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Eighths, sixteenths, and market depth: changes in tick size and liquidity provision on the NYSE☆

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Abstract

Using limit order data provided by the NYSE, we investigate the impact of reducing the minimum tick size on the liquidity of the market. While both spreads and depths (quoted and on the limit order book) declined after the NYSE's change from eighths to sixteenths, depth declined *throughout* the entire limit order book as well. The combined effect of smaller spreads and reduced cumulative limit order book depth has made liquidity demanders trading small orders better off; however, traders who submitted

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larger orders in lower volume stocks did not benefit, especially if those stocks were low priced.

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Bids or offers in stocks above one dollar per share shall not be made at a less variation than 1/8 of one dollar per share; in stocks below one dollar but above 1/2 of one dollar per share, at a less variation than 1/16 of one dollar per share; in stocks below 1/2 of one dollar per share, at a less variation than 1/32 of one dollar per share …

Rule 62, NYSE Constitution and Rules, May 1997

Bids or offers in securities admitted to trading on the Exchange may be made in such variations as the Exchange shall from time to time determine and make known to its membership.

Rule 62, NYSE Constitution and Rules, July 1997

1. Introduction

On June 24, 1997 the New York Stock Exchange (NYSE) reduced the minimum price variation for quoting and trading stocks from an eighth to a sixteenth, marking the first time in the 205-year history of the exchange that the minimum price variation had been altered. This minimum price variation, often referred to as tick size, implies that both quoted and transaction prices must be stated in terms of this basic unit. By cutting the tick size in half, the NYSE adopted a finer price grid, causing the universe of realizable quoting and trading prices to double overnight.

The move by the NYSE was the latest in a series of tick size reductions, including reductions by Nasdaq, the American Stock Exchange (AMEX), and the regional exchanges.[1] Despite these recent reductions, the appropriateness

[1] The recent changes in tick size were partially brought about by the introduction of the Common Cents Stock Pricing Act of 1997 (H.R. 1053) into the U.S. Congress. Although it did not contain a restriction on the minimum tick size, H.R. 1053 called for U.S. equity markets to quote prices in terms of dollars and cents.

and effects of changes in tick size remain open to debate. Some, such as Hart (1993), Peake (1995), O'Connell (1997), and Ricker (1998), argue that smaller tick sizes benefit liquidity demanders as competition between liquidity providers is likely to force a reduction in the bid–ask spread. Others, such as Grossman and Miller (1988) and Harris (1997), argue that while such a change may benefit some liquidity *demanders*, it may damage liquidity *providers*, as it could increase their costs and thus decrease their willingness to provide liquidity. As Harris (1997) notes, the tick size effectively sets the minimum bid–ask spread that can be quoted and thus helps determine the profitability of supplying liquidity. Consequently, changes in the tick size have important implications for the quoted spread, the supply of liquidity, trading by specialists and floor brokers, and order submission strategies (including market versus limit order placement, limit order prices, and trade size). The interactions among these changes are dynamic, not static, and may produce aggregate effects that increase, instead of decrease, transaction costs.

Unlike previous studies that focused primarily on changes in the quoted bid–ask spread and the quoted depth, our focus is how NYSE liquidity providers have been affected by the change in tick size and what these changes imply about the transactions costs faced by market participants.[2] The response of liquidity providers to a reduction in the minimum tick size and its impact on spreads and depths is uncertain. One possible response is that while liquidity providers supply less depth at the new, narrower quoted spread, they may continue to supply the same liquidity at the previous prices. While the depth at the quoted spread will be reduced, the cumulative depth at a certain price – defined as the sum of the depth for all limit orders up to and including that price – will remain unaffected. (Cumulative depth at a certain price is calculated by adding up all of the shares available at that price or better. For example, if there are 200 shares offered at 20, 300 shares offered at 20 1/16, and 600 shares at 20 1/8, the cumulative depth at 20 1/16 is 500 shares and the cumulative depth at 20 1/8 is 1100.) Alternatively, liquidity providers could shift their limit orders to prices further from the quotes or, if the costs to liquidity providers sufficiently increase, choose to leave the market altogether. As a result, the number of liquidity providers could decrease overall, causing not only the depth at the quoted bid and ask to decline, but the cumulative depth to decline

[2] Liquidity on the floor of the NYSE is provided by limit order traders as well as floor brokers and specialists (see Sofianos and Werner, 1997). Investors who place orders in the limit order book provide liquidity by publicly stating the amount that they are willing to trade at a certain price. NYSE floor brokers, when trading as agents for their clients, often have discretion in whether to supply or demand liquidity when working orders. Furthermore, this floor broker liquidity may or may not be displayed to the general market. The specialist could supply additional liquidity by choosing to improve upon the limit order book or floor broker interest either by improving the price or by displaying more depth.

as well.[3] Thus, while order sizes smaller than the quoted depth could benefit from the reduction in spreads, larger sized orders could become more expensive as they could be forced to eat into the limit order book to find sufficient liquidity. The question remains, therefore, whether the change in tick size will cause sufficient changes in the cumulative depth to increase costs for larger orders while still reducing costs for smaller ones.

As Lee et al. (1993) note, any study of liquidity provision must examine the changes in both prices and depths. Moreover, Harris (1994) notes that to address properly whether or not liquidity has been enhanced or hampered requires an investigation into how the depth throughout the limit order book has been altered. Thus, to study the combined effects of change in the spread, depth at the market, and cumulative depth, we use order data provided by the NYSE to reconstruct the limit order book before and after the change in tick size.

Similar to previous studies, we find that quoted spreads have declined by an average of \$0.03 or 14.3% and quoted depth declined by an average of 48%. However, unlike previous studies, we also find that limit order book spreads (i.e., the spread between the highest buy order and the lowest sell order) have *increased* by an average of \$0.03 or 9.1% and depth at the best prices on the limit order book declined by 48%.

More important, we find that cumulative depth on the limit order book *declines* at limit order prices as far out as half a dollar from the quotes. In addition, NYSE floor members have decreased the amount of liquidity they display, as measured by the difference between the depth on limit order book and the depth quoted by the specialist at the current quote price. However, this reduction in displayed additional depth by NYSE floor members is much less than the depth reduction on the limit order book.

Overall, we find that the cumulative effect of the changes in the limit order book and NYSE floor member behavior has reduced the cost for small market orders. However, larger market orders have not benefited, realizing higher trading costs after the change if required to transact against the limit order book alone. The effect of the minimum tick size reduction is sensitive to trade size, trading frequency, and the price level of each stock; the benefit to small orders is sharply reduced for infrequently traded and low-priced stocks, especially if the liquidity is solely derived from the limit order book. Thus, in contrast to previous studies that found liquidity increases after tick size reductions, we do not find evidence of additional liquidity for some market participants.

[3] Studies considering only the posted quotes and depths are not able to evaluate whether liquidity provision has changed or remained constant. If spreads decrease, even measures that relate posted spreads to posted depths cannot determine if these newer spreads are caused by newer limit orders or a shift of limit orders closer to the quotes. If such a shift occurred, such measures cannot tell if it was a uniform shift or if new limit orders have tightened the spread while other limit orders have left the book. Using the cumulative depth measure, we are able to determine how this liquidity provision has changed.

The remainder of the paper is organized as follows. Section 2 provides a review of the effects of tick size changes. Section 3 briefly describes the data set and procedure used in constructing the estimates of the limit order book. Section 4 details the impact of the minimum tick size on spreads, depths, and the cost of transacting. Section 5 describes the effects on various liquidity providers and Section 6 concludes.

2. Effects of tick size reductions

A number of papers examine the effects of reductions in tick size both theoretically and empirically. While several theoretical models consider the issue of optimal tick size, the most relevant to this study are Seppi (1997) and Harris (1994).[4] Seppi's model demonstrates that when the price grid is fine, the limit order book's cumulative depth decreases as the minimum tick size declines. Thus, although small traders prefer finer price grids while large traders prefer coarser ones, both groups agree that extremely coarse and extremely fine price grids are undesirable. Harris (1994) also makes a compelling argument that a reduction in tick size would reduce liquidity. For stocks where the tick size is binding, bid–ask spreads should equal the tick size with relatively high quoted depth, as specialists and limit order traders find liquidity provision a profitable enterprise. A reduction in tick size would lower quoted spreads on constrained stocks but would also lower quoted depth, because of a decrease in the marginal profitability of supplying liquidity. Harris further notes that the reduction in tick size would likely affect stocks even where the constraint is not binding: since the tick size represents the subsidy paid to liquidity providers, a reduction in that subsidy will alter the level and nature of the liquidity provided. Specifically, in the wake of a tick size reduction, liquidity providers could choose to reduce the number of shares they pledge at a given price, shift their shares to limit prices further from the quotes to recapture some of the lost profit, or, if the liquidity provider is at the margin, exit the market altogether. In addition to potentially altering the level of liquidity provided, traders could be able to jump ahead of standing limit orders to better their place in the queue, as noted in Amihud and Mendelson (1991) and Harris (1996).

[4] In the theoretical literature, the optimal tick size hinges upon whether the model casts a minimum tick size as pure friction to the Bertrand competition of liquidity providers, as in Anshuman and Kalay (1998), Bernhardt and Hughson (1996), and Kandel and Marx (1996), or whether a minimum tick size coordinates negotiation, as in Brown et al. (1991) and Cordella and Foucault (1996). A related literature debates the relation between tick size and payment-for-order flow. Chordia and Subrahmanyam (1995) develop a model where smaller tick sizes represent frictions that allow for enough slack to make payment for order flow a profitable strategy. In contrast, Battalio and Holden (1996) present a model that shows that movements toward smaller tick sizes will not eliminate payment for order flow arrangements.

Empirical research on minimum tick size reductions of international and U.S. equity markets have tested and corroborated the predictions of Harris (1994) using quoted bid–ask spreads and quoted depths. Angel (1997), using international data to investigate the connection between minimum tick sizes and stock splits, argues that a small tick size increases liquidity by allowing for a small bid–ask spread; however, it also diminishes liquidity by making limit order traders and market makers more reticent to supply shares. Using data from the Stockholm Stock Exchange, Niemeyer and Sandås (1994) also corroborate the arguments in Harris (1994), showing that the tick size is positively related to the bid–ask spread and market depth, and negatively related to trading volume. Bacidore (1997), Ahn et al. (1998), Huson et al. (1997), and Porter and Weaver (1997) study the impact of the April 15, 1996 Toronto Stock Exchange's (TSE) reduction in the minimum tick size to five cents. These studies found a significant decline in the quoted bid–ask spreads of 17–27% and in the quoted depth of 27–52% (depending on study and sample), while average trading volume displayed no statistically significant increase. Collectively, these results generally confirm the predictions made by Harris (1994). The authors argue that the smaller tick size had at worst no effect and at best a liquidity improving effect on the TSE because of the dramatic decrease in spreads and despite the decrease in quoted depth.

Domestically, Crack (1994) and Ahn et al. (1996) assess the impact of the September 3, 1992 American Stock Exchange reduction in the minimum tick size for stocks priced under five dollars, finding approximately a 10% decline in quoted spreads and depths in addition to an increase in average daily trading volume of 45–55%. Bessembinder (1997) studies Nasdaq stocks whose price level breaches the ten-dollar price level and thus changed tick size from eighths to sixteenths. His results show that for those stocks whose price level fell below the ten-dollar level the effective spread fell by 11%.

In research on more recent U.S. tick size reductions, Ronen and Weaver (1998) study the impact of the May 7, 1997 switch to sixteenths by the American Stock Exchange. Their results, conditioning the sample by price level and trading volume, are consistent with Harris (1994) as well as with other earlier empirical work. Their results on reduced quoted spreads and depth cause the authors to conclude that the implemented reduction to the minimum tick size has decreased transactions costs and increased liquidity.

Bollen and Whaley (1998) and Ricker (1998) conduct analyses of the minimum tick size reduction on the NYSE. Their results demonstrate that the volume weighted bid–ask spread declined by approximately \$0.03 or 13–26% depending on the study. Furthermore, the authors find that quoted depth decreased between 38% and 45%. Collectively they conclude that the NYSE tick size reduction has improved the liquidity of the market especially for low-priced shares. Van Ness et al. (1999) also examine the impact of the tick size

reduction on the NYSE, AMEX, and Nasdaq. They find that on the NYSE quoted spreads and depths, volatility, and average trade size all declined.

Finally, using institutional data, Jones and Lipson (1998) examine the effects of the change in tick size at the NYSE and on Nasdaq. Supporting the results in this study, they find that although trading costs decreased for smaller trades, they have increased for larger trades. Jones and Lipson argue that spreads alone are insufficient for measuring market quality because of these differential effects and conclude that smaller tick sizes may not be pareto-improving.

3. Data and methodology

Because of limitations on data availability, previous studies on tick size reductions have been confined to using trade and quote data, restricting the scope of their analyses. Using a new data set that contains system order submissions, executions, and cancellations as well as quotes, this study examines the reactions of different liquidity providers (both limit order traders and members on the NYSE floor) to examine and explain changes in their behavior related to changes in tick size.

Our investigation of the impact of the minimum tick reduction requires that we be able to assess depth away from the quote. Thus, our analysis requires knowledge of the limit order books that compete with the specialist and floor brokers to supply liquidity. Using SuperDOT order data provided by the NYSE, we reconstruct the limit order books using the technique described in Kavajecz (1999). The order data provide information about system order placements, executions, and cancellations and are similar in nature to the Trades, Orders, Reports, and Quotes (TORQ) data set previously released by the NYSE. We start with the 110 surviving TORQ stocks as of October 1997.[5] We then eliminated the ten surviving closed-end funds or unit investment trusts because their limit order books are substantially different from the limit order books of the other stocks in the sample. The remaining one hundred stocks are separated into four groups of 25 stocks each, based on their trading volume and price level as of December 1996. Stocks are ranked by trading volume. The top 50 stocks are placed in the high trading volume group, and the remaining stocks are placed in the low trading volume group. Within each trading volume group, stocks then are ranked by price level and separated into high- and low-price groups. This method of grouping the stocks provides an opportunity to conduct a bivariate analysis of the minimum tick size reduction based on trading volume and price.

[5] The original TORQ data set is a stratified sample of 144 NYSE-listed securities over the three months of November 1990 through January 1991. The surviving one hundred firms are slightly overweighted in the largest stocks but are nonetheless reasonably well distributed across NYSE quintiles. For further information on the TORQ data set, see Hasbrouck (1992) and Hasbrouck and Sosebee (1992).

The principle behind the limit order book estimation is that, at any instant in time, the limit order book should reflect those orders remaining after the orders placed before the time in question are netted with all prior execution and cancellation records. We first use data from March 1997 through November 1997 to search for all records that have order arrival dates prior to March. We use these good-'til-cancelled limit orders as an estimate of the initial limit order book just prior to March. We create snapshots of the limit order book by sequentially updating the limit order book estimates using records whose date and time stamp are previous to the time of the snapshot.

We generate limit order book estimates for three four-week sample periods, one period before the minimum tick reduction and two periods after the minimum tick reduction. The period prior to implementing sixteenths, called the pre-reduction period, begins on May 27, 1997 and ends June 20, 1997. The first period after the tick reduction begins June 30, 1997 and ends July 25, 1997, and the second period after the tick reduction begins August 25, 1997 and ends September 19, 1997. The week of the change was eliminated to avoid any potential data errors associated with the switch. Two separate post-reduction periods are used to control for any transition period caused by market participants taking time to adjust their strategies to the new equilibrium. Given that the data in the two post-reduction periods are both qualitatively and quantitatively similar, we aggregate them into a single period. In addition, because the overall market was rising during the time periods in the study, there could be asymmetries between the bid and ask sides of the market that have little to do with the minimum tick size reduction. Consequently, in the analysis to follow we average the bid and ask sides of the market to reduce any effect resulting from general price direction.

Limit order books are estimated at 30-min intervals for each business day in the pre- and post-reduction periods that the NYSE was open. The result is a sequence of limit order books snapshots comprised of approximately 266 observations in the pre-reduction period and approximately 532 observations in the combined post-reduction period for each of the one hundred stocks in the sample.[6] Results are equally weighted averages across these 30-min snapshots, either overall or by trading volume/price grouping.[7]

[6] Estimates are calculated at the time of the opening quote and each half-hour on the half-hour thereafter. For example, if a stock opened at 9:40:28 AM, an estimate would be taken at that time and then at 10:00:00, 10:30:00, etc. The number of limit order books for each stock is approximate because occasional late openings (later than 10:00:00) causes differences in the number of estimates for each stock.

[7] One unusual stock in our sample deserves special comment. Although Allegeny (Ticker Symbol: Y) is a thinly traded stock, its price at the end of December 1996 was more than $200. During the pre-period of our study, the dollar quoted spread for Allegeny was $1.78 and during the post-period it increased to $2.62. However, Allegeny's average limit order book spread was $2.74 in both the pre-period and the post-period.

4. Spreads, depths, and the cost of transacting

Similar to other studies, we begin by documenting the effect that the tick reduction had on quoted spreads and quoted depth. Table 1 shows the quoted spreads and quoted depths results: Panel A displays the results for the

Table 1
Data on the spreads and their associated depths quoted by the specialist for the one hundred NYSE stocks in our sample. The pre-reduction period includes data from May 27 to June 20, 1997. The post-reduction period includes data from June 30 to July 25, 1997 and from August 25 to September 19, 1997. The stocks are then separated into quartiles based on their December 1996 average daily trading volume and price. The spreads and depth are equally weighted averages of 30-min snapshots in time.Depth numbers are the average of bid and ask depth. Differences in bold in Panel C are significant at the 1% level for both parametric and nonparametric tests.In Panel C, F-tests for equality across high/low trading volume holding price category constant are rejected at the 1% level, except for the quoted dollar spread in the low price category. In Panel C, F-tests for equality across high/low price holding trading volume category constant are rejected at the 1% level, except for the quoted dollar spread in the high volume category. F-tests for equality across all four categories in Panel C are rejected at the 1% level.

Stock category	Quoted dollar spread	Quoted percentage spread	Average quoted depth
Panel A: Pre-reduction period			
All100 stocks	0.21	0.86	9353
High volume			
High	0.17	0.32	14,112
Low	0.16	0.67	15,950
Low volume			
High	0.32	0.63	2904
Low	0.19	1.79	4446
Panel B: Post-reduction period			
All 100 stocks	0.18	0.68	4824
High volume			
High	0.13	0.23	6488
Low	0.11	0.44	7742
			Low volume
High	0.32	0.52	2133
Low	0.18	1.55	2935
Panel C: Change from pre- to post-reduction period			
All 100 stocks	**−0.03**	**−0.18**	**−4529**
High volume			
High	**−0.04**	**0.09**	**−7624**
Low	**−0.05**	**0.23**	**−8208**
Low volume			
High	0.00	**−0.11**	**−771**
Low	− 0.01	**−0.24**	**−1511**

pre-reduction period; Panel B, the results for the post-reduction period; and Panel C, the change. Consistent with the predictions of Harris (1994) and the empirical studies of other comparable tick size reductions, we find that the average quoted spread *decreased* by \$0.03 or 14.3% and average quoted depth declined by 48.4%.[8] These changes are significant at the 1% level. (Throughout the paper, to consider a result significant at the 1% level, we require that the *p*-values for *both* parametric and nonparametric tests be less than 1%. In particular, we require that *t*-tests for both equal and unequal variances have *p*-values less than 0.01 and that both the Wilcoxon 2-sample test and the Kruskal–Wallis test had *p*-values of less than 0.01. Only in the case that all four tests had *p*-values less than 0.01 do we consider the result significant at the 1% level.) Furthermore, the reductions in both the quoted spread and quoted depth are largest for frequently traded stocks. The average quoted spread *increased* for the most infrequently traded stocks.

Earlier research on the impact of a tick reduction has been limited to the information available in Table 1. Consequently, inferences made from the results in Table 1 must be limited to noting that liquidity demanders trading sizes less than or equal to the reduced quoted depth have realized a transaction cost decrease. For liquidity demanders trading sizes larger than the reduced quoted depth, the improved bid and ask prices apply only to a portion of their required size. Absent additional liquidity provided by the floor, for the remainder of their trades, the sequence of prices and depths further into the limit order book also apply. For larger size orders, inferences about the transaction costs cannot be made without knowing how liquidity further into the limit order book has been altered by the tick reduction. Having the benefit of a richer data set, we simultaneously assess the effect of the reduction in the bid–ask spread and the effect of the change in depth – both at the quotes and throughout the limit order book – to determine the impact on overall liquidity.

Table 2 provides some results of how the limit order books have been altered because of the tick size reduction. One measure of how the limit order book has changed is the spread between the best limit price on the buy side and the best limit price on the sell side of the limit order book. As noted in Kavajecz (1999), this limit order book spread need not be equal to the spread quoted by the specialist, since the specialist has the ability to supplement liquidity provided by the limit order book with floor interest as well as his own interest. The specialist can supplement liquidity by posting a better price than that on the limit order book or by adding depth to that already on the limit order book.

[8] Trading volume, unlike the spread and depth measures, is likely to have an upward trend unrelated to the tick size reduction. As a result, trading volume is not shown because no control sample is available to help assess whether the increase was abnormally high. While we do not specifically control for variance changes, Van Ness et al. (1999) find that the variance was lower during the post-period.

Table 2

Data on characteristics from the limit order books for the one hundred NYSE stocks in our sample. The pre-reduction period includes data from May 27 to June 20, 1997. The post-reduction period includes data from June 30 to July 25, 1997 and from August 25 to September 19, 1997. Limit order books (LOB) were estimated using the technique described in Kavajecz (1999). The stocks are then separated into quartiles based on their December 1996 average daily trading volume and price. Results are from equally weighted averages of snapshots of the limit order book every 30 min. Limit order book spread is the spread between the best buy or sell limit order prices on the limit order book. LOB quote depth is the depth at the best buy or sell limit order prices on the limit order book. Depth numbers are the average of bid and ask depth. Average number of orders is the average number of limit orders on the limit order book. Average order size is the average size in shares of the limit orders on the limit order book. Cumulative limit order book depth is the average cumulative depth of the limit order book measured from the quoted bid–ask spread midpoint. Differences in bold in Panel C are significant at the 1% level for both parametric and nonparametric tests. In Panel C, except for the high/low price comparison holding high volume constant for the LOB dollar spread, F-tests for equality across high/low price holding volume constant, across high/low volume holding price constant, or across all four categories are rejected at the 1% level.

Stock category	LOB dollar spread	LOB percent spread	Best LOB quote depth	Average number of orders	Average order size	Cumulative limit order book depth			
						1/8	1/4	3/8	1/2
Panel A: Pre-reduction period									
All 100 stocks	0.33	1.25	9111	105	1358	9377	17,698	23,741	28,248
High volume									
High	0.18	0.34	13,725	280	1109	14,682	28,135	37,850	45,421
Low	0.18	0.72	13,846	95	1286	14,365	25,943	34,199	40,265
Low volume									
High	0.65	1.23	3454	18	1633	2894	5671	7907	9592
Low	0.32	2.72	5422	28	1405	5215	10,395	14,158	16,712
Panel B: Post reduction period									
All 100 stocks	0.36	1.40	4667	127	1234	7265	13,022	17,262	20,778
High volume									
High	0.14	0.25	6069	367	941	11,065	20,439	27,715	33,945
Low	0.15	0.57	6827	94	1239	11,087	19,082	24,450	28,695
Low volume									
High	0.70	1.22	2279	19	1430	2407	4177	5357	6365
Low	0.48	3.59	3495	27	1326	4129	7721	10,635	13,033
Panel C: Change from pre- to post-reduction period									
All 100 stocks	**0.03**	**0.15**	**−4444**	22	**−124**	**−2112**	**−4676**	**−6479**	**−7470**
High volume									
High	**−0.04**	**−0.09**	**−7656**	**87**	**−168**	**−3617**	**−7696**	**−10,135**	**−11,476**
Low	**−0.03**	**−0.16**	**−7019**	− 1	**−47**	**−3278**	**−6861**	**−9749**	**−11,570**
Low volume									
High	0.05	− 0.01	**−1175**	1	− 203	**−487**	**−1494**	**−2550**	**−3227**
Low	**0.16**	**0.87**	**−1927**	**−1**	**−79**	**−1086**	**−2674**	**−3523**	**−3679**

We find that the limit order book spread *increased* by \$0.03 or 9.1%, which is statistically significant at the 1% level. However, this increase is not uniform across quartiles. While the limit order book spread displays a statistically significant decrease of three to four cents for frequently traded stocks regardless of price level, low-volume, low-price stocks display a statistically significant 16-cent increase. In addition, the quoted spread and the limit order book spread are the similar in magnitude for the most actively traded stocks both before and after the change, while for less frequently traded stocks the limit order book spread is approximately double that of the quoted spread.

These results reveal that the impact of the tick reduction is not as clear-cut as the quoted spread results suggest. Like the quoted depth results reported in Table 1, depth on the limit order book at the best limit order prices decreased significantly, with the largest decline occurring in the most frequently traded stocks. Thus, determining where depth is positioned on the limit order book is paramount to assessing the impact of the tick size reduction. If the tick size reduction incorporated a shift in the existing shares to prices further away from the quotes, then even if overall new shares are added to the limit order book, liquidity may have been reduced for certain size orders.

The important measure, therefore, is how the cumulative depth has been affected. To illustrate this point, suppose that prior to the tick reduction a stock had a quoted price schedule of 20 bid, 20 1/8 ask with corresponding depths of 1000 and 2000 shares. (Assume that the specialist is choosing to add no depth beyond that provided by the limit order book.) Immediately after the tick size reduction, the quoted price schedule is revised to 20 bid, 20 1/16 ask with the depths being 500 shares at the bid and 800 shares at the ask. A liquidity demander who wishes to buy 800 or fewer shares is clearly better off under the smaller tick size. However, a liquidity demander who wishes to buy more than 800 shares could be better off or worse off depending on the cumulative depth on the limit order book. Without knowing the exact size that the larger liquidity demander wishes to trade, a sufficient condition for this large liquidity demander to be better off would be if the cumulative depth on the limit order book at each price level increased or at worst remained unchanged. If so, we could conclude that the transactions costs faced by this liquidity demander would have been reduced regardless of the amount he wishes to trade.

Table 2 also displays the change in the cumulative depth on the limit order books for limit prices that are as far as 50 cents away from the quoted bid–ask spread midpoint. (We also calculated the changes in cumulative depth measured from the same side quote and the opposite side quote. The results, not reported here, are substantively similar.) By adding up all of the depth available on the limit order book, measured from the quoted bid–ask spread midpoint, we measure the cumulative depth that is available to a liquidity demander immediately. Measuring cumulative depth from the quoted bid–ask spread midpoint accounts for the changes in the quoted spread that occurred because of the

change in tick size as well as creates a similar point of reference for both the bid and the ask side of the market.

Evidence in Table 2 reveals that cumulative depth falls significantly as far as half a dollar away from the quoted bid–ask spread midpoint, with the strongest decline for frequently traded stocks. Depth has been reduced for prices both near and relatively far away from the quotes. For example, the average cumulative depth for all one hundred stocks an eighth away from the quotes was 9377 shares before the change, but only 7265 afterwards. This decrease of 2112 shares is significant at the 1% level. Depth further out on the limit order book showed similar significant declines.

While the decline occurred in both trading volume groups, it was much sharper in the more frequently traded stocks, with little variation across high- and low-priced stocks. Consequently, trading volume seems to be more important than price in determining cumulative depth. For the more (less) frequently traded high-priced stocks, the average cumulative depth an eighth away from the quote was 14,682 (2894) before the change but only 11,065 (2407) afterwards, resulting in a statistically significant decrease of 3617 (487) shares. Moreover, this change in depth was even more noticeable further out on the limit order book. Overall, the results of Table 2 indicate that no clear statement about liquidity can be made ex ante without empirically evaluating the transaction costs associated with different trade sizes before and after the tick size reduction.

Figs. 1 and 2 measure ex ante expected costs (from the midpoint of the bid–ask spread) facing a liquidity demander based on the number of shares that he wishes to transact assuming that only publicly stated liquidity is available. Fig. 1 calculates these costs as if the trade were executed solely against the limit order book, while Fig. 2 calculates the costs using the depth in the limit order book plus any additional depth contributed by the floor that is displayed in the specialists' quotes. All figures are average share prices for that size transaction expressed as percentage distance from the quoted bid–ask spread midpoint. These figures are based on a shapshot in time and represent the cost to orders of different sizes submitted at that time that will be filled solely by the stated liquidity on the limit order book (Fig. 1) or limit order book and the stated liquidity from the floor (Fig. 2). As such, it does not account for any additional nondisplayed liquidity that is available from the floor, as noted by Sofianos and Werner (1997).

This analysis directly measures the net impact of the spread decline and the cumulative depth decline. The figures show the average ex ante cost a trader faces who wishes to trade a given number of shares. For example, suppose a trader wanted to sell 5000 shares of a frequently traded high-priced stock and assume that the quoted bid–ask midpoint proxies for the expected value of the stock. Before the tick size reduction, the trader would receive 45 basis points less than the midpoint (assuming that the trade was executed solely against the limit order book) for the execution, but 55 basis points after the tick reduction. If we

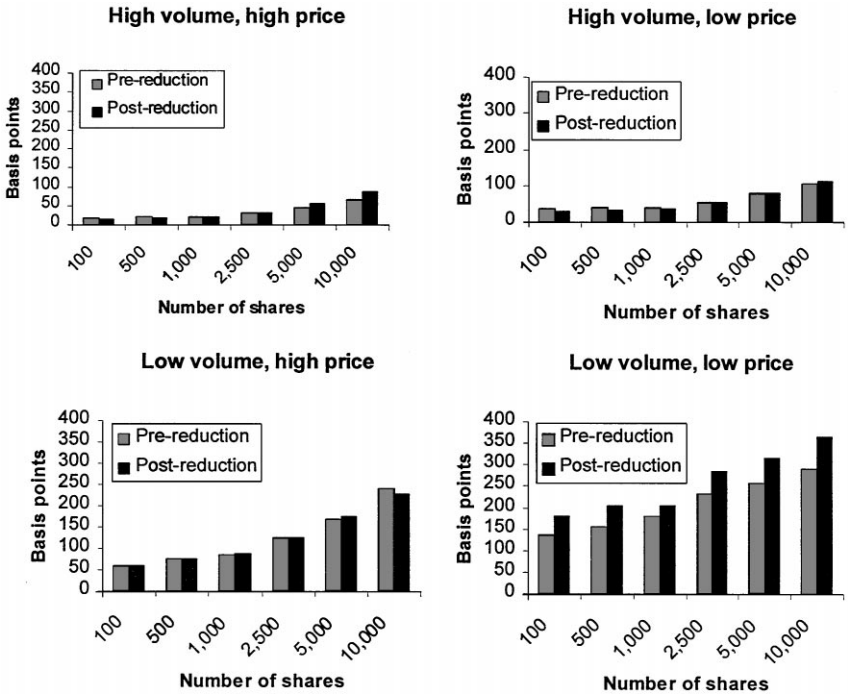

Fig. 1. The cost of demanding liquidity for order sizes of 100, 500, 1000, 2500, 5000, and 10,000 shares, assuming that the only source of liquidity available is the orders on the limit order book. The cost is measured as the cumulative percent markup of the average execution price(s) over the midpoint of the contemporaneous bid–ask quote.

include any additional depth in the specialist's quote, then the trader would receive 35 basis points less before the change and 42 basis points after. As such, the charts represent the slope of the demand and supply curves in place for shares before and after the tick size reduction. The relative position of these schedules indicates how these cost calculations have changed since the minimum tick size reduction. In general, while the most frequently traded stocks have generally realized statistically significant improvements for smaller sizes, the result is by no means universal. As Fig. 1 indicates, if liquidity demanders rely solely on the limit order book to fill their trades, transaction costs have increased for large trades in general and, for infrequently traded low-priced stocks, have even increased for a minimum round lot trade.

Fig. 2 considers all the publicly stated liquidity, accounting for not only the limit order book but also the specialist and floor broker interest displayed by the specialist in his quotes. The inclusion of this floor interest causes a sharp improvement in the cost change, particularly for smaller share sizes. In total, the

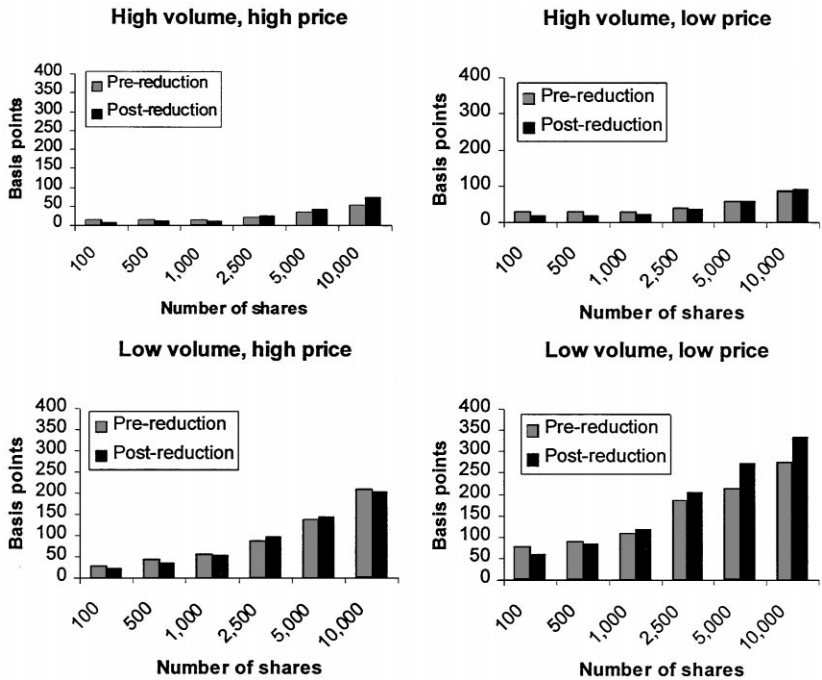

Fig. 2. The cost of demanding liquidity for order sizes of 100, 500, 1000, 2500, 5000, and 10,000 shares, using all available publicly stated liquidity (i.e., the orders on the limit order book and any additional depth available in the specialist's quotes). The cost is measured as the cumulative percent markup of the average execution price(s) over the midpoint of the contemporaneous bid–ask quote.

tick size reduction has produced a statistically significant decrease in the costs for smaller trades, but an insignificant increase in the costs for trades of 5000 or 10000 shares. Liquidity demanders in high-volume, high-priced stocks received the most benefit, while those demanding liquidity in low-volume, low-priced stocks saw little benefit for order sizes larger than 1000 shares.

While Figs. 1 and 2 examine the effects on transaction costs for hypothetical orders, Fig. 3 examines the actual change in transaction costs for actual orders. Fig. 3 provides signed percent effective spreads for order sizes ranging from 100 shares to 10,000 shares. The percent effective spreads are calculated as $2I$(execution price $-$ midpoint)/midpoint, where $I = 1$ if it was a buy order and $I = -1$ if it was a sell order. This measure allows us to capture any price improvement while still requiring that we would get the exact percent quoted spread if all buy orders were executed at the ask and all sell orders were executed at the bid.

To make Fig. 3 as analogous to Figs. 1 and 2 as possible, the percent effective spreads were measured from the midpoint of the quote at the time the order was

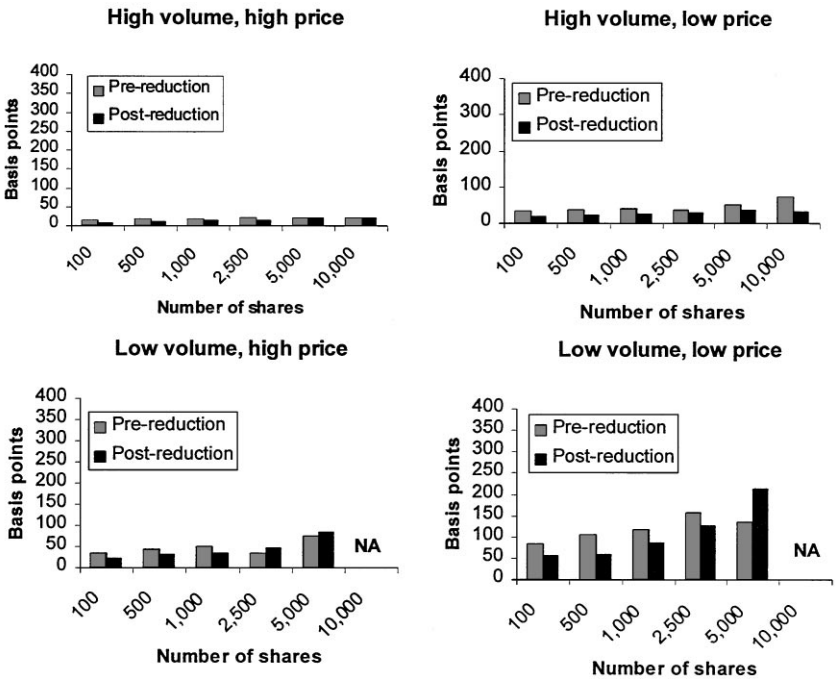

Fig. 3. The cost of demanding liquidity for orders with original order sizes of 100, 500, 1000, 2500, 5000, and 10,000 shares. The cost is measured as the cumulative percent markup of the average execution price(s) over the midpoint of the contemporaneous bid–ask quote at the time of submission.

submitted. We ensured that the reference midpoint for all trades that were part of a single order was the midpoint of the quote at the time the order was submitted, not the time the trades executed. If an order was broken up into multiple trades, all trades were assigned the same midpoint as all trades were part of the same order and therefore have the same order time. Therefore, if a 10,000-share order is broken up into three trades of 5000 shares, 2000 shares, and 3000 shares – each with a different execution price – each of these three trades was attributed as part of a 10,000-share order. We compare each of the three execution prices with the midpoint of the quote at the time the original order was received. This procedure results in a volume-weighted average percent effective spread for the 10,000-share order.

Because we know the direction (buy or sell) of the trade, we signed this difference appropriately.[9] Unlike other effective spread studies using publicly

[9] We also ran the analyses assuming that we did not know whether the order was a buy or sell order. For those analyses, we took the absolute value of the measure stated above, resulting in a measure similar to that in Blume and Goldstein (1992). The results were substantively similar.

available data, we are able to classify our trades correctly in that we know not just the print size but also the trade size. More important, given that we are using order data, we know that some trades are the result of a larger order that has been broken up. While other studies would treat each of these trades separately (and therefore potentially attribute later trades with a new quote), we treat each of these trades as part of the original order. Fig. 3, therefore, examines orders – not prints or trades – that were submitted for execution.

The results in Figs. 1–3 are nested. Fig. 1 provides the worst-case scenario, as it assumes no additional provision of liquidity beyond that found in the limit order book. Fig. 2 partially relaxes this assumption, allowing for the inclusion of the additional interest in providing liquidity that is shown in the specialist's quotes. However, the results in Fig. 2 do not provide for any hidden liquidity. Fig. 3 relaxes all these assumptions and takes into account all additional liquidity, stated or hidden, that was provided at the time the order was received.

As Fig. 3 indicates, for frequently traded stocks, reductions are evident in percent effective spreads for all order categories through 2500 shares. The percent effective spread for less frequently traded stocks was lower for all order categories through 1000 shares. (The 10,000-share category for infrequently traded stocks had very few observations in both the pre- and post-periods; we therefore marked these data as not available.) However, there is variation across price categories for larger sized orders. High-priced frequently traded stocks did not see an appreciable difference in percent effective spreads for orders of 5000 to 10,000 shares, although low-priced frequently traded stocks saw a decline.

Overall, these findings are consistent with the results in Jones and Lipson (1998) that show a decrease in transaction costs for smaller sized trades but an increase for larger trades for institutional orders. Our analysis can help explain the results found by Jones and Lipson in that less cumulative depth is immediately available on the limit order book. While this decrease would not affect smaller orders, it will affect larger ones. Therefore, our results indicate that while execution costs for smaller orders might have decreased, at best larger orders saw little benefit. The results in Figs. 1–3 suggest that liquidity demanders have at least partially adjusted their strategies to account for the thinner limit order book. However, market participants could incur many costs by adopting more sophisticated trading strategies. These additional costs may include incurring more price risk and additional commission costs – perhaps as a result of the use of floor brokers, instead of electronic transmission, to process orders. Because many of these costs could be captured by the data in Jones and Lipson (1998), our results not only provide support for theirs, but also are suggestive as to the cause.

In total, our results are consistent with previous empirical research in that we document a reduction in quoted spreads of 14.3% and a reduction in quoted depth of 48.4%. In addition, we find that the cumulative depth on the book has declined and the volume on the limit order book has shifted away from the

quotes. The combined effect of the quoted spread reductions and quoted and cumulative depth reductions is a transaction cost improvement for the most frequently traded stocks with some evidence of a transaction cost deterioration for the most infrequently traded stocks, especially for the larger trade sizes.

5. The effect on liquidity providers

While the previous section described the macro effects of the tick reduction, this section investigates on a micro level how the behavior of particular groups of liquidity providers has changed since the implementation of the minimum tick size reduction. While the impact of the change on any group is endogenous to the new equilibrium, it is useful to analyze some of the observed changes in specific aspects of their behavior.

5.1. Specialists and NYSE floor members

Liquidity provided by floor members through the specialists' quotes plays a key role in decreasing the costs that liquidity demanders face for virtually all trades sizes.[10] One way specialists (either for their own account or on behalf of a floor member) accomplish this is by quoting a price/quantity schedule that either improves upon the best prices on the limit order book or matches the best prices on the book and adds depth to the shares already on the book. As liquidity providers, floor members – like limit order traders – might be less willing to display liquidity given the reduction in the tick size. However, unlike limit order traders, the specialist is required to maintain a presence in the market given his special status in the market process. An important consequence of the minimum tick size reduction would be how much, if any, floor brokers and specialists have decreased their contribution to quoted depth.

Table 3 breaks down the percentage of time floor members added depth to the displayed quote as well as the relative share contributions to displayed depth from both the specialist's quote and limit order book. The first column represents the percentage of time that the specialist's quote provides no additional liquidity beyond that already provided by the limit order book. The second column represents the percentage of time that the price of the specialist's quote

[10] This is not to suggest that without a specialist or floor traders transaction costs would increase precipitously. The liquidity provided by the limit order book, floor traders and the specialist are jointly determined, with each provider conditioning on the presence of its competitor. Thus, absent a specialist or floor traders, limit orders would likely be more aggressive in providing liquidity because they no longer have to face the "second adverse selection problem" discussed by Rock (1990) and Seppi (1997).

Table 3
Data on the average floor contribution to the displayed quote depth for the one hundred NYSE stocks in our sample.The pre-reduction period includes data from May 27 to June 20, 1997. The post-reduction period includes data from June 30 to July 25, 1997 and from August 25 to September 19, 1997. Limit order books (LOB) were estimated using the technique described in Kavajecz (1999). The stocks are then separated into quartiles based on their December 1996 average daily trading volume and price. Results are from equally weighted averages of snapshots of the limit order book every 30 min. No depth from the floor indicates that the floor is adding no additional depth to the depth on the limit order book. Additional floor depth indicates that the quoted prices match the limit order book and the quoted depth exceeds the limit order book depth at that price. Floor alone indicates that the quoted prices improve upon the best limit order book prices.LOB depth is the depth at the quote that was provided by the limit order book; floor depth is the depth at the quote that was provided by floor participants. Differences in bold in Panel C are significant at the 1% level for both parametric and nonparametric tests. In Panel C, F-tests for equality across quartiles for each category are rejected at the 1% level.

Stock category	Depth contribution (% of time)			Depth contribution (shares)	
	No depth from floor	Additional floor depth	Floor alone	LOB	Floor
Panel A: Pre-reduction period					
All 100 stocks	51.74	32.70	15.56	8403	2623
High volume					
High	50.28	39.59	10.14	13,106	3750
Low	48.62	43.33	8.06	13,178	5047
Low volume					
High	51.20	24.97	23.83	2575	928
Low	56.85	22.95	20.20	4754	765
Panel B: post-reduction period					
All 100 stocks	52.04	14.68	33.29	3354	1708
High volume					
High	54.96	16.66	28.39	4640	2091
Low	51.93	18.10	29.97	4926	3103
Low volume					
High	48.81	11.82	39.37	1385	805
Low	52.45	12.12	35.42	2463	834
Panel C: Change from pre- to post-reduction period					
All 100 stocks	0.30	**−18.02**	**17.73**	**−5049**	− 915
High volume					
High	4.68	**−22.93**	**18.25**	**−8466**	− 1659
Low	3.31	**−25.23**	**21.91**	**−8252**	− 1944
Low volume					
High	− 2.39	**−13.15**	**15.54**	− 1190	− 123
Low	− 4.40	**−10.83**	**15.22**	− 2291	69

matches the prices on the limit order book but the depth of the specialist's quote is greater than that on the limit order book at that price. The third column represents the percentage of time that the specialist's quote improves upon the

best prices on the limit order book. The limit order depth represents the average depth, denominated in shares, provided by the limit order book, while the floor depth represents the average additional depth contributed to the displayed quote by the NYSE floor through the specialists' quotes. Table 3 indicates that NYSE floor members are more frequently improving upon the limit order book spread since the tick size reduction. This statistically significant result is consistent with the findings of Amihud and Mendelson (1991) and Harris (1996) that argue that reducing the tick size lowers the costs for floor members to gain priority by bettering the limit order price. Despite the relatively unchanged frequency of additional floor displayed depth, the level of displayed depth provided has fallen on average, especially for the most actively traded stocks. In particular, the floor's contribution to displayed depth has fallen by 35% on average.

Another way specialists play a role in decreasing costs is to stop incoming orders as in Ready (1996). Stopping an order is a way in which a specialist can guarantee an execution price to an order while holding it for the possibility of price improvement. As the tick size is reduced we might expect the volume of stopped orders to increase, as the finer price grid could enable specialist to price improve orders more easily. The analysis of the order records in Table 4 shows that the ratio of stopped order volume to market order volume increased by 15%.

Thus, we conclude that, while the tick reduction has not altered the strategies of NYSE floor members with respect to the frequency of contributing depth to specialists' quotes, it has decreased the level of depth displayed and could have increased specialists' propensity to stop incoming orders for price improvement.

5.2. Limit order traders

While we have discussed the aggregate effect on all limit order traders, it is useful to investigate the decision-making problems of individual limit order traders. When considering a liquidity provision strategy, each limit order trader weighs the profit to be gained if a particular order is executed against the loss incurred by that specific trader if that same order goes unexecuted. Works by Handa and Schwartz (1996) and Harris and Hasbrouck (1996) show that this trade-off determines whether, and at what limit price, traders submit their limit orders. If we further assume that the market to supply liquidity is competitive as modeled by Rock (1990), Hollifield et al. (1996), Seppi (1997), and Sandås (1998), limit orders will be placed at a given limit price until the expected profit from supplying liquidity at that limit price is driven to zero. In this competitive environment, only inframarginal traders earn positive profits from providing liquidity. This assumption is a useful reference point to understand better the impact that reducing the minimum tick size had on individual limit order traders.

Table 4
Data on selected results for particular market participants for the one hundred NYSE stocks in our sample. The pre-reduction period includes data from May 27 to June 20, 1997. The post-reduction period includes data from June 30 to July 25, 1997 and from August 25 to September 19, 1997. Limit order books (LOB) were estimated using the technique described in Kavajecz (1999). Results are from equally weighted averages of snapshots of the limit order book every 30 min. Stopped orders (%) is the ratio of stopped order volume to market order volume. Orders greater than (less than or equal to) 1000 shares is the fraction of shares on the limit order book that are part of orders whose total size is greater than (less than or equal to) 1000 shares. Good-'til-cancel (%) is the percentage of shares on the limit order book that are good-'til-cancelled orders. Cancelled limit orders (%) is the percentage of cancelled limit orders to total limit orders submitted. Differences in bold are significant at the 1% level for both parametric and nonparametric tests.

Market participant	Pre-reduction	Post-reduction	Change
Panel A: Specialists			
Stopped orders (%)	1.45	1.67	0.22
Panel B: Limit order traders			
Limit orders less than or equal to 1000 share	28,538	33,468	4930
Limit orders greater than 1000 shares	86,051	90,582	4531
Good-'til-cancel (%)	66.1	67.6	**1.5**
Cancelled limit orders (%)	35.4	37.6	**2.2**

In this competitive limit order market, if the minimum tick size were a binding constraint for a given stock, a tick size reduction would allow those limit order traders wishing to provide liquidity at the new tighter spread a chance to do so. There could be limit order traders who do *not* wish to provide liquidity at the new tighter spread and who would therefore lose their priority over other orders because of the tick reduction. This reshuffling of the limit order queue could cause some limit order traders to reduce their contribution to depth and others to leave the market entirely.

A limit order trader operating in this reduced tick size environment has a number of ways to improve the profitability of providing liquidity. First, for any given level of depth provided, a limit order trader could find it more attractive to split his order and place the orders on multiple limit prices. This strategy would allow the trader to compete on price using only a fraction of his contributed depth. The limit order book data confirm this intuition. The fraction of shares on the limit order book that are part of 1000-share or larger orders increased by 5.3% while the fraction of shares that are part of orders less than or equal to 1000 shares increased by 17.3%.

Second, because of the tick size reduction, the implicit subsidy furnished to liquidity providers was reduced. A trader wishing to recapture some of this subsidy may choose to place her limit orders slightly further from the quotes, a result we found earlier in looking at the change in the distribution of the

cumulative depth. Conditional on a limit order trader placing his limit order further from the quote, she must be more patient to realize the profit associated with his less aggressive limit order. We might expect that patience would be revealed in the duration of an order or length of time that an order is to remain active. As Table 4 indicates, we find that the duration of limit orders increased statistically significantly as good-'til-cancelled orders increased their proportion of shares on the limit order books by an average of 1.5 percentage points.

Third, the increased price grid offers limit order traders more flexibility in choosing limit prices. That additional flexibility might manifest itself as an increase in the limit order cancellation rates, as limit order traders are better able to reposition their orders if necessary. The results in Table 4 are consistent with this argument as the order flow data reveal a statistically significant increase of 6.2 percentage points in the ratio of cancelled limit orders to total limit orders submitted. Harris (1996) finds a similar result using data on the Toronto and Paris stock exchanges.

6. Conclusion

Our results demonstrate that after the reduction in tick size on the NYSE, in addition to the decline in the quoted bid–ask spread, cumulative depth falls uniformly for all stocks in our sample, for all prices as far way as 50 cents from the midpoint. While the cost of executing smaller orders decreased, execution costs for larger orders either did not see any benefit (for frequently traded stocks) or saw an increase in costs (for infrequently traded stocks). In addition, displayed liquidity decreased – both in the specialist quotes and the publicly offered liquidity available on the limit order book – providing less certainty to liquidity demanders. Consequently, moves by equity markets to decrease their minimum tick size are not an unambiguous welfare enhancement for liquidity demanders.

Because an exchange is set up to provide liquidity, modifications to the market structure that enhance the liquidity provision capacity serve to make the exchange a more viable entity. Our analysis highlights two important points when considering rule changes such as changing the minimum tick size. First, merely examining changes in the quoted spread and quoted depth is insufficient to assess changes in overall market liquidity. The level and position of depth on the limit order book is crucial to understanding how liquidity has been altered. Second, markets and regulators must consider the ramifications and incentives of their actions on liquidity providers as well as liquidity demanders.

While many might argue that the structure of the trading mechanism should be set up to benefit small investors, how best to benefit these retail traders is not

as simple as minimizing the quoted spread. Ultimately, while small investors in their trading portfolio might transact only a few round lots at a time, these same small investors might do the bulk of their investing through mutual funds. To the extent that costs of transacting have increased for fund managers, that added cost will likely get passed on to small investors who use the fund as an investment vehicle.

Should exchanges decide to continue moving toward smaller minimum tick sizes, our results suggest that a tiered tick function based upon a stock's trading activity and price level could be preferable to a uniform reduction. Frequently traded stocks would have the smallest minimum tick size, while infrequently traded stocks would have a coarser price grid to promote liquidity provision. This policy would allow frequently traded stocks to realize further reductions in transaction costs through increased liquidity provider competition while maintaining incentives to provide liquidity for infrequently traded stocks.

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