The Effects of Order Handling Rules and 16ths on Nasdaq: a Cross-sectional Analysis

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Abstract: Two major changes occurred on the Nasdaq Stock Market during 1997: the implementation of the SEC's Order Handling Rules, and a reduction in the quotation ticksize for many Nasdaq stocks to one-sixteenth from one-eighth. This paper presents a detailed empirical analysis of the impact of these changes on spreads, depth, use of Electronic Communications Networks, and market making positions. Of special focus is the extent to which the impact of the changes varies across stocks. It is found that while many stocks experienced major changes in their trading characteristics, other stocks, particularly thinly-traded issues, were largely unaffected.

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Introduction and Summary of 1997 Changes

The year 1997 witnessed some of the most significant changes to the Nasdaq Stock Market since its founding in 1971. The first of these changes was the implementation of what are collectively called the Order Handling Rules (hereafter OHR). The second was the change in the Nasdaq quotation ticksize to $1/16, down from the traditional $1/8. Together these changes (jointly referred to herein as OHR/16ths) have had a major impact on the characteristics of the Nasdaq Stock Market, particularly the more actively traded stocks.

This paper presents an analysis of the effects of these changes on various dimensions of Nasdaq market quality. The main focus is the cross-sectional variation in these effects. Nasdaq stocks exhibit a wide spectrum of trading characteristics, ranging from some of the most actively to the least actively traded securities in the U.S. Concern has been raised regarding the effects of the OHR/16ths on certain types of stocks. It has been argued, for example, that these changes may particularly hurt the liquidity of small-cap stocks. If profits to market making are diminished, goes the argument, then dealers may be unwilling to make markets in these stocks. The ability of new companies to raise equity capital may be seriously diminished. By way of counter argument, the OHR/16ths may have had less effect on thinly-traded stocks than on the actively-traded stocks, as the changes by design do not necessarily have to affect the trading of any particular stock. This study provides some empirical resolution to this debate.

In recent years Nasdaq has come under intense scrutiny, triggered by the study of Christie and Schultz (1994). In 1996 both the U. S. Department of Justice (1996) and the U. S. Securities and Exchange Commission (1996a) concluded investigations which cast serious doubt on the integrity of the market. Spurred by these findings, the SEC approved the OHR in August 1996 (SEC (1996b)). The new rules were implemented on a phased-in basis. The first wave of stocks to be covered by the OHR began January 20, 1997, and the last wave started October 13, 1997 (see Appendix for more details). The immediate effect of the OHR for the first 100 stocks to be phased-into compliance was studied by Barclay et al. (1997). These first 100 stocks were drawn from the most actively-traded Nasdaq issues. The ticksize change became effective June 2, 1997. The present study adds to Barclay et al. by providing cross-sectional results for the full spectrum of Nasdaq stocks, as well as considering the effects of 16ths. As shown below, there are important interactive effects between the OHR and 16ths.

The following sections summarize the details of the 1997 OHR/16ths changes.

Limit Order Display Rule

There are two parts to the Order Handling Rules. One is the Limit Order Display Rule, now codified in SEC Rule 11Ac1-4. This rule mandated for all Nasdaq securities a principle of quoting long employed on securities exchanges—that public limit orders should be reflected in the Best Bid and Offer (BBO) disseminated by the market. Public limit order display on Nasdaq was among the recommendations of the SEC's Market 2000 study (1994, Studies IV and V). Specifically, the new rule requires market makers holding customer limit orders to reflect those orders in their quotes. When the quote coincides with the best price (i.e., the inside quote) the size of the public order is also required to be displayed. There are a number of waivers to the rule, e.g.: when the order exceeds 10,000 shares; is less than 100 shares; is an "All or None" order; the customer requests non-display; or the order is routed to some entity that does reflect it.

Quote Rule with ECN Alternative

Amendments to the Quote Rule, SEC Rule 11Ac1-1, are the other part of the OHR. The amended rule states that market makers may not post one quote on Nasdaq and a different quote on an alternative quote dissemination system, termed an Electronic Communication System (ECN). The privately-held Instinet system was the model ECN.[1] The SEC expressed concern over the lack of universal access on the part of all investors to such systems, which in some cases represented a substantial share of the Nasdaq market (SEC 1996b).

The amended Quote Rule provides an "ECN Alternative." If the ECN on which a dealer has posted a quote transmits its best market maker orders to Nasdaq, where these quotes are both displayed and accessible, then the dealer can post different quotes on Nasdaq and the ECN. The ECN alternative applies, strictly speaking, only to the quotes of market makers. The ECN may hold other orders with prices superior to those of dealers, but these prices are optionally transmitted to Nasdaq. If the communication link between the ECN and Nasdaq is disrupted, market makers are alerted to the fact that the ECN Alternative is not available. All the ECNs have elected to make themselves eligible for the ECN Alternative. Further, some ECNs have elected to transmit to Nasdaq the best among all quotes in their systems, not just the best dealer quotes.

Change in Quote Ticksize

The integration of ECNs into Nasdaq precipitated a reconsideration of the quotation ticksizes that had been in place since Nasdaq's founding in 1971. The ECN best bid and offer prices transmitted to Nasdaq are displayed at the same resolution as Nasdaq quotes. ECNs, however, have finer pricing increments than Nasdaq, typically $1/64 or

[1] Not all proprietary trading systems are ECNs. For example, crossing systems such as POSIT or the Arizona Stock Exchange are not ECNs since they are not vehicles for disseminating continuously available quotes.

smaller. At the OHR implementation in January 1997, the ECN quote price for stocks over $10 had to be rounded on Nasdaq, when necessary, to the nearest eighth *away* from the inside market (i.e., bids were rounded down and offers rounded up). For stocks below $10, the Nasdaq display resolution was $1/32. Thus a non-ECN subscriber viewing an ECN order on Nasdaq could not be sure of its true price. It was determined that lowering the Nasdaq quote ticksize to $1/16 for stocks over $10 would greatly reduce the magnitude of the discrepancy between the true and displayed price, since most of the non-eighth orders placed on ECNs were in sixteenths. Accordingly, on April 18 the NASD filed with the SEC a rule change proposing that the ticksize be reduced.[2]

As it happened, the Spring of 1997 also brought renewed interest in proposals to decimalize prices on U.S. stock markets. Spurred perhaps by the decimalization of Canadian stock markets in the spring of 1996 and increased interest voiced by SEC Commissioner Steven Wallman (1996), the matter came to a head with Congressional hearings held in April 1997. The hearings were held to consider a bill, carrying substantial bipartisan support, that would mandate the decimalization of securities prices.[3] During these hearings concern was raised that the traditional ticksize of an eighth of a dollar was too wide, and that the fractional system of pricing stocks was too hard to understand relative to the decimal system (see Subcommittee on Finance and Hazardous Materials (1997), and Peake (1994) for general background). Subsequent to these hearings, the NYSE announced in June that it would join the NASD in lowering its ticksize to $1/16.

On Nasdaq, the ticksize change was approved by the SEC on May 27, 1997 and implemented on June 2, 1997. Effective that date, any market maker with a bid price exceeding $10 was free to post a quote in increments of $1/16, down from the $1/8 increment which had been the rule since Nasdaq's founding in 1971. With a bid less than $10, quotes continued to be expressible in increments of $1/32, the same as before.[4]

Reasons for Cross-sectional Variation

Limit Order Display

The OHR introduced principles associated with agency auction markets to a quote-driven dealer market. Is such a hybrid market structure feasible? As alluded to above, it has been argued, especially with regard to small-cap stocks, that the level of

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[2] Filing No. SR-NASD-97-27. See SEC Release 34-38531 (62 FR 20233 (April 25, 1997)).

[3] H.R. 1053, The Common Cents Stock Pricing Act of 1997, 105th Congress, 1st Session

[4] On Nasdaq, unlike the exchanges, ticksize restrictions have always applied to quotations only. Trade prices, for the purposes of clearing and settlement, can be expressed down to an increment of $1/256, or they can be expressed in decimal format with as many as eight digits to the right of the decimal. "Last Sale" trade prices reported to the tape via the Nasdaq Trade Dissemination System (NTDS) are always rounded to the nearest $1/64.

support and sponsorship afforded by the dealer market is critical. Attempts to undermine the role of the dealer could seriously harm the quality of the market for secondary trading of such stocks, ultimately raising the cost of capital to emerging companies. It is possible, however, that the OHR would have little or no effect on such stocks. To the extent that professional dealers commit capital at quotes better than those of public investors, the Limit Order Display Rule will be of no consequence. On the other hand, if dealers are displaced by public limit orders for some stocks, then arguably dealers are simply not needed for that stock.

Ideally, the situation arises in which professional and public liquidity supply can coexist. Professional capital can stand as the "core" of supply, augmented by public investors who from time to time outbid professionals in supplying liquidity. Such a situation exists on markets such as the New York Stock Exchange, where the specialist acts as a dealer of last resort. As shown by Madhavan and Sofianos (1998), NYSE specialist intermediation varies greatly across stocks, with the more actively traded stocks requiring less specialist intermediation.

Role of ECNs

The revised Quote Rule and ECN Amendment may likewise have a differential effect on Nasdaq stocks. The existence of market maker quotes in ECNs differing from their Nasdaq counterparts constitutes a form of price discrimination. The trading venues provided by the ECN may differ from Nasdaq in a variety of dimensions such as the anonymity of the order placer, the allowable pricing increments, the structure of fees associated with using the ECN, and the clientele of the ECN. It is well-known that ECN usage varies substantially across stocks, implying that demand for the special services provided by ECNs must vary as well. It follows therefore that the impact of the Quote Rule's prohibition of ECN-based price discrimination should vary across stocks, with some stocks experiencing virtually no effect since ECNs had been relatively unimportant for them.

Ticksize Reduction

Research done on the decimalization of the Toronto Stock Exchange (Bacidore (1996), Weaver (1996), Huson et al. (1997), Ahn et al. (1997)) showed substantial cross-sectional variation. Not surprisingly, stock price, among other factors, was an important determinant of the impact of the ticksize reduction. It may be argued that it is not so much the ticksize but the ticksize *relative* to price that matters (see Angel (1997)). For high-priced stocks, it is possible that the eighth tick was an adequate increment for measuring price that did not place a materially binding lower bound on spread. The story may be different for lower priced stocks, where the ticksize is high relative to price. Therefore, there again is reason to expect a differential impact of 16ths, with the stock price being the primary discriminating variable.

The next section of this paper considers the combined effects of OHR/16ths on quoted inside spreads, ECN importance in setting the inside, the quoted depth of the market at the inside, and the number of market making positions. Results concerning cross-sectional variation are derived using regression analysis. The last section of the paper considers the OHR and 16ths separately, focusing on the role of each in contributing to the overall change.

Cross-Sectional Analysis of Combined OHR/16th Effect

To determine the overall change in market quality resulting from the combined effects of the OHR and move to 16ths, market characteristics from the first half of January 1997 are compared with those from November 1997. By November all stocks had been phased-into OHR compliance, the last wave having been phased in on October 13. This analysis therefore presents the total picture of what happened on Nasdaq during 1997. Though the total effect of OHR and 16ths is captured, the nine-month gap between the pre- and post- data periods is sufficiently long that changes unrelated to the two market structure efforts may confound the results. Regression analysis, detailed below, attempts to net out these spurious effects.

Methodology Details

The results shown in this study are drawn from cross-sectional regressions. The primary variable of interest is the *change* in a given market quality measure. The estimating equation used is motivated as follows. Consider some market quality variable y observed before and after the imposition of the OHR/16ths. The variable is assumed to be generated by the equations:

$$y_i^0 = \alpha_i + \sum \beta^0 \cdot x_i^0 + \varepsilon_i^0 \qquad (1)$$

$$y_i^1 = \alpha_i + \delta + \sum \beta^1 \cdot x_i^1 + \varepsilon_i^1 \qquad (2)$$

where the subscript i indicates the stock and the superscript (0/1) represents the pre-/post-time period. The intercept α_i represents a constant stock-specific effect, while δ represents a global shift parameter indicating the effects of the market structure change. In both periods variation in y_i can be explained by a set of explanatory variables x_i. The coefficients on these variables can change from one period to the next. Finally, the ε_i represent random, independent errors.

Subtracting (1) from (2) yields:

$$\begin{aligned}
\Delta y_i &= \delta + \sum \beta^1 \cdot x_i^1 - \sum \beta^0 \cdot x_i^0 + \Delta\varepsilon_i \\
&= \delta + \sum \beta^1 \cdot x_i^1 + \left(-\sum \beta^1 \cdot x_i^0 + \sum \beta^1 \cdot x_i^0 \right) - \sum \beta^0 \cdot x_i^0 + \Delta\varepsilon_i \qquad (3) \\
&= \delta + \sum \beta^1 \cdot \Delta x_i + \sum \left[(\beta^1 - \beta^0) \cdot x_i^0 \right] + \Delta\varepsilon_i
\end{aligned}$$

In words, the change in y equals: the global shift parameter; a sum of terms involving the change in the explanatory variables; a sum of terms involving changes in the coefficients; and the difference in the error, which we assume continues to itself be an independent error.

Based on examination of model residuals as well as for theoretical reasons, it was deemed appropriate to conduct all analyses using the logarithms of the market quality variables. Therefore, Δy can be interpreted as the percentage change in the market quality variable.

An advantage of (3) is that stock-specific effects (α_i) are eliminated. Estimation of (3) provides estimates of β^1, though arguably such estimates are best obtained by estimating (2) directly. The point of including Δx_i in the model is to account for changes in y that can be explained by changes in x. Primary interest focuses on the terms

$(\beta^1 - \beta^0)\cdot x^0$, which indicate systematic cross-sectional differences in the effect on market quality as a function of x^0.

All three models (1) - (3) are estimated and the results are presented below. Model (3) is deemed to be the most useful for the purposes of this analysis, since it provides a direct model of the cross-sectional determinants of the *change* in market quality. The inputs to the estimates are the logs of the sample means of the variables in question. The same explanatory variables are used for each market quality variable. They are: the average daily number of trades;[5] the average price; the number of shares outstanding in the hand of the general public (i.e., float), and a measure of interday price volatility.[6]

The sample size for all regressions was 5,166 stocks. To be included in the sample, the stock had to be present in both the January and November sample periods. There were 6,390 active Nasdaq stocks in January and 6,333 in November, but of these only 5,582 were active in both months. Further, the stock had to have non-missing values of all the dependent and explanatory variables. Recognizing that the logs of variables were used in the regressions, a stock must have strictly positive values of all the variables to be in the sample. This condition eliminates stocks that had no trades during both sample periods, or whose inside bid/ask quotes did not change during the sample periods.

[5] Models of this type often use share volume, not number of trades, as the measure of trading frequency. Though trades and volume are highly correlated, our analysis has found that the former typically provides superior explanatory power.

[6] The volatility measure is calculated as the standard deviation of the log of the change in the end-of-day quote midpoint. The pre-period value is computed using data from Dec. 1996 through Jan. 17, 1997. The post-period value is computed using data from Oct. and Nov. 1997, excluding Oct. 27 and 28, which were days of highly unusual volatility.

All data used in the study were obtained from the NASD. There were two primary sources. Trade reports, dealer quotes, and Nasdaq inside quotes were obtained from the NASD's Market Data Server. Data concerning cross-sectional characteristics of a stock, such as total shares outstanding and float, were obtained from another NASD database referred to internally as "Commfin."

Quoted Spreads

By far the most visible and widely cited measure of market quality is the inside quoted spread. This measure is probably a valid component of the transaction costs facing small retail traders, though not necessarily for institutional traders. Though it overstates the true cost of trading (or its inverse, the profitability of supplying liquidity), it is often assumed to be highly correlated with more accurate measures such as the effective spread or realized spread.

It is well-known that the OHR led to an immediate and sizeable reduction in quoted spreads (Barclay et al. (1997)). This was to be expected, since to a large extent the OHR can be thought of as essentially a redefinition of Nasdaq BBO. Rather than being the highest bid and lowest ask among the proprietary quotes of registered market makers, the new BBO extends its scope to include the dealer quotes on ECNs and the public limit orders held on the books of market makers. The change in quote ticksize has also been reported as having an additional spread-reducing effect. Many stocks whose spreads were roughly $1/8 now have fallen to $1/16. The overall cross-sectional (equally weighted) average log change in quoted spread from January to November was -0.235, implying that spreads fell on average by a factor of 0.79.

Results from regression models (1)-(3) are in Table 1. The results for models (1)-(2) show reasonable spread relationships for both January and November data—spreads are lower for more actively traded stocks, higher for higher-priced stocks, lower for stocks of larger firms (measured by market capitalization), and higher for stocks with greater price volatility. The regressions have high explanatory power and the coefficients have a high degree of statistical significance. It is clear, however, that the coefficients for November and January are different. With the exception of the coefficient for Float, the November coefficients are higher in magnitude. Also, the explanatory power of the November regression is higher than that of the January. To some extent, then, the OHR/16th change made spreads more "rational" in the sense of being more explainable by economic factors.

The results for the change in spreads (regression model (3)) are consistent with the other two. The coefficients for the changes in the explanatory variables are similar to those for the other regressions, and the coefficients for the January levels of the explanatory variables are similar to the differences between the November and January coefficients, as derived above in (3). The magnitude of the January coefficients, in conjunction with their statistical significance, illustrates the fact that OHR/16ths affected quoted spreads differentially. Specifically, the spread declines tended to be greater for more actively traded stocks, but lower for higher-priced stocks, for larger companies, and for more volatile stocks.

The magnitude of the cross-sectional differences may be visualized by calculating predicted values of model (3). To do so, the assumed values of the changes in the explanatory variables (e.g. Δ Log Trades) are set to zero in order to make an "all else equal" comparison. The assumed values of the January levels of the explanatory variables are set to various sample quantile values. Specifically, the 10%, 50% (median) and 90% cross-sectional sample quantiles are used as representative values. To measure, say, the impact of the number of trades, the predicted change in spread at the 10%, 50% and 90% trade quantiles is computed. All other variables are set to their median values. Table 2 provides these predicted changes in quoted spread. This table shows, for example, that the 10% quantile for trades is 37 per day. Using this value, in combination with the median values for the other three variables, leads to a predicted percentage change in quoted spread of a seven percent decline.[7] For a stock with trading activity at the 90% level, about 2,500 per day, all else equal, the model predicts a spread decline roughly five times greater, about 36%.

Table 2 illustrates the fact that the number of trades has the greatest quantitative impact on the change in quoted spread, with a five-fold difference between a stock at the 10% and 90% quantiles. The other three factors show roughly a reduction of about one half of the magnitude in the spread decline as one moves from the 10% to the 90% quantile. The price effect is consistent with the idea that the eighth ticksize was a binding constraint on spreads. The volatility effect may be consistent with the idea that spread-reducing public limit orders are more likely to be submitted for less-volatile stocks. Public limit order placers are presumably less able to closely follow the market than professionals, and would therefore be at a comparative disadvantage in supplying liquidity for volatile stocks.

Role of ECNs

The OHR led to the addition of the best ECN orders appearing on the quote montage. One indicator of the importance of this provision is the amount of time that the inside market is set by one or more of the four ECNs that were operational during November. For this variable, a pre/post comparison is not useful since all stocks had no ECN orders setting the inside market prior to the OHR. Therefore, a simple cross-sectional model was estimated using November data, using as explanatory variables the logs of the same four variables used in the analysis of spreads.

[7] The percentage change measure shown in Table 2 is the common measure of percentage change (Nov. Spread ÷ Jan. Spread) - 1. The regression model, however, produces a logarithmic percentage change. The latter is converted to the former via the transformation exp(x) - 1.

For many stocks, an ECN never set the inside during November. Of the 5,166 stocks in the sample, 386 (about 7%) never had an instance of an ECN setting the inside Since the dependent variable cannot take negative values but can be clustered at zero, it was appropriate to estimate a Tobit model, which is designed for such a situation involving a censored dependent variable. Technically, the Tobit model posits the existence of an unobserved latent variable that may be termed the "propensity of an ECN to set the inside market." When this variable is positive, it coincides with the actual observed time that one or more ECNs set the inside. When it its negative, the observed time that an ECN sets the inside is zero. Since the level of censoring is relatively low, the model was also estimated using ordinary least squares (OLS) after removing the censored observations from the sample (i.e., the observations where the dependent variable has a value of zero).

Table 3 presents the results for both models, showing little difference in the results. All the explanatory variables are statistically significant, though only the number of trades and the price show relationships that are economically significant. The model indicates that increases in price and number of trades increases the time that an ECN sets the inside.

Predicted values generated by the Tobit model are provided in Table 4. The table uses the same assumed values as were used for Table 2. It shows, for each assumed value, the probability that an ECN sets the inside at least some of the time, as well as the expected time that an ECN sets the inside. The results in the table can be interpreted as follows. When, for example, a stock's trades average 37 per day while its price, float and volatility are at sample median values, there is about a 75% probability that the stock will have ECNs setting its inside market at least some of the time. In other words, 75 out of every 100 stocks with these characteristics will, during the course of a month, have some instances where an ECN quote sets the inside. The overall unconditional expected fraction of the time that such an event happens for that type of stock is about 5.8%. The table indicates again that Trades and Price are the variables driving cross-sectional variation in the importance of ECN quotes. It also illustrates that ECNs play at least some role in setting the Nasdaq BBO for a very wide range of stocks.

The result that ECNs are more important for actively-traded stocks squares with the result of the previous subsection that showed that actively traded stocks experienced larger spread declines. Apparently, ECN quotes are somewhat responsible for the decline.

It is not immediately obvious why price should matter so much to the importance of ECN quotes. Two possible explanations are the following. During the sample period, Nasdaq market maker quotes were subject to size minima that were fixed in share, not dollar terms.[8] For a higher stock price, the size minimum becomes more important in dollar terms, increasing the risk of market making. Spreads may widen to compensate for the added risk. At the same time, the need may increase for a secondary quote not subject

[8] Size minima were rescinded on Nasdaq on 20 July 1998.

to the size restriction (i.e., an ECN quote). An second explanation concerns the effect of SOES day traders. It is well known that day-traders prefer to trade high-priced stocks, all else equal. With such stocks, it is more likely that quotes will move the requisite $1/8 or $1/16 necessary for the day-trader to earn a profit, since such a movement is a smaller fraction of a higher price. Day traders are heavy users of ECNs for layoff orders, particularly the ECN Island. It follows then that Island is more likely to be used, and to consequently set the inside, for higher-priced stocks.

Quoted Depth

This subsection considers the changes that have occurred regarding the depth of the market. A specific, admittedly narrow measure of depth is used here: the aggregate shares quoted at the inside bid and offer. That is, at any point in time the displayed depth of all entities, market makers and ECNs, at the inside is aggregated. A summary measure is found by taking a duration-weighted average of depth on both the bid size and the ask side. The measure is narrow since, as is well known, the posted size represents the quoter's minimum obligation. Many market makers routinely fill orders for sizes larger than that displayed in their quote.

Table 5 shows the results of the three regression models (1)-(3) for quoted depth.

The table shows three similar qualitative patterns for depth in both January and November: depth tends to increase with trading frequency and float, and decrease with price volatility. The price coefficient, however, shows a substantial change. In January price had a very small impact on depth, but in November it had a sizeable negative impact. That depth, stated in shares, would have a negative relationship with per share price is to be expected. It is consistent with the idea that what matters to a market maker is the dollar value of the depth, not the number of shares. In fact, one might expect, in the absence of constraints, that the price coefficient in a logarithmic regression to tend towards a value of -1, suggesting that quoted shares falls to the same proportion as price rises.

The fact that the coefficients change from January to November implies cross-sectional variation of the impact of OHR/16ths. Indeed, the regression of the change in depth shows a pronounced role for price—the higher the price, the greater the decline (or smaller the increase) in depth. OHR/16ths created a situation in which depth became more responsive to price, implying less variation of depth in dollar terms. This change could be due to the addition of depth provided by ECNs which is not subject to size restrictions the way market makers quotes are.

The figures at the bottom of Table 5 show that the unconditional cross-sectional change in depth was a decline of about 4%. Greater detail on the effects of the change are shown in Table 6, which presents the predicted change in depth for differing quantiles of the explanatory variables. The table shows the important role played by price. The model indicates that low-priced stocks have experienced an increase in depth of 45%, while stocks with high prices have experienced large declines in depth, averaging 28%. Float has a noticeable effect, with small companies experiencing no change in depth, and large ones a decline of 12%. The trading frequency or price volatility have little impact on the change in depth.

Market-making Positions

Concern has been raised over the effects of OHR/16ths on the profitability and therefore the presence of market makers in Nasdaq. This subsection considers the change in the number of market making positions. It should be recognized that a simple count of the number of market making positions is of limited value. Certainly not all market makers are of equal importance in, say, the capital commitment they bring to the marketplace. Nevertheless, the simple count provides a basic sense of direction of any trends that may be present.

Regression results for the number of market making positions are given in Table 7. The table indicates that cross-sectionally, the number of market makers varies, not unexpectedly, in a fashion similar to that of quoted depth. Unlike the case with depth, however, there are no major changes in the coefficients of the models for January and November. Unconditionally, the results indicate a small increase in the number of market making positions, of about 3%.

Table 8 below shows model predictions. Surprisingly, for almost all scenarios considered, the model predicts increases in the number of market making positions, though the effect is not large. Cross-sectionally, higher levels of trades, price, and volatility are associated with increases in market-making positions. This change cannot be simply related to changes in profitability as measured by the quoted spread, since, as shown in Table 2, spread declines were greater for the more actively-traded stocks.

Separating OHR and 16ths Effects

The previous section presented an analysis of the combined effect of the Order Handling Rules and 16ths. It is also of interest to separate the two effects. Particularly in light of the recent debates on decimalization, the move to 16ths in isolation provides an excellent case study for assessing the role of ticksize on market quality. In addition, understanding the effect of the OHR in isolation sheds light on the extent to which agency-auction principles impact a dealer market.

Identifying the separate effects of OHR and 16ths is facilitated by the way that the OHR were implemented (see Appendix for further detail). Stocks were "phased-in" to OHR compliance in a sequence of 22 waves, the first of which was on January 20, 1997, and the last on October 13, 1997. The change in the Nasdaq quote ticksize occurred on June 2, 1997 for all Nasdaq stocks. At the time of the ticksize change, nine waves of roughly 50 stocks each had already come under the OHR. The tenth wave of 50 stocks occurred the same day as the ticksize change, and waves 11 through 22 came after the ticksize change. Thus, due to the staggered OHR implementation schedule, one can observe the effect of the OHR with and without 16ths, and the effect of 16ths with and without the OHR.

The OHR-only effects are estimated by comparing the average of a number of market quality variables one week before and one week after OHR implementation. The 16ths -only effect is estimated by comparing the three-week average from May 12-30 with that from June 2-23. Under this design, waves 1-9 (the latter wave phased-in on May 27) can be used to test the effect of the OHR without 16ths. Similarly, waves 12-22 (the former starting June 23) can be used to test the effect of 16ths without the OHR.

Cross-sectional Regressions

Again, the focus of the analysis is the cross-sectional variation in the effects. The regression specification used in the analysis can be simpler than that given by (3) above. Given the fact that the estimation windows are short, with the post-change window following immediately after the pre-change window, it was not deemed necessary to control for changes in the four explanatory variables. It is only necessary to control for the pre-change levels of the four explanatory variables. That is, the regression models are all of the form:

$$\Delta \log(mkt\ quality) = \delta + \beta_1 \log(trades_{pre}) + \beta_2 \log(price_{pre}) + \\ \beta_3 \log(float_{pre}) + \beta_4 \log(volatility_{pre}).$$

OHR-Only Effects

Consider first the effect of OHR without 16ths. As detailed in the Appendix, waves 1-9, which became subject to the OHR before 16ths, are all drawn from the top 1000 dollar-volume stocks. Thus, the extent of cross-sectional variation is somewhat limited. Table 9 presents the results of the regressions for quoted spread, percentage of time that ECN(s) set the inside, and quoted depth. Given the short length of the estimation window, it was not thought useful to analyze changes in market marker positions, an effect that would seemingly require more time to be manifest.

The Tobit model was used for the ECN model, so an R-squared measure was not available. Looking at all three models overall, the results show far less cross-sectional variation than was observed for the model of the combined OHR/16ths effects. This is evident from the smaller magnitudes of the coefficients and smaller R-squared values.

Regarding quoted spreads, the coefficient on trades is one-third the magnitude and of the opposite sign of the coefficient in the combined model (in Table 1). The price and float coefficients are virtually zero, and the volatility coefficient is of the same magnitude but opposite sign as the combined model. One explanation for this finding is the following. As shown in Table 1, spreads tend to narrow for high-trade and low-volatility stocks. Especially for the 447 sample stocks analyzed here, such stocks would be more likely to have quoted spreads close to $1/8 before imposition of the OHR. The OHR would have no impact of the spreads of these stocks. Thus, as indicated by the results of Table 9, it was the less actively traded and more volatile stocks that experienced a larger spread reduction. This pattern, of course, was reversed after the ticksize change when stocks constrained to an $1/8 spread could now drop to a $1/16 spread.

Table 3 indicated that ECNs tend to set the inside more frequently for the more active and higher-priced stocks. Table 9 shows the same relationship with price, but no relationship with trading activity or volatility.

Table 9 shows that the largest cross-sectional variation among stocks occurs for depth, driven mostly by price variation. Higher-priced stocks experienced smaller increases/greater reductions in quoted depth. (This effect was subsequently amplified by the move to 16ths, as shown by Table 5.) A key change of the OHR regarding depth was to augment the size posted by market makers with that of the best dealer orders on ECNs and public limit orders. Unlike market maker proprietary sizes fixed at 1000 shares, such orders were not subject to size minima. It is reasonable to expect unconstrained quotation sizes, expressed in share terms, to be inversely related to price. Order placers are presumably more interested in the dollar value of the order rather than the number of shares the order happens to represent.

16ths-Only Effects

Consider now the changes in stocks that experienced the quote ticksize change without being subject to the OHR. By measuring the post-16ths environment using data from June 2-20, roughly 5300 stocks that came under OHR compliance after that period can be analyzed. There is, of course, no need to analyze ECN usage for these stocks, so attention is restricted to spreads and depth. It is important, however, to distinguish between stocks that are above $10 in price from those that are not. The ticksize change applied to the former group only. Therefore, the regressions were run separately for the two price groups. To ensure the accuracy of the separation, roughly 300 stocks whose prices fell into the $9-$11 range were removed from the analysis. By virtue of how the OHR was phased-in, the 16ths-only sample is disproportionately drawn from thinly-traded stocks that form the numerical majority of Nasdaq stocks. Nevertheless, the results are not materially changed when the model is estimated using stocks from the same population of top 1000 stocks used for the initial phase in of the OHR.

Cross-sectional regression results are shown in Table 10, which indicate a modest effect of 16ths overall. Further, they indicate little cross-sectional variation, especially for the stocks over $10 for which the ticksize change was relevant. Remarkably, it appears that the ticksize change may have had a bigger impact on the lower-priced stocks, for which it technically had no effect.

Effect of 16ths on ECNs

It might be expected that 16ths would have a substantial impact on the importance of ECNs in setting the inside. Prior to 16ths, many ENC orders might have set the inside market alone had they been rounded to 16ths rather than eighths. Consider then the effect of 16ths on the percentage of time that ECN(s) set the inside market. Table 11 presents two regressions on the change (absolute, not percentage) in this variable due to 16ths. The regression is run only for stocks subject to the OHR as of May 12 (waves 1-7), and it is run separately for stocks with prices above and below $10. Table 11 clearly shows that the advent of 16ths led to greater importance of ECNs for stocks above $10 but little impact on the stocks below $10. For stocks above $10, ECNs set the inside on average about 14% of the time, up from 8%. The increase was more pronounced for actively-traded stocks, but less pronounced for higher-priced stocks. This result mirrors the result that spreads tend to be narrower for actively-traded lower-priced stocks. For these stocks, the former eighth tick was more of a constraint on ECN quotes.

Decomposition of Total Change

Quoted Spreads

To complement the preceding analysis, the total change in market quality from OHR/16ths can be separately attributed to OHR and 16ths. That is, one can write: $\Delta y_{Total} = \Delta y_{OHR} + \Delta y_{16ths}$ for market quality variable *y*. In the case of spreads, it is reasonable to presume that both Δy_{OHR} and Δy_{16ths} are non-positive. In this case, one can consider the fraction of the total change that is due to the OHR:

$$OHR\ \ percentage = \frac{\Delta y_{OHR}}{\Delta y_{OHR} + \Delta y_{16ths}}\ .$$

This OHR percentage, and its obverse, the 16ths percentage, may be expected to vary cross-sectionally, and may depend on whether the OHR or 16ths came first.

Table 12 shows the incremental effects of OHR and 16ths for two groups of well-known, actively-traded stocks: those that experienced the OHR before 16ths, and those that were phased-into the OHR after 16ths. The former group are drawn from the Top 10 stocks that were part of the initial OHR phase-in. The latter group were from waves 12 or higher, yet in the top decile of the Top 1000 stocks. The two components of the change, Δy_{OHR} and Δy_{16ths}, are estimated as described above. The table shows a major difference in the respective roles played by the OHR and 16ths in terms of reducing quoted spread. For the very actively-traded stocks that received the OHR before 16ths, the OHR had little impact on spreads. As shown, the spreads of these stocks were for the most part already close to the lower bound of $0.125. No further spread reduction was possible until the ticksize change. On the other hand, the stocks that phased-in to OHR after the ticksize had little spread change when the ticksize was changed. For these stocks, the ticksize was apparently not a binding constraint. It was not until the OHR came that spreads fell.

Results from a broader sample of stocks are shown in Table 13. Estimating the OHR percentage is not easy from a statistical perspective because it involves a random variable in the denominator. Due to sampling error, $\Delta y_{OHR} + \Delta y_{16ths}$ can be positive or very close to zero, leading to hugely volatile estimates of the OHR percentage. To minimize the problem, attention is restricted to the "top 1000" dollar volume stocks that were the universe of stocks chosen for the initial OHR phase in. These stocks generate estimates of Δy_{OHR} and Δy_{16ths} that are less noisy, leading to more stable estimates of the OHR percentage. Further, the stocks are classified into strata based on price level (above or below $10) and pre-OHR/16ths spread, and stratum medians are computed (rather than the more outlier-sensitive means).

For stocks over $10, Table 13 shows a pronounced difference in the relative effects of OHR and 16ths depending on whether OHR or 16ths came first. Low-spread stocks were much less affected by the OHR when they became subject to the OHR before 16ths. When 16ths came first, the OHR accounted for about 88% of the spread decline, regardless of the initial level of spread. For stocks below $10, whether OHR or 16ths came first does not affect the OHR percentage. Though the estimates are noisy due to the small number of observations, it appears that the initial spread level does not influence the OHR percentage. It is remarkable, however, that the OHR percentage for these stocks, averaging around 80%, is less than 100%, since the ticksize change did not apply to these stocks.

Quoted Depth

Changes in quoted depth can also be decomposed into an effect due to the OHR and another due to 16ths. It might be expected that 16ths would tend to lower depth, as the lower ticksize leads to a given number of shares bid or offered being "spread out" over a finer pricing grid, leading to fewer shares available at a tighter inside spread. The OHR could produce a net change in inside depth going either way. On the one hand, the OHR led to the size of public limit orders and ECN orders being added to Nasdaq quotes. On the other hand, these orders have lowered inside spreads. To the extent that new tighter spreads are set by small limit orders, the OHR actually can work towards lowering quoted depth at the inside, even while it adds to the total amount of share bid or offered.

Given the potentially opposite effects of OHR and 16ths on depth, it is not appropriate to consider an "OHR percentage" for depth as it was for spreads. Instead, the mean percentage change in depth due to the OHR and to 16ths can be estimated separately. Table 14 presents such a calculation for the same stocks and in the same format as done for Table 13. The table indicates substantial differences in the relative effects of OHR and 16ths, depending on the order of the effect and the characteristics of the stock. Consider stocks over $10 that experienced the OHR before 16ths. For the lower-spread stocks, the net effect of the OHR was to increase depth while for the high-spread stocks, the net effect was the opposite. The change to 16ths brought uniformly a reduction in depth, with the largest reduction occurring for the low-spread stocks. This result is reasonable, since the ticksize change was presumably more relevant to stocks with small spreads. Thus for these stocks, the OHR and 16ths had opposing effects vis a vis the base spread level of the stock.

Consider now stocks over $10 that experienced 16ths before OHR. Again 16ths led to depth declines, with the decline larger the lower the base spread. The OHR, however, led to a further decline in depth. Unlike the stocks that had the OHR first, with these stocks the OHR-induced decline was greater for the low-spread stocks.

For stocks below $10, there appears to be no difference between stocks that had OHR before 16ths and those that did not. In both cases, the OHR added to depth at the inside, with lower-spread stocks receiving proportionately more depth, consistent with the idea that actively-traded stocks have been more affected by the OHR. Surprisingly, 16ths had a small but noticeable decline in depth. This result is consistent with the finding shown above indicating that 16ths had a small spread-reducing effect for stocks below $10.

Summary

The Order Handling Rules and the ticksize reduction to 16ths have had a major impact on the market quality of many Nasdaq stocks. Substantial cross-sectional variation in these effects has been demonstrated. This variation speaks directly to the question of how well the agency-auction principles embedded in the OHR and narrow ticksizes can work in what is still fundamentally a dealer market. It appears stocks can adapt naturally to both the OHR and 16ths, and that these changes do not necessarily impact the trading characteristics of all stocks.

Quoted Spreads

The OHR and 16ths had a major spread-reducing effect on Nasdaq stocks. The effect was most pronounced, however, for actively-traded, low-priced stocks. Thinly-traded stocks have not experienced much of a spread decline. For many of the very active stocks, the OHR in isolation did not impact spreads since spreads of these stocks were already at their lower bound of $1/8. It was not until the quotation ticksize was reduced that the full effects of the OHR could be manifested. For most stocks, the OHR had a much larger role in reducing spread than did 16ths, accounting for roughly 85% of the reduction.

Importance of ECNs

Post-OHR, the inside spread can be set by orders placed in ECNs. This study has found that this occurs with greater likelihood for actively-traded, high-priced stocks. There are many Nasdaq stocks that only rarely have their spread established by an ECN order. The fact that higher-priced stocks are more widely used may have to do with fixed share size minima for market maker quotes, and the fact that day-traders, whose limit orders are often placed in ECNs, tend to trade more in high-priced stocks.

ECN prices are rounded away from the inside to the same level of precision as market maker quotes on Nasdaq. Therefore, the advent of 16ths lead to an increase in the importance of ECN orders, many of which are placed in 16th or finer increments. Prior to 16ths, these prices were not able to influence the spread.

Quoted Depth

The OHR and 16ths have had the impact of increasing the quoted depth (measured in shares) at the inside for some stocks, while reducing it for others. The key variable influencing the variation is the price of the stock. Higher-priced stocks have experienced greater declines/smaller increases in depth compared to lower-priced stocks. This change has moved the market toward greater uniformity of quoted depth in terms of dollars, not shares.

Change in Market Making Positions

In spite of what appears to be a large reduction in the profitability of market making, there have not been major reductions in the number of market making positions within the time frame of this study. If anything, the number of positions has increased, particularly for actively-traded stocks, the very stocks that experienced the greatest spread declines.

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Appendix—Implementation Schedule for Order Handling Rules

In order to allow Nasdaq and the rest of the securities industry to implement the OHR in an orderly way without creating undue stress, the SEC approved a plan whereby stocks were phased into compliance in a sequence of 22 waves, from January 20, 1997 to October 13, 1997. This appendix provides details concerning the phase-in.

The universe for the initial waves was the set of "Top 1000" Nasdaq securities, ranked according to the median daily dollar volume during the last three months of 1996. The top 1000 were subdivided into ten deciles. The initial wave of OHR stocks was drawn from a) the top ten dollar volume stocks, and b) a random draw of eight stocks from each of the top five deciles, for a total of 50 stocks. The second wave, implemented February 10, 1997, was drawn from a) stocks of rank 11-20 in dollar volume, and b) a random draw of eight stocks from each of the top five deciles, for a total of 50 stocks. The next two waves of 50 stocks were drawn randomly from the top five deciles (of the Top 1000). Eventually, waves were created by draws from all 10 deciles, through July 7, 1997.

Wave 14, starting August 4, was the first from which stocks were drawn from the entire universe of Nasdaq stocks. The vast majority of stocks were phased-in in large groups of about 850 stocks during September and the first half of October. The following table presents the entire schedule.

Phase-in of Nasdaq Issues under Order Handling Rules

Wave	Date	No. of Stocks
1	Jan. 20	50
2	Feb. 10	50
3	Feb. 24	50
4	Apr. 21	50
5	Apr. 28	50
6	May 5	50
7	May 12	53
8	May 19	50
9	May 27	50
10	June 2	50
11	June 9	50
12	June 23	50
13	June 30	49
14	July 7	61
15	Aug. 4	250
16	Aug. 11	250
17	Sept. 8	850
18	Sept. 15	820
19	Sept. 22	850
20	Sept. 29	850
21	Oct. 6	850
22	Oct. 13	867

Table 1: Regression Results for Quoted Spreads

	Model (1)	Model (2)		Model (3)
Dependent Variable	Log Jan. Quoted Spread	Log Nov. Quoted Spread	Dependent Variable	Change in Log Quoted Spread
Intercept	0.8841 (15.57)	0.9699 (22.14)	Intercept	-0.0583 (-0.87)
Log Trades	-0.2396 (-39.40)	-0.3460 (-77.51)	∆ Log Trades	-0.2664 (-33.31)
Log Price	0.6021 (95.03)	0.6943 (150.44)	∆ Log Price	0.6095 (55.15)
Log Float	-0.1352 (-18.00)	-0.0577 (-10.03)	∆ Log Float	-0.0318 (-2.30)
Log Volatility	0.1946 (19.01)	0.3650 (40.41)	∆ Log Volatility	0.2602 (20.38)
			Log Jan. Trades	-0.0891 (-12.23)
			Log Jan. Price	0.0818 (10.71)
			Log Jan. Float	0.0564 (6.47)
			Log Jan. Volatility	0.0985 (6.69)
R^2	0.745	0.872		0.437
Uncond. Mean of Dep. Var.	-1.112	-1.346		-0.235

This table presents cross-sectional regressions comparing the average quoted spread from Jan. 1-17, 1997 (before OHR and 16ths) with that from Nov. 1997 (after OHR and 16ths). Models (1) - (3) refer to equations (1) - (3) presented in the text. The independent variables include the daily average number of trades of the stock, its average price, its float (shares outstanding in the hands of the public), and the standard deviation of interday return volatility. 5166 stocks are used in the regression.

Table 2: Predicted Changes in Quoted Spread

	10% Quantile	Change in Spread	Median	Change in Spread	90% Quantile	Change in Spread
Trades	37	-7.0%	311	-23.1%	2,501	-36.1%
Price	$1.40	-34.0%	$9.11	-23.1%	$29.11	-15.4%
Float (000s)	1,146	-28.5%	4,185	-23.1%	17,734	-16.5%
Volatility	0.0094	-31.5%	0.0304	-23.1%	0.0650	-17.1%

This table presents predicted values generated from the results of regression model (3) shown in Table 1. Each row shows, for the indicated variable (e.g. Trades), the predicted percentage change in quoted spread when the January value of the variable takes either the 10%, 50% (median), or 90% sample quantile. The other independent variables are set at their sample median values. The predictions are generated assuming that the independent variables have the same value in November as they did in January (e.g., Δlog Trades = 0).

Table 3: Model Results for Percent of Time that ECN(s) Set Inside Market

	Tobit Model	OLS Model
Intercept	-0.0932 (-9.45)	-0.0641 (-6.38)
Log Trades	0.0286 (27.18)	0.0282 (26.13)
Log Price	0.0226 (22.14)	0.0181 (17.09)
Log Float	0.0030 (2.29)	0.0035 (2.66)
Log Volatility	0.0082 (4.02)	0.0088 (4.24)
R^2	n/a	0.3598
Observations	5166	4780

This table presents regression results concerning the fraction of time during November 1997 that one or more of the four Nasdaq ECNs set the inside bid or ask (i.e., the time that ECN quotes were at the inside but no market maker quote was). For some stocks, an ECN quote never set the inside, indicating the need for estimating a Tobit model. See notes to Table 1 for a description of the independent variables.

Table 4: Predicted Percentage of Time ECN Sets Inside Market

Variable	Reference Value		Prob. ECN Sets Inside Some of Time	Expected Time ECN Sets Inside
Trades	10% Quantile	37	75.3%	5.8%
	Median	311	91.4%	9.9%
	90% Quantile	2,501	97.9%	14.4%
Price	10% Quantile	$1.40	72.7%	5.4%
	Median	$9.11	91.4%	9.9%
	90% Quantile	$29.11	96.7%	13.0%
Float	10% Quantile	1,146	90.5%	9.5%
	Median	4,185	91.4%	9.9%
	90% Quantile	17,734	92.4%	10.3%
Volatility	10% Quantile	0.0094	89.1%	9.0%
	Median	0.0304	91.4%	9.9%
	90% Quantile	0.0650	92.7%	10.4%

This table presents predicted values based on the results of the Tobit model shown in Table 3. See the notes to Table 2 for a discussion of the way in which the values of the independent variables were selected. The parameters of the model, including a scale parameter, are used to calculate the probabilities and expectations shown in the two right-hand columns of the table. Formulas for the calculations are from standard textbook treatments of the Tobit model.

Table 5: Regression Results for Quoted Depth at Inside

	Model (1)	Model (2)		Model (3)
Dependent Variable	Log Jan. Quoted Depth	Log Nov. Quoted Depth	Dependent Variable	Change in Log Quoted Depth
Intercept	-0.2361 (-3.38)	0.7260 (13.96)	Intercept	0.8570 (10.12)
Log Trades	0.1892 (25.25)	0.1703 (32.14)	Δ Log Trades	0.1650 (16.27)
Log Price	-0.0262 (-3.36)	-0.2556 (-46.66)	Δ Log Price	-0.3719 (-26.54)
Log Float	0.1561 (16.87)	0.1162 (17.00)	Δ Log Float	0.0238 (1.36)
Log Volatility	-0.2200 (-17.45)	-0.2002 (-18.67)	Δ Log Volatility	-0.1040 (-6.42)
			Log Jan. Trades	0.0009 (0.09)
			Log Jan. Price	-0.2305 (-23.81)
			Log Jan. Float	-0.0487 (-4.41)
			Log Jan. Volatility	0.0020 (0.10)
R^2	0.421	0.516		0.310
Uncond. Mean of Dep. Var.	2.900	2.856		-0.044

This table presents cross-sectional regressions comparing the average quoted depth at the inside. See the note to Table 1 for a description of the time frame of the data and the independent variables. The depth at inside includes the size posted by market makers as well as ECNs. The measure is an average of depth posted at the inside bid and inside offer.

Table 6: Predicted Change in Quoted Depth at Inside

	10% Quantile	Change in Depth	Median	Change in Depth	90% Quantile	Change in Depth
Trades	37	-6.0%	311	-5.8%	2,501	-5.7%
Price	$1.40	45.1%	$9.11	-5.8%	$29.11	-28.0%
Float (000s)	1,146	0.3%	4,185	-5.8%	17,734	-12.2%
Volatility	0.0094	-6.1%	0.0304	-5.8%	0.0650	-5.7%

This table presents predicted values generated from the results of regression model (3) shown in Table 5. See the note to Table 2 for a description of the methodology.

Table 7: Regression Results for Number of Market Makers

	Model (1)	Model (2)		Model (3)
Dependent Variable	Log Jan. No. Mkt Makers	Log Nov. No. Mkt. Makers	Dependent Variable	Change in Log No. Market Makers
Intercept	-0.6028 (-10.91)	-0.6278 (-12.72)	Intercept	0.0680 (1.41)
Log Trades	0.2827 (47.75)	0.2935 (58.37)	∆ Log Trades	0.1684 (29.24)
Log Price	-0.2439 (-39.56)	-0.2086 (-40.13)	∆ Log Price	-0.0924 (-11.61)
Log Float	0.1114 (15.24)	0.1163 (17.93)	∆ Log Float	0.0436 (4.38)
Log Volatility	-0.1779 (-17.85)	-0.1548 (-15.21)	∆ Log Volatility	-0.0742 (-8.07)
			Log Jan. Trades	0.0250 (4.76)
			Log Jan. Price	0.0422 (7.68)
			Log Jan. Float	-0.0030 (-0.48)
			Log Jan. Volatility	0.0610 (5.74)
R^2	0.617	0.704		0.241
Uncond. Mean of Dep. Var.	2.103	2.134		0.031

This table presents cross-sectional regressions comparing the average number of market making positions. See the note to Table 1 for a description of the time frame of the data, the independent variables, and the data sources.

Table 8: Predicted Change in Number of Market Makers

	10% Quantile	Change in No. Market Makers	Median	Change in No. Market Makers	90% Quantile	Change in No. Market Makers
Trades	37	1.4%	311	6.9%	2,501	12.6%
Price	$1.40	-1.2%	$9.11	6.9%	$29.11	12.3%
Float (000s)	1,146	7.3%	4,185	6.9%	17,734	6.5%
Volatility	0.0094	-0.5%	0.0304	6.9%	0.0650	12.0%

This table presents predicted values generated from the results of regression model (3) shown in Table 7. See the note to Table 2 for a description of the methodology.

Table 9: Effects of OHR Before 16ths (447 Stocks)

	Change in Log Quoted Spread	Percent of Time ECN Sets Inside	Change in Log Quoted Depth
Intercept	-0.7536 (-7.08)	0.1105 (4.32)	0.2168 (1.66)
Log Trades	0.0310 (2.50)	-0.0047 (-1.59)	0.0720 (4.74)
Log Price	0.0115 (0.65)	0.0173 (4.04)	-0.1801 (-8.24)
Log Float	-0.0096 (-0.66)	0.0019 (0.54)	-0.0104 (-0.58)
Log Volatility	-0.1005 (-3.80)	0.0225 (3.53)	-0.0359 (-1.10)
R^2	0.065	n/a	0.194
Mean of Dep. Variable	-0.312	0.083	0.030

This table presents regression results for 447 stocks that were phased into OHR compliance before the 2 June 1997 ticksize reduction. For the models of quoted spread and depth, the regression has as dependent variable the change in the log of the average value of the variable prevailing one week before and one week after the OHR implementation. Theses regressions can be compared with those of Table 1 and 5. The model of ECNs setting the inside is a Tobit model, based on averages prevailing one week after OHR implementation. It is comparable to the model of Table 3. See the note to Table 1 for a description of the independent variables.

Table 10: Effects of 16ths Before OHR

	Change in Log Quoted Spread		Change in Log Quoted Depth	
	Price Below $10	Price Above $10	Price Below $10	Price Above $10
Intercept	-0.1978 (-4.46)	-0.1219 (-2.04)	-0.0476 (-1.08)	-0.1018 (-1.32)
Log May Trades	0.0159 (2.85)	0.0066 (1.27)	-0.0015 (-0.27)	-0.0032 (-0.47)
Log May Price	-0.0502 (-7.49)	0.0082 (0.72)	-0.0343 (-5.13)	0.0122 (0.83)
Log May Float	-0.0143 (-2.41)	-0.0089 (-1.39)	-0.0019 (-0.32)	-0.0054 (-0.66)
Log May Volatility	-0.1015 (-9.94)	-0.0360 (-3.45)	-0.0279 (-2.74)	-0.0258 (-1.92)
R^2	0.032	0.008	0.012	0.006
Mean of Dependent Variable	-0.038	-0.021	-0.019	-0.023
Observations	2998	1996	2998	1996

This table presents regressions of changes in spreads and depth for the indicated number of stocks that experienced the 2 June 1997 ticksize reduction before being phased into OHR compliance. The data were based on averages from the last three weeks in May before the change and the first three weeks in June after the change. The regressions are comparable to those in Tables 1 and 5. Regressions were run separately for stocks above and below $10 because the ticksize reduction from $1/8 and $1/16 applied only to stocks above $10. Stocks below $10 continued to have a ticksize of $1/32.

Table 11: Change in Percentage of Time ECN(s) Set Inside Market (Before and After 16ths)

	Stocks Below $10	Stocks Above $10
Intercept	0.1463 (1.77)	-0.1053 (-3.47)
Log May Trades	-0.0038 (-0.32)	0.0218 (6.06)
Log May Price	0.0108 (0.58)	-0.0153 (-2.45)
Log May Float	-0.0151 (-1.41)	0.0055 (1.30)
Log May Volatility	-0.0031 (-0.19)	-0.0136 (-1.64)
R^2	0.246	0.326
Mean of Dependent Variable	0.004	0.061
Mean ECN Percentage in May	0.098	0.083
Observations	27	306

This table presents regressions of the absolute (not percentage) change in the fraction of time that ECNs set the inside market, comparing the last three weeks of May (before the ticksize change) with the first three weeks of June (after the change). The 333 stocks analyzed were those stocks that had been phased into OHR compliance by the beginning of May. The stocks above and below $10 were analyzed separately because the ticksize change only applied to stocks above $10.

Table 12: Percentage Change in Quoted Spread Due to OHR and 16ths

	Change in Log Spread: Effect of OHR	Change in Log Spread: Effect of 16ths	OHR Effect as Percent of Total Effect	January Spread
Stocks with OHR First				
Intel	-0.048	-0.488	9.0%	$0.140
Oracle	-0.118	-0.536	18.0%	$0.141
Cisco	-0.087	-0.495	14.9%	$0.148
Sun	-0.112	-0.571	16.4%	$0.152
Microsoft	-0.137	-0.321	29.9%	$0.158
3Com	-0.169	-0.510	24.9%	$0.167
Dell	-0.225	-0.262	46.2%	$0.181
Ascend	-0.148	-0.568	20.7%	$0.204
Stocks with 16ths First				
Baan Co	-0.202	-0.013	94.0%	$0.217
Teva Pharm ADR	-0.273	-0.021	92.9%	$0.229
Biochem Pharma Inc.	-0.193	-0.046	80.8%	$0.312

This table shows, for the indicated heavily-traded stocks, the impact of the OHR and the impact of 16ths on quoted spread. The change is measured by comparing the logarithmic percentage change in average spread from one week before the change with that from one week after the change. The table shows the ratio of the effect of OHR to the combined effect. Also shown is the average spread from January 1-17, 1997.

Table 13: Percentage of Spread Decline Due to OHR

	Stocks above $10			
	OHR First		16ths First	
Jan. Log Spread Category	Median OHR Pct.	No. Stocks	Median OHR Pct.	No. Stocks
[-2, -1.5)	41.3%	59	87.0%	44
[-1.5, -1)	71.5%	88	88.8%	137
[-1,-.5)	76.4%	91	88.2%	143
[-.5,0)	86.5%	36	86.4%	49
	Stocks below $10			
	OHR First		16ths First	
Jan. Log Spread Category	Median OHR Pct.	No. Stocks	Median OHR Pct.	No. Stocks
< -2	82.7%	7	92.4%	8
[-2, -1.5)	92.6%	13	67.5%	15
[-1.5, -1)	54.3%	5	77.6%	7

The percentage of spread decline due to OHR is defined as the ratio of the percentage spread change associated with the implementation of the OHR, relative to the overall change associated with both the OHR and 16ths. Stocks are categorized by the logarithm of their average pre-OHR January spread, and by whether their price was above or below $10.

Table 14: Changes in Quoted Depth at Inside: OHR and 16ths Effects

	Stocks above $10					
	OHR First			16ths First		
Jan. Log Spread Category	Mean OHR Effect	Mean 16ths Effect	Total	Mean OHR Effect	Mean 16ths Effect	Total
[-2, -1.5)	0.094	-0.369	-0.275	-0.081	-0.078	-0.159
[-1.5, -1)	0.002	-0.177	-0.175	-0.042	-0.041	-0.083
[-1,-.5)	-0.038	-0.085	-0.123	-0.012	-0.044	-0.056
[-.5,0)	-0.103	-0.059	-0.162	0.023	-0.028	-0.005
	Stocks below $10					
	OHR First			16ths First		
Jan. Log Spread Category	Mean OHR Effect	Mean 16ths Effect	Total	Mean OHR Effect	Mean 16ths Effect	Total
< -2	0.323	0.014	0.337	0.564	-0.062	0.502
[-2, -1.5)	0.093	-0.067	0.026	0.249	-0.097	0.152
[-1.5, -1)	0.216	-0.019	0.197	0.202	-0.056	0.146

This table shows the (logarithmic) percentage change in quoted depth at the inside, associated separately with phase-in of the OHR and the reduction in ticksize. Stocks are categorized by the level of spread in January 1997 and the price level, just as done for Table 13.