in differential depths

This table reports the results of the regression model: $\text{STDS}i,t = \alpha_0 + \alpha_1 D_1 + \alpha_2 D_2 + \alpha_3 D_3 + \alpha_4 D_4 + \alpha_5 D_5 + \alpha_6 D_6 + \varepsilon_{i,t}$; where $\text{STDS}_{i,t}$ is the standarized differential depth of stock i during time interval t, and D_1 through D_6 are dummy variables each of which represents a 30-minute time interval. We report, for each dummy variable, the average coefficient estimate from the individual time-series regressions, the aggregated p-value from the chi-square test, the Z-statistic and its p-value.

		Differential depths between time period 1 and time period 2	Differential depths between time period 2 and time period 3
D_1	Average coefficient	− 0.8730	− 0.3990
	P-value from χ^2 test	0.0001	0.0001
	Z-statistic	− 34.59	− 15.52
	P-value from Z-stat	0.0001	0.0001
D_2	Average coefficient	− 0.4262	− 0.2240
	P-value from χ^2 test	0.0001	0.0001
	Z-statistic	− 19.81	− 9.89
	P-value from Z-stat	0.0001	0.0001
D_3	Average coefficient	− 0.2738	− 0.1467
	P-value from χ^2 test	0.0001	0.0001
	Z-statistic	− 14.00	− 6.97
	P-value from Z-stat	0.0001	0.0001
D_4	Average coefficient	− 0.0687	− 0.1172
	P-value from χ^2 test	0.0001	0.0001
	Z-statistic	− 3.91	− 4.40
	P-value from Z-stat	0.0001	0.0001
D_5	Average coefficient	0.0736	0.0014
	P-value from χ^2 test	0.0239	0.0050
	Z-statistic	− 0.50	− 1.03
	P-value from Z-stat	0.6206	0.3038
D_6	Average coefficient	0.1277	− 0.1525
	P-value from χ^2 test	0.0001	0.0001
	Z-statistic	3.25	− 4.95
	P-value from Z-stat	0.0012	0.0001

traders may place large orders before the close to avoid unwanted positions overnight. Similarly, market makers may want to trade large quantities to return to their desired inventory positions before the market close.

4.2. Effects of the tick-size change on intraday variation in spreads and depths

To examine the effects of the tick-size change on intraday variation in spreads, we calculate the difference in the time-weighted spread between time period

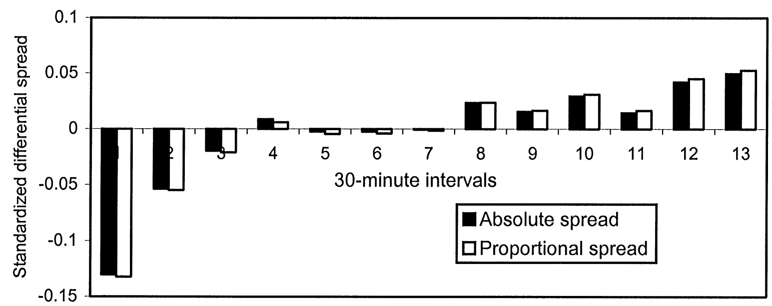

Fig. 3. Intraday variation in the standardized differential spread between time period 2 and time period 3.

2 and time period 3 during each 30-minute interval. The results show (see Table 2) that the tick-size change has reduced the absolute spread by 2.78 cents to 3.74 cents and the proportional spread by 0.21% to 0.23% across different 30-minute intervals of the day. The results are consistent with the findings of Ahn et al. (1996, 1998), Bacidore (1997), Porter and Weaver (1997), Van Ness, Van Ness et al. (2000), and Goldstein and Kavajecz (2000) that the bid–ask spread declines with a smaller tick size.

We show intraday variation in the standardized differential spread in panel B of Table 2 and also in Fig. 3. The differential spread is largest during the last 30-minute interval and smallest during the first 30-minute interval. To test whether the observed results are statistically significant, we estimate the regression model (4) using the standardized differential spread between time period 2 and time period 3. The regression results, reported in Table 3, show that the coefficients for the last two 30-minute intervals are positive and statistically significant according to both the chi-square test and *Z*-test.

These results are supportive of hypothesis 2 and are consistent with the conjecture that Nasdaq dealers become more aggressive in managing their inventory near the close as the smaller tick size makes it less costly for them to jump in front of the inside spread. Considering that all liquidity providers, dealers and limit-order traders alike, saw a reduction in the cost of jumping ahead of their competitors, the large reduction in spreads could also be due to limit-order traders (e.g., mutual fund managers) who wish to transact at the close. In addition, our results are consistent with the conjecture that the minimum tick was more likely to be binding at the close relative to the middle of the day before the introduction of the smaller tick size.

Consistent with hypothesis 2, we find that the regression coefficients for the first three 30-minute intervals are negative and significant, suggesting that the smaller tick size led to a smaller reduction in spreads during the early hour of trading than the rest of the day. This result may indicate that liquidity providers are less inclined to jump in front of the inside spread during the early hour of trading because the extent of information asymmetry between informed traders and liquidity providers is likely to be greater during this time period.

Table 4 shows intraday variation in differential depths (i.e., the time-weighted average depth after the tick-size change minus the corresponding figure before the tick-size change) during each 30-minute interval. We find that the average depth declined after the tick-size reduction throughout the trading day and the magnitude of the decrease is smallest during the early hour of trading. The smaller depth after the tick-size change is consistent with the finding of Goldstein and Kavajecz (2000) for NYSE stocks. The regression results presented in Table 5 show that the coefficients for the first three 30-minute intervals are negative and statistically significant according to both the chi-square test and Z-test. The smaller decrease in depths during the early hour of trading may indicate that liquidity providers are less inclined to quote large depths during the early hour of trading to protect themselves from informed traders.

5. Summary and conclusion

Numerous studies examine the effects of market structure on price discovery and trading costs in different securities markets. Researchers show that differential trading costs between the NYSE and Nasdaq are largely due to differences in their market structures. A recent market reform on Nasdaq which entails several structural changes in order-handling and quote-dissemination protocols provides an excellent opportunity to study the effects of market structure on trading costs and market quality. This study analyzes the effect of these rule changes on intraday variation in execution costs and thereby provides additional insight on the effects of market structure on execution costs and market quality.

Our empirical results show that bid–ask spreads declined significantly after the introduction of the new order handling rules and the extent of the decline is particularly large during midday. These results are consistent with our conjecture that limit-order traders play an important role in shaping the intraday pattern of trading costs on Nasdaq. We also find a significant decrease in spreads when the tick size declined from one eighth to one sixteenth and the magnitude of the decline is largest during the final hour of trading. We explain this result using inventory and information models of the spread. These results underscore the view that market structure has a significant effect on trading costs and thus a proper regulatory oversight of securities markets and establishment of proper trade and quote dissemination protocols are essential for investor welfare and market quality.

While we suggest that the observed intraday variation in differential spreads around the order handing rule changes can be attributed to intraday variation in competition among limit-order traders, we cannot rule out the possibility that the observed variation is driven by other unobserved exogenous variables. For example, perhaps market makers and limit-order traders all respond to informed trading and/or uncertainty in ways that are consistent with the observed intraday variation in spreads. Similarly, the observed intraday variation in differential spreads after the tick-size change may also be driven by some unknown factors. Further investigations into these issues are a fruitful area for future research.

References

Ahn, H., Cao, C., Choe, H., 1996. Tick size, spread, and volume. Journal of Financial Intermediation 5, 2–22.

Ahn, H., Cao, C., Choe, H., 1998. Decimalization and competition among stock market: evidence from the Toronto Stock Exchange cross-listed securities. Journal of Financial Markets 1, 51–87.

Amihud, Y., Mendelson, H., 1980. Dealership market: market-making with inventory. Journal of Financial Economics 8, 31–53.

Amihud, Y., Mendelson, H., 1982. Asset pricing behavior in a dealership market. Financial Analysts Journal 38, 50–59.

Bacidore, J., 1997. The impact of decimalization on market quality: an empirical investigation of the Toronto Stock Exchange. Journal of Financial Intermediation 6, 92–120.

Barclay, M., Christie, W., Harris, J., Kandel, E., Schultz, P., 1999. The effects of market reform on the trading costs and depths of Nasdaq stocks. Journal of Finance 54, 1–34.

Brock, W., Kleidon, A., 1992. Periodic market closure and trading volume: a model of intraday bids and asks. Journal of Economic Dynamics and Control 16, 451–489.

Chan, K., Christie, W., Schultz, P., 1995a. Market structure and the intraday pattern of bid–ask spreads for Nasdaq securities. Journal of Business 68, 35–60.

Chan, K., Chung, P., Johnson, H., 1995b. The intraday behavior of bid-ask spreads for NYSE stocks and CBOE options. Journal of Financial and Quantitative Analysis 30, 329–346.

Chung, K., Van Ness, B., Van Ness, R., 1999. Limit orders and the bid–ask spread. Journal of Financial Economics 53, 255–287.

Copeland, T., Galai, D., 1983. Information effects on the bid-ask spread. Journal of Finance 38, 1457–1469.

Foster, F., Viswanathan, S., 1994. Strategic trading with asymmetrically informed investors and long-lived information. Journal of Financial and Quantitative Analysis 29, 499–518.

Gibbons, M., Shanken, J., 1987. Subperiod aggregation and the power of multivariate tests of portfolio efficiency. Journal of Financial Economics 19, 389–394.

Glosten, L., Milgrom, P., 1985. Bid, ask and transaction prices in a specialist market with heterogeneously informed traders. Journal of Financial Economics 14, 71–100.

Goldstein, M., Kavajecz, K., 2000. Eighths, sixteenths and market depth: changes in tick size and liquidity provision on the NYSE. Journal of Financial Economics 56, 125–149.

Hansen, L., 1982. Large sample properties of generalized method of moment estimator. Econometrica 50, 1029–1054.

Harris, L., 1997. Decimalization: a review of the arguments and evidence. Working paper. University of Southern California, Los Angeles.

Ho, T., Stoll, H., 1981. Optimal dealer pricing under transactions and return uncertainty. Journal of Financial Economics 9, 47–73.

Huang, R., Stoll, H., 1996. Dealer versus auction markets: a paired comparison of execution costs on NASDAQ and the NYSE. Journal of Financial Economics 41, 313–357.

Lee, C., Mucklow, B., Ready, M., 1993. Spreads, depths, and the impact of earnings information: an intraday analysis. Review of Financial Studies 6, 345–374.

Madhavan, A., 1992. Trading mechanisms in securities markets. Journal of Finance 47, 607–642.

McInish, T., Wood, R., 1992. An analysis of intraday patterns in bid/ask spreads for NYSE stocks. Journal of Finance 47, 753–764.

Meulbroek, L., 1992. An empirical analysis of illegal insider trading. Journal of Finance 47, 1661–1699.

Newey, W., West, K., 1987. Hypothesis testing with efficient method of moments estimation. International Economic Review 28, 777–787.

Porter, D., Weaver, D., 1997. Decimalization and market quality. Financial Management 26, 5–26.

Simaan, Y., Weaver, D., Whitcomb, D., 1998. The quotation behavior of ECNs and Nasdaq market makers. Working paper. Baruch College, CUNY.

Stoll, H., 1978. The pricing of security dealer services: an empirical study of NASDAQ stocks. Journal of Finance 33, 1153–1172.

Stoll, H., Whaley, R., 1990. Stock market structure and volatility. Review of Financial Studies 3, 37–71.

Van Ness, R., Van Ness, B., Pruitt, S., 2000. The impact of the reduction in tick increments in major U.S. markets on spreads, depth, and volatility. Review of Quantitative Finance and Accounting, 15, 153–167.