Do Investors Prefer Even-Eighth Prices? Evidence from NYSE Limit Orders

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Abstract

Using a large sample of limit orders on NYSE stocks, we find that investors submit more limit orders with even-eighth prices than odd-eight prices. However, even though there are a greater number of even-eighth limit orders, the proportion of executing limit orders submitted with even prices is greater than those submitted with odd prices for a large portion of our sample. We find that clustering on even prices is a positive function of stock price and investor uncertainty. The preference for even price affects stock quotes: investors are more likely to submit a quote improving limit order if the limit price is even and quoted depth is higher for even quotes than for odd quotes.

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1. Introduction

We examine a large sample of electronically placed limit orders on NYSE stocks to investigate (1) what limit prices investors choose, (2) limit order execution rates, (3) the determinants of investor's pricing preferences, and (4) the relation between investor pricing preferences and stock quotes. Our examination of limit prices is motivated by Harris' (1991) study of NYSE, AMEX, and over-the-counter stock and quote prices. Harris shows that whole-dollar prices are more common than prices on the half-dollar and quarter-dollar. Odd-eighth prices are the least common of all observed prices. Harris argues that the price clustering on even fractions is consistent with traders using rounded prices to reduce the cost of negotiation. That is, negotiations over the selling price for an asset can converge more rapidly when traders restrict the set of possible prices than when they are free to choose from any possible price.

Numerous studies of price clustering have followed. For example, Christie and Schultz (1994) document the extensive use of even-eighth quotes by dealers of certain Nasdaq stocks. The difference in quoting practices across their sample of stocks provided evidence of possible collusion among those Nasdaq dealers who restricted their quotes to even-eighth prices and prompted the Nasdaq Market Makers civil lawsuit.[1] More recently, work by Bessembinder (1999) and Chung, Van Ness, and Van Ness (2001) show that price clustering on even price increments (i.e., even-sixteenths and even decimals) continues on the Nasdaq despite the publicity generated from the lawsuit and the initiation of several new regulations meant to increase competition. Both studies find clustering on even prices on the NYSE as well.

One common aspect of these studies is their investigation of stock quotes or transaction prices. In contrast, we directly examine investors' pricing preferences. The limit order market provides a unique laboratory that can be used to determine the "normal" amount of clustering at the even-eighth (and other price increments, such as whole-dollars) in a competitive market with numerous participants. The clearest picture of investor preferences for even prices is seen from the portion of limit orders placed in the morning

[1] Although the results presented by Christie and Schultz (1994) provided the original motivation for the investigation into Nasdaq market maker quoting practices, the most damaging evidence was found in taped telephone conversations. In those conversations, "conspiratorial reminders, warnings, and verbal abuse" were used against those Nasdaq market makers that narrowed the spread [In Re: NASDAQ Market-Makers Antitrust Litigation to: Consolidated Amended Complaint, M21-68 (RWS), 94 Civ. 3996 (RWS), M.D.L. No 1023, Section VII, No. 107].

before the NYSE specialist posts the day's first quotes. During the day, investors can refer to the quotes when setting their limit prices. Before the posting of the first quote, no equivalent reference price exists. Hence, investors' unconstrained preferences for even-eighth prices are more likely to be revealed with these "early" limit orders. We initially assume, as a null hypothesis, that limit order investors have no preference for certain price increments (e.g., even-eighth or odd-eighth). If so, the percentage of even- and odd-eighth limit orders should be roughly equal. However, for this portion of our sample we find that 69.7 percent of limit orders are placed at the even-eighth. Early limit orders also cluster on the dollar (29.6 percent) and half dollar (16.8 percent), suggesting that investors prefer dollar and half-dollar prices to finer price increments.

Of the limit orders placed during the day, most sell limit orders are placed within one-eighth of the ask quote and most buy limit orders are placed within one-eighth of the bid quote. For these limit orders placed close to the quote, we observe that investors react differently to an even-eighth quote versus an odd-eighth quote. When the NYSE posted quote is even, investors tend to submit their limit orders at the quote. Conversely, when the quote is odd, investors avoid the quote and move to the even-eighth prices on either side of the quote.

Since only a small portion of limit orders are placed more than one-eighth outside the quotes, and since they rarely execute, these limit orders may not be as informative about investor pricing preferences as those placed close to the quote.[2] Even so, we find evidence that further supports the conclusion that investors prefer even prices – limit orders placed more than one-eighth outside the quotes are *four times* more likely to be submitted at the even-eighth than at the odd-eighth. Overall, investors appear to prefer even prices.

The next part of our study examines execution rates of limit orders conditioned on the relation between the limit price and quote price. Higher limit prices for buy limit orders (and lower limit prices for sell limit orders) should result in higher execution rates. However, a more interesting question is whether the higher frequency of even-eighth limit orders causes execution rates to be lower for even-eighth limit orders than for odd-eighth limit orders. For the portion of limit orders placed close to quotes, we observe that the

[2] For buy (sell) limit orders, more than one-eighth "outside" the quote means more than one-eighth of a dollar below the bid price (above the ask price). Likewise, more than one-eighth "inside" the quote means more than one-eighth above the bid price (below the ask price).

proportion of limit orders that fully execute is actually highest for limit orders placed at the *even-eighth*. Limit orders placed further from the quotes, or prior to the posting of the day's first quotes, have higher execution rates for odd-eighth limit orders. Therefore, for the bulk of our sample (i.e., limit orders placed close to the quotes) investors choosing even-eighth limit prices are not penalized by lower execution rates. Apparently, even numbers provide a natural focal point for buyers and sellers when setting the trade price for a stock.

There is a wide cross-sectional variation in the percentage of even-eighth limit orders across the 108 stocks in our sample. For the sample of limit orders placed before (after) the posting of the first quotes, the percentages range from 36.4 percent to 94.3 percent (47.5 percent to 100 percent). We draw on the insights of Harris (1991) and our observations about limit order execution rates to explore possible determinants of even- versus odd-eighth limit pricing. Harris argues that investors use rounded prices to reduce the time needed to negotiate a transaction price. Consistent with his hypothesis, he finds that the percentage of even-eighth transaction prices is a positive function of stock price and investor uncertainty. (High stock prices reduce the monetary cost of using rounded prices as opposed to more precise prices. Less uncertainty about the stock value decreases the probability that buying and selling investors will agree to transact on a rounded price.) Although there is no explicit (back-and-forth) negotiation over the transaction price, the intuition provided by Harris (1991) should also apply to limit orders. That is, the number of investors willing to transact at a rounded limit price should be high when the stock price is high and when investors are uncertain about the value of the stock. However, for lower price stocks, and for stocks with less uncertainty, a more precise limit price would need to be used to attract investors willing to take the other side of the trade. Consistent with this hypothesis, we find that the percentage of even-eighth limit orders for a stock is positively related to both stock price and the various proxies for investor uncertainty.

The final part of our study centers on the relation between investor pricing preferences and stock quotes. Specifically, we investigate whether investor preferences for rounded prices influences (1) the frequency of limit orders placed inside the quotes (i.e., quote improving limit orders) and (2) quoted depth at even versus odd quotes. Consistent with investor preferences for rounded prices, the likelihood of a quote improving limit order submission increases if the resulting limit price moves to a rounded number. For instance, the frequency of sell limit orders submitted one-eighth inside the ask quote is highest when the ask quote is at the

$1/8 (e.g., $25 1/8). Similarly, the highest frequency of sell limit orders submitted 25 cents inside the ask quote is when the ask quote is at the $2/8 (e.g., $25 1/4). This same pricing pattern presents itself for buy limit orders around bid quotes. Results from these tests suggest that investors' decisions to improve the quote by $1/8 (or $2/8) are influenced by whether the resulting limit price will be at a rounded price.

The second implication of investors' preferences for even prices is that the quoted depth should be higher at even quotes than at odd quotes. To investigate, we use the technique developed by Chung, Van Ness, and Van Ness (1999) to decompose the quoted depth into the portion from limit order investors and the portion from the floor (i.e., the specialist and floor traders). Our tests reveal that limit order quoted depth is highest when quotes are even. Further, our tests show that floor quoted depth is also highest when the quote is even. This suggests a preference for even prices among specialists and floor traders.

The rest of the paper is organized as follows. Section 2 discusses the data used in this study. Section 3 gives the results. Concluding remarks are contained in section 4.

2. Data Description

Data for this study was gathered from the TORQ database, compiled by Joel Hasbrouck (1992) and the NYSE. The data cover trades, quotes, and orders for a total of 144 NYSE firms over a three-month period from November 1990 to January 1991.[3] Quotes are contained in the consolidated quote (CQ) file. The CQ file contains NYSE quotes as well as quotes from regional exchanges. The "orders" portion of the TORQ database is given in the system order database (SOD) file. The SOD file only includes electronic orders made through SuperDOT, OARS, and ITS and therefore does not include all limit orders for these stocks. For example, it would not include standing orders by floor broker to buy or sell stock at a certain price. Hasbrouck (1992) also notes that some limit orders placed far away from the current quote may not have been recorded.

Table 1 provides information on our sample. After screening out orders with obvious data errors, there are 476,394 electronic limit orders recorded in the SOD file. Limit orders are identified as SOD variable *OCOND* equal to "1" or "9" and the second character of variable *OCODE* equal to "L." During our sample

[3] Originally, 150 firms were selected for inclusion into the TORQ database (fifteen firms from each of ten equity capitalization deciles), but six of the firms were delisted from the NYSE resulting in the final total of 144 firms.

period, stocks trading below $5 per share were permitted to seek NYSE permission to trade at the sixteenth of a dollar, rather than the eighth of a dollar used for higher-priced stocks. Since the main focus of our study is on orders placed on the even- versus odd-eighth and their relation to posted quotes, we remove thirty-six stocks from our sample that had trades below $5 per share during our sample period as well as any limit order not priced in eighths of a dollar. We further eliminate any limit order carried over from a previous day or placed after the market's close at 4 p.m.[4] Our final sample has 366,092 electronic limit orders covering 108 stocks of which 51,468 were submitted before the first quote of the day, and the remaining 314,624 were submitted after the posting of the first quote, but before the close of the market.

Table 2, Panels A and B, presents stock price and equity capitalization statistics for the 108 firms used in our sample (figures for the 144 TORQ firms are also provided). Stock price and equity capitalization are calculated as of 10/31/1990 using information from the *Center for Research in Securities Prices (CRSP)* database. The sample firms have an average stock price of $23.96 and an average equity capitalization of $3,466 million.

Table 3 provides information on the number of limit orders, mean shares per limit order, and mean dollar value per limit order by investor type: proprietary, agency, individual investor, and unidentified.[5] Of the four groups, individual investors have the smallest dollar value per limit order. For instance, individual investors placed 15,946 limit orders to buy or sell stock of our sample firms before the day's first quote with an average dollar value of $20,560 per limit order. 3,386 proprietary limit orders are placed before the day's first quote with an average dollar value of $71,021. For agency limit orders, the total number is 16,248 with an average dollar value of $63,307. The dollar value of limit orders placed by "unidentified" investors is the highest of the four with an average of $202,429 per order. Comparable figures are observed for limit orders placed during the day.

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[4] By excluding limit orders placed on a previous day, we prevent counting the same limit order more than once. As shown in Table 1, the number of limit orders placed after the close of the market (a total of 276) is too small for meaningful analysis.

[5] The SOD variable *ACCTYP* identifies limit orders as *proprietary*, *agency*, or *individual investor* limit orders. If the investor type is not given, we label the investor as *unidentified*. Koski and Scruggs (1998) explain that the TORQ designation "*individual investor*" is somewhat misleading. It includes not only individual investors, but also taxable corporations and nontaxable corporations (such as pension funds). *Proprietary* limit orders are those placed for the account of a NYSE member firm and *agency* limit orders are those placed by a NYSE member firm for another party (possibly another NYSE member firm). According to Koski and Scruggs, these *agency* limit orders could contain a mixture of limit orders submitted by all four groups: NYSE member firms, individual investors, taxable and non-taxable corporations.

3. Results

In this section, we document the frequency of limit orders placed at even- and odd-eighths, limit order execution rates, determinants of limit order price clustering, and the impact of investors' price preferences on quote prices and quoted depth.

3.1. *The frequency of even-eighth limit orders for limit orders placed before the posting of the first quote*

In comparison to limit orders placed during the day, investors that place limit orders before the posting of the first quote are at an informational disadvantage. They know the last transaction price of the previous day and closing bid and ask quotes; and for some stocks, they might have price information from overnight trades made on other markets. However, they cannot precisely predict how information released after the close of the market on the previous day will affect the day's opening quotes.

Panel A of Table 4 shows the results for these early limit orders. Of the 51,468 early limit orders, 15,242 (29.6 percent) are placed at the dollar and 8,653 (16.8 percent) are placed at the half-dollar. In total, 35,860 limit orders (69.7 percent) are placed at the even-eighth. The percentage of odd-eighth limit orders (30.3 percent) is only slightly higher than the percentage of dollar limit orders. Separately analyzing buy and sell limit orders yields similar percentages of even-eighth prices: 69.2 percent for buy limit orders and 70.3 percent for sell limit orders. The percentage of even-eight limit orders is significantly different than 50 percent. Although not reported on the table, we also reject the null hypothesis that the percentages of whole- and half-dollar limit orders are equal to 12.5 percent. From these results, we infer that when investors cannot use the current quote as a reference price, they exhibit a preference for even prices.

We also calculate the *mean dollar value* of even- versus odd-eighth limit orders. If sophisticated investors place large limit orders, then this test will provide some indication of whether sophisticated investors primarily populate the even- or odd-eighth. Results are presented in Table 4, Panel B. As shown, the average dollar value for even-eighth buy limit orders is statistically *higher* than the average dollar value for odd-eighth buy limit orders. For sell limit orders, the averages are statistically indistinguishable. We interpret this to mean that sophisticated investors set their limit prices at the even-eighth just as frequently as unsophisticated investors. (Section III.D. compares limit order placement by individual and institutional investors and therefore provides another look at this issue of investor sophistication.)

3.2. *The frequency of even-eighth limit orders for limit orders placed after the posting of the first quote*

The analysis for limit orders placed after the first quotes are posted is more complicated. These limit orders are aligned in time with the quote currently in effect (CQ variable *QTIM* and SOD variable *OTIME*).[6] [7] Only NYSE quotes are used in the matching procedure.[8] The frequency of even and odd limit orders, conditioned on the current quote, is calculated as follows. If the current quote is even, then even limit orders will be found at the quote, and in 25-cent increments above and below the quote (e.g., ?$2/8, ?$4/8, ?$6/8). Likewise, odd limit orders are ?$1/8, ?$3/8, ?$5/8, and so forth, around the even quote. When the current quote is odd, then even limit orders are ?$1/8, ?$3/8, ?$5/8, etc., around the quote and odd limit orders are at the quote and ?$2/8, ?$4/8, ?$6/8, etc., around the quote.

Table 5, Panel A, gives results for buy limit orders placed around the bid price. Results for sell limit orders around ask prices are shown in Panel B. Most limit orders are placed within one-eighth of the current quote. For example, 60,569 of the total of 168,846 buy limit orders in our sample (35.9 percent) are placed at the current bid price with an additional 51,841 (30.7 percent) one-eighth above the bid. The next most frequent limit order price is one-eighth below the bid (13,765 buy limit orders or 8.2 percent). In total, 126,175 of 168,846 (74.7 percent) buy limit orders and 112,391 of 145,778 (77.1 percent) sell limit orders are placed within one-eighth of the quote. The frequency of limit orders declines almost monotonically the further the limit order price is from the current quote.

For limit orders placed more than one-eighth from the quote, the number of limit orders with even prices exceeds, and in most cases *greatly* exceeds, the number of limit orders with odd prices. Combining all limit orders placed more than one-eighth outside the quotes, we find that 80.1 percent of buy limit orders and 79.2 percent of sell limit orders are set at the even-eighth. Limit orders placed more than one-eighth inside the quotes yields 62.9 percent even-eighth buy limit orders and 71.7 percent even-eighth sell limit orders. The

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[6] Before merging with our sample of limit orders, we eliminate any quotes with obvious data errors. Errors include quotes marked as bad, late, or in error, quotes in which the bid or ask price is zero, quotes in which the quoted depth at the bid or ask is zero, and quotes where the bid is greater than the ask.

[7] Lee and Ready (1991) recommend adding five seconds to the quote time to match with trade times. We match five-second delayed quotes with our sample of limit orders and find almost identical results to those presented in Table 5.

[8] Blume and Goldstein (1997) investigate NYSE and regional exchange quotes and find that the regional exchanges have the better quote (lowest ask or highest bid) only one percent of the time.

lowest percentage of even-eighth limit orders is observed for limit orders placed within one-eighth of the quote. Here, the percentage of even-eighth limit orders is 54.2 percent for buy limit orders and 56.5 percent for sell limit orders and are comparable to the average percentages of even-eighth quotes for our sample firms (52.68 percent for bid quotes and 52.74 percent for ask quotes). Results for the four subsamples of limit orders, (1) limit orders submitted before the first quote, (2) limit orders placed more that one-eighth inside the quotes, (3) within one-eighth of the quotes, and (4) more than one-eighth outside the quotes, are summarized in Figure 1.

Table 6 reports the mean dollar values for even-eighth versus odd-eighth limit orders placed during the day. In general, these values are statistically the same. Similar to the conclusion drawn in Section 3.1., we interpret these results to mean that sophisticated investors use even-eighth limit prices just as frequently as unsophisticated investors. Table 6 shows another interesting pattern – limit orders immediately outside the quote are much larger than limit orders at the quote or immediately inside the quote. This indicates the investors placing large limit orders seek price improvement at the expense of trade immediacy.

3.3. *An analysis of limit orders placed close to the quote*

A high percentage of even-eighth limit prices is observed for limit orders placed before the first quote of the day and also for limit orders placed during the day, but far from the quotes. In contrast, the percentage of even-eighth limit orders placed within one-eighth of the quote is approximately 50 percent. On the surface, it would appear that only a slight preference for even-eighth prices is seen for the majority of limit orders placed by investors. This evidence *seems* to be mixed. However, a closer examination of Table 5 shows a striking regularity. When the quote is at the even-eighth, investors are more likely to set their limit price at the quote than at odd-eighth prices on either side of the quote. Conversely, when the quote is at the odd-eighth, investors are more likely to submit limit orders at even-eighth prices on either side of the quote than at the odd-eighth quote. For instance, there are 126,175 buy limit orders with limit prices within one-eighth of the bid price. Of these, 63,504 are submitted when the bid is at the even-eighth and 62,671 are submitted when the bid is at the odd-eighth. When the bid is at the even-eighth, 52.2 percent of the 63,504 buy limit orders are placed at the bid with the remainder placed on either side of the bid. When the bid is at the odd-eighth, 43.8 percent of the 62,671 buy limit orders are placed at the bid with the remainder placed on

either side of the bid. A comparable shift is found for sell limit orders around the ask price: 58.0 percent set at the ask when the ask is even, but only 45.1 percent set at the ask when the ask is odd. These percentages indicate a statistically significant difference in investor pricing behavior depending on whether the quote is even or odd.

On the whole, the results from our investigation of all four subsamples of limit orders (those placed before the first quote, more than one-eighth inside the quote, within one-eighth of the quote, and more than one-eighth outside the quote) show that investors have a consistent preference for even-eighth prices.

3.4. *Investor type*

In this section we explore institutional versus individual investors' tendencies to select even-eighth prices to see if one group is driving the results presented above. To analyze, we separate limit orders into four categories: (1) proprietary, (2) agency, (3) individual, and (4) unidentified.[9] Results are presented for all 366,092 limit orders in our sample; however, we find essentially identical results when we exclude the 17,030 limit orders coded as a "program trade" or an "index arbitrage."

Similar to Figure 1, Figures 2A and 2B show the percentage of even-eighth limit orders by investor type for the four subsamples of limit orders. As seen, individual investors are more likely to submit even-eighth limit orders than institutional investors (as proxied by proprietary and agency limit orders). For the sample of limit orders placed by individual investors before the first quote, 75.4 percent of buy limit orders and 77.2 percent of sell limit orders are submitted with even-eighth prices. Even higher percentages, 83.9 percent for buy limit orders and 83.8 percent for sell limit orders, are observed for those individual investor limit orders placed more than one-eighth outside the quotes. Although the percentages for institutional investors are smaller, these investors also demonstrate a preference for even-eighth limit prices.

A breakdown of limit orders placed within one-eighth of the quote by investor type is presented in Table 7. Consistent with the results presented in Table 5, all four groups of investors are more likely to place their limit orders at the quote if the quote is even than if the quote is odd. In addition, similar to the results

[9] As discussed, limit orders placed by "individual" investors (as that term is defined in the TORQ database) includes not only limit orders placed by individual investors, but also by taxable and non-taxable corporations. Although not perfect, this group probably gives the best picture of individual investor pricing preferences. Institutional investor preferences are best determined by examining proprietary limit orders (and to a lesser extend, agency limit orders).

summarized in Figures 2A and 2B, individual investors demonstrate the largest shift of their order placement between instances when the quote is even versus odd. When the bid is even, individuals investors place 44.2 percent of their buy limit orders at the bid with the remainder at the odd prices on either side of the even bid. When the bid is odd, they place only 31.1 percent of their buy limit orders at the bid with the remainder at the even prices on either side of the odd bid. An even wider disparity is seen for individuals' sell limit orders around the ask. Institutional (proprietary) investors have the smallest shift in limit order placement, but the shift is still statistically significant at the 1 percent level.

3.5. *Odd and even limit order executions*

In this section we examine the execution of limit orders. The null hypothesis is that the *number* of even-eighth limit orders that execute is the same as the number of odd-eighth limit orders that execute. Therefore, since investors submit more even-eighth limit orders than odd-eighth limit orders (and since, as reported later in section 3.7., limit order depth is higher when the quote is even than when the quote is odd), the *proportion* of even-eighth limit orders that execute should be significantly *less* than the *proportion* of odd-eighth limit orders that execute.[10] For example, there are 8,205 buy limit orders submitted one-eighth below an odd bid price (i.e., an even-eighth limit order) and 5,560 buy limit orders submitted one-eighth below an even bid price (i.e., an odd-eighth limit order). Under the null hypothesis, if the same number of limit orders execute, the proportion of executing odd-eighth limit orders should be higher.[11]

We compute the number and proportion of fully executing limit orders for our sample of limit orders placed during the day. The sample of limit orders is broken into ten subsamples based on whether the limit order is to buy or sell stock and the relation of the limit order price to the quote. An executing limit order is defined as a limit order that fully executes on the day that the limit order is placed. Results are given in Table 8. Overall, 52.7 percent of buy limit orders and 56.6 percent of sell limit orders fully execute. The probability of execution should be a function of the limit price. In other words, limit orders placed outside the quotes

[10] Since specialist shares are executed after limit shares, the limit order portion of the quoted depth is the relevant amount to consider when assessing execution probabilities for a limit order investor.

[11] The null hypothesis might be better framed in terms of equal dollar values executing across the two groups of limit orders. However, the analyses in Table 4 (Panel B) and Table 6 show that the mean dollar value of even-eighth limit orders is similar to the mean dollar value of odd-eighth limit orders suggesting that the modification of this null hypothesis is not needed.

should execute less frequently than limit orders placed at the quotes, or inside the quotes. Our results confirm this premise – buy limit orders placed one-eighth above the bid execute 81.8 percent of the time. Placement one-eighth below the bid reduces the rate of execution to 28.2 percent. A similar decline in execution rates is seen for sell limit orders as the limit price increases with respect to the ask quote.[12]

As stated, the null hypothesis is that the numbers of fully executing even- and odd-eighth limit orders are the same. However, Table 8 shows that the number of executing even-eighth limit orders greatly exceeds the number of executing odd-eighth limit orders.[13] For example, 2,416 of the 8,205 even-eighth buy limit orders placed one-eighth below the bid fully execute. For odd-eighth buy limit orders placed one-eighth below the bid, only 1,470 of the 5,560 limit orders fully execute. The null hypothesis of having the same number of executing limit orders is rejected with a *Z*-statistic of 15.18. The null hypothesis is also rejected at all other price levels for both buy and sell limit orders.

Execution rates for even- and odd-eighth limit orders are also presented in Table 8. We first examine the six-subsamples of limit orders placed within one-eighth of the quotes. As noted, most limit orders are submitted with prices within one-eighth of the quotes and most of these limit orders are placed at the even-eighth. However, despite the greater number of even-eighth limit orders, investors experienced a statistically significant *higher* rate of execution in five of these six subsamples. (For the remaining subsample, the execution rates for even and odd limit orders are statistically indistinguishable.) Four of the subsamples examine limit orders placed more than one-eight from the quotes. Three of these four subsamples have statistically higher execution rates for odd-eighth limit orders, with the remaining subsample showing statistically similar execution rates.

Table 8 also presents an analysis of the number of executions and execution rates for the sample of limit orders placed prior to the day's first quotes. Similar to the results from the sample of limit orders placed during the day, the number of fully executing even-eighth limit orders is significantly higher than the number

[12] It is interesting to note that limit orders placed more than one-eighth inside the quotes execute slightly less frequently than those placed one-eighth inside the quotes. We examined a small sample of these limit orders and found that they were either placed late in the day (too late to execute in full), or were only partially executing before the quote moved.

[13] To simplify the presentation, rather than giving the results based on whether the quote is at the even- or odd-eighth, Table 8 presents even-eighth limit orders in one column and odd-eighth limit orders in another column.

of fully executing odd-eighth limit orders. Execution rates for even-eighth limit orders are statistically lower than those for odd-eighth limit orders.

This evidence suggests that investors submitting limit orders close to the quotes are not irrational when using even-eighth limit prices. For these limit orders, execution rates for even-eighth limit orders are the same, or better than, execution rates for odd-eighth limit orders. Evidence of investors irrationally using even-eighth limit orders is observed for limit orders placed far from the quotes and for limit orders submitted before the posting of the day's first quotes. But, these limit orders represent a small portion of our sample.

3.6. *Determinants of the percentage of even limit orders*

Harris (1991) investigates whether stock price clustering on rounded numbers is consistent with buyers and sellers desire to reduce negotiation time. In support of his costly negotiation hypothesis, Harris finds more clustering on even fractions when there is more uncertainty about stock value and for stocks with a high price.[14] With limit orders, an investor submits *one* price, and then waits to see if another market participant (e.g., another investor, floor trader, specialist) takes the other side of the trade. Since there is no explicit negotiation with limit orders, limit order investors do not submit rounded prices to reduce the *time* needed to negotiate a transaction price. However, as discussed in the previous section, execution rates for even-eight limit orders exceed execution rates for odd-eighth limit orders for a large portion of our sample. This suggests that investors might rationally use rounded limit prices to increase the probability of finding market participants willing to take the other side of the trade.

Similar to Harris (1991), we hypothesize that the number of market participants willing to transact at a rounded limit prices will be high when the stock price is high and when investors are uncertain about the value of the stock. However, for lower price stocks, and for stocks with less uncertainty, a more precise limit

[14] In Harris' model, investors negotiate from a course set of prices, e.g., \$24.75, \$25, \$25.25, when they are uncertain about the stock's true value. However, with more certainty about stock value, investors may not be willing to trade significantly away from their reservation price. Thus, the benefit of the courser set (i.e., less negotiation time) is offset by a decreased chance that the buyer and seller will agree to transact at one of these prices (thereby losing any gains from trade). Therefore, a finer set of possible prices is used when uncertainty is low, e.g., \$24.75, \$24.875, \$25, \$25.125, \$25.25. This results in more rounded transaction prices being observed when uncertainty about stock value is high than when uncertainty is low. Harris' model also assumes that investors form their discrete price sets using a constant fraction around the stock price. Since an eighth is a larger fraction of a low-priced stock than a high-priced stock, larger price variations (e.g., \$0.25 versus \$0.125) should be seen in the discrete price sets for high-priced stocks than for low-priced stocks. Thus, Harris predicts a positive relation between the percentage of rounded prices and the stock price.

price would need to be used to attract investors willing to take the other side of the trade. If so, the percentage of even-eighth limit orders will be a positive function of stock price and investor uncertainty.

To test our hypothesis, we calculate the difference in the percent of even and odd buy (and sell) limit orders for the samples of limit orders placed before and after the posting of the day's first quotes. *Percent difference buy (sell) limit orders* are regressed against two independent variables – *Stock Price* (the average of the closing stock prices on CRSP from November 1, 1990 to January 31, 1991) and *Return Volatility* (the standard deviation of the CRSP returns calculated over the period November 1, 1990 to January 31, 1991). Results are presented in Panel A of Table 9 for early limit orders and Panel B of Table 9 for day limit orders. Consistent with our hypothesis, the percentage of even-eighth buy limit orders for the sample of early limit orders (Regression one, Panel A) is positively related to *Stock Price* and *Return Volatility*. Similar results are obtained for early sell limit orders (Regression three, Panel A). For the sample of day limit orders (Regressions one and three, Panel B), *stock price* has a positive and significant coefficient in both regressions. The coefficients for *return volatility* in the two regressions are positive, but insignificant.

Harris (1991) uses four variables to proxy for investors' uncertainty about stock value: the standard deviation of the overlapping five-day price changes (*STD? P*), log of the market value of equity (*LogMVE*), the inverse of the square root of the stock's average daily number of transactions (*InvSqrtTrans*), and a dummy variable equal to one if the stock is a closed-end fund (*CEF*). Greater uncertainty is expected with higher values of *STD? P* and *InvSqrtTrans* and lower values of *LogMVE* and *CEF*. [See Harris (1991) for a full discussion.] We repeat the regression analysis, using *Stock Price* and the four proxies for investor uncertainty, *STD? P, LogMVE, InvSqrtTrans,* and *CEF* as independent variables and present the results as Regressions two and four in Table 9, Panels A and B. For the sample of early sell limit orders, as well as the samples of day buy and day sell limit orders, the results largely follow our hypothesis – the coefficients for *Stock Price* and several of Harris' proxies for investor uncertainty are statistically significant, with the predicted sign. For the sample of early buy limit orders (Regression two, Panel A), the coefficient for *CEF* is significantly negative; however, coefficients for the remaining independent variables are not significantly different from zero.

Overall, these regression results are consistent with our adaptation of Harris' negotiation hypothesis. Investors are more likely to submit even-eighth limit orders when stock prices are high and when there is

greater uncertainty about stock values. The weakest set of regression results are found for the subsample of early buy limit orders. It is interesting to note that this particular subsample of limit orders has relatively low execution rates: 30.8 percent and 36.7 percent for even- and odd-eighth limit orders respectively. Apparently, for our sample, these limit orders were submitted far from the market, possibly affecting investor motivations and the results of our regressions.

3.7. *The relation between limit order prices and quote prices*

The relation between the observed preference among investors for even-eighth limit prices and quote prices is explored in two ways. First, we examine the frequency of limit orders placed inside the quotes. Second, we examine quoted depth to determine the relative contribution of limit order investors and floor traders / specialists to the setting of quote prices at even and odd quotes.

Investors submitting limit orders inside the quotes reduce the quoted spread and thereby reduce transactions costs for investors submitting market orders and other impatient traders. If investors prefer rounded numbers, they may be more likely to submit quote improving limit orders if the limit price is at a rounded number. Consistent with this hypothesis, and as already seen in Table 5, the frequency of limit orders placed one-eighth inside of the quotes is highest when the current quote is at the odd-eighth. Table 10, Panel A, gives more detailed information about quote improving limit orders. In this panel, the frequency of buy limit orders submitted at and inside the bid quote and sell orders submitted at and inside of the ask quote are presented for eight subsamples – quotes ending with \$0/ 8, \$1 / 8, … , \$7/ 8.

The results show that investors are most likely to place a buy (sell) limit order at the quote when the bid (ask) quote is at the dollar. Limit orders submitted inside the quotes follow a similar pattern. That is, the highest percentage of limit orders submitted one-eighth inside (i.e., above) the bid price is when the bid quote is at the \$7/8. The most frequent sell limit order submitted one-eight inside (i.e., below) the ask quote is when the ask quote is at the \$1/8. In both instances, the resulting limit order is at the whole dollar. In the same way, buy limit orders are submitted most frequently two-eighths inside the bid quote when the quote is at the \$6/8 and sell limit are submitted most frequently two-eighths inside the ask quote when the quote is at the \$2/8. Again, both result in whole dollar limit prices. Some of the differences in frequencies are quite dramatic. For instance, the frequency of sell limit orders submitted two-eighths inside the ask when the quote

is at the $2/8 is more than four times greater than the frequency when the quote is at the $1/8.[15]

Overall, it appears that investors' selection of quote improving limit orders is strongly influenced by whether the limit price will be at a rounded or non-rounded number. This has important implications for spread-related transactions costs for impatient investors. For instance, if the ask quote is currently $25 1/8, the likelihood that the quote will be revised down by an eighth may be higher than if the quote is $25. Similarly, the probability the quote will be revised down two-eighths may be more likely if the quote is $25 1/4 than $25 1/8.

We next examine quoted depth at even- and odd-eighth quotes. We use the technique developed by Chung, Van Ness, and Van Ness (1999) to decompose the depth for each quote into the portion from limit orders and the portion from the "floor" (i.e., quoted depth provided the specialist and floor brokers).[16] A greater frequency of even limit orders should result in greater quoted depth provided by limit order investors at even quote prices. Our null hypothesis is that the floor's portion of the quoted depth is unaffected by whether the quote price is even or odd.

To facilitate a comparison of quoted depths across different firms, we compute a *normalized bid depth* equal to the bid depth for a particular quote on a stock divided by the average bid depth across all NYSE bid quotes for that stock. (There are 320,375 quotes in our sample.) We next compute a *normalized limit order bid depth* and *normalized floor bid depth*. Similar to the calculations above, the *normalized limit order bid depth* for a particular bid quote on a stock is equal to the limit order depth for that bid quote divided by the average limit order bid depth across all NYSE bid quotes for that stock. Likewise, *normalized floor bid depth* is calculated as floor depth for the bid quote divided by the average floor bid depth for the stock. Normalized depth from the ask side of the quote is computed in a similar manner.

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[15] At first glance, it might appear that the submission of a limit order $2/8 inside the quote is irrational since submitting $1/8 inside the quote gives the investor top priority for execution. However, even if first in line for execution, the investor still has to attract someone willing to take the other side of the trade. Thus, some investors might rationally prefer to submit at a whole dollar limit price that is $2/8 inside the spread rather than one that is set at an odd price.

[16] The Chung, Van Ness, and Van Ness (1999) algorithm identifies the total number of shares offer for sale (or purchase) at the current ask (or bid) quote from investors that submit electronic limit orders. Next, the algorithm compares the number of limit shares to the quoted depth. The difference between the two numbers is assumed to represent the floor's participation in the quote. For example, if the quoted ask depth is 5,000 shares at $25 and there are a total of 3,000 shares offered for sale at that price by limit order investors, then the floor's participation at the ask is assumed to be 2,000 shares.

Results from the analysis of the normalized depth are provided in Table 10, Panel B. As shown, the mean normalized bid depth is 108.1 percent when the bid is even (i.e., 8.1 percent above the average bid depth) and 91.0 percent when the bid is odd (9.0 percent below the average bid depth). This indicates a significantly higher depth when the bid quote is even. As expected based on the prior results, the mean normalized limit order bid depth for even bid quotes is higher than for odd bid quotes. For even bid quotes, the normalized limit order depth is 107.8 percent; this ratio is only 91.3 percent for odd bids. Normalized floor depth is also highest when the quote is even: 108.2 percent versus 90.8 percent for even and odd bids respectively. (All means are statistically different from each other at the 5 percent level.) The analysis of quoted depth for ask quotes yields similar percentages. In summary, both limit order depth and floor depth is highest for even-eighth quotes. Although only suggestive, it appears that specialists / floor brokers prefer rounded prices.[17]

3.8. *Limitations*

Although our sample includes a large number of limit orders and quotes, these observations are drawn from only 108 stocks over a three-month period of time. Also, our sample only includes electronically placed limit orders. Analysis of a different sample of stocks, a different time period, or of limit orders that were not electronically submitted may produce different results.

4. Summary and Concluding Remarks

Many research articles have investigated the clustering of stock prices and quotes – mainly focusing on the quote setting behavior of market makers and specialists. We extend this line of research by studying individual and institutional investors and their preferences for even- versus odd-eighth limit prices on 108 NYSE stocks for the period November 1990 to January 1991. For our sample firms, 61.5 percent of limit order prices are set at the even-eighth. However, a detailed investigation of the sample of limit orders points to a much stronger preference by investors for even-eighth prices.

One piece of evidence showing investors' preferences for even prices is seen with their pricing of limit

[17] The Chung, Van Ness, and Van Ness (1999) algorithm does not differentiate between the portion of the depth provided by the specialist and the portion from floor brokers. If specialists and floor traders have similar motivations for providing liquidity to the market, then our conclusion should apply to both groups. However, if specialist and floor traders are motivated differently, then the empirical results should reflect the group that dominates our sample.

orders placed before the NYSE specialist has posted the first quotes of the day. Since investors cannot refer to the quote when setting these limit prices, early limit orders may present the clearest picture of investor preferences for even versus odd prices. Here, 69.2 percent of buy limit orders and 70.3 percent of sell limit orders are set at the even-eighth (75.4 percent and 77.2 percent, respectively, for individuals).

We analyze limit orders placed within one-eight of the quote and document that investors are more likely to place their limit orders at the quote when the quote is even than when it is odd. Individual investors have the greatest difference between the percentage of limit orders set at an even quote price versus an odd quote price. Results from an analysis of limit orders placed more the one-eighth from the quote further support the assertion that investors prefer even-eighth prices. For instance, for limit orders placed more than one eighth outside the quote, 80.1 percent of buy limit orders and 79.2 of sell limit orders (83.9 percent and 83.8 percent, respectively, for individual investors) are set at the even-eighth.

We provided evidence that execution rates for limit orders placed close to the quote are highest for those submitted with even-eighth prices. Apparently, for these limit orders (which represent the majority of our sample) there is a sufficient increase in participation by other market participants to absorb the increased supply of stock provided by limit order investors at even prices. For limit orders placed further from the quotes, or for limit orders submitted prior to the posting of the day's first quotes, execution rates are highest for odd-eighth limit orders.

If investors use even limit prices to attract market participants willing to take the other side of the trade, then the extent of their use should decrease with low stock prices and low investor uncertainty. (Low stock prices increase the percentage difference between even and odd limit prices. With low investor uncertainty about stock values, buyers and sellers are less likely to meet at a rounded limit price, thereby necessitating the need for a more precisely set limit price.) Consistent with this hypothesis, we find that the percentage of even-eighth limit orders is a positive function of stock price and various proxies for investor uncertainty.

We conclude our empirical tests by examining the relation between investor preferences for even prices and stock quotes. We find that the probability that an investor will submit a quote improving limit order increases if the resulting limit price is an even number. This implies that bid (ask) quote prices are more likely increase (decrease) if the quote is at an odd price than at an even price. Our examination of quoted depth

shows that the portion of quoted depth from limit order investors is highest when the quote is even. Similarly, we observe that the portion of the quoted depth from floor brokers and the specialist is also highest when the quote is even. This suggests that all market participants prefer to transact at even price.

Our results provide a useful benchmark for other studies of price and quote clustering which analyze the period prior to the switch to smaller tick sizes (i.e., sixteenths and decimal pricing). Using figures derived from limit orders placed before the posting of the day's first quotes, roughly 70 percent of prices can be expected at the even-eighth in a free and competitive stock market. Since quotes continue to cluster on even prices following the reduction in tick size from eighths to sixteenths to decimal pricing [Bessembinder (1999), Chung, Van Ness, and Van Ness (2001)], we speculate that investor preferences for even numbers continue to provide an explanation for the disproportionately high percentage of even quotes. However, it is worth noting that the percentage of even quotes for our sample firms is only 52.7 percent. Since NYSE quotes often come from the trading interests of limit order investors [Chung, Van Ness, and Van Ness (1999) and Kavajecz (1999)], the high percentage of even-eighth limit orders should result in a comparably high percentage of even-eighth quotes. Further research is needed to determine how limit order investor and market markers pricing preferences influence quote prices.

Our study does not directly address the Nasdaq market makers lawsuit. However, this study does shed light on a perplexing question raised by Christie and Schultz (1994). If Nasdaq dealers colluded with each other to keep spreads at a minimum of 25 cents, why did they decide to use even-eighth prices instead of odd-eighth prices to achieve this goal? Christie and Schultz answer this question from the dealers' point of view. Referring to a book on game theory by Fudenberg and Tirole (1993), they say, "In situations where agents collude, round numbers can be used as 'focal points' to coordinate prices (page 1834)." Our study adds weight to this argument by showing that an agreement by Nasdaq dealers to quote on the even-eighth would naturally fit with investor preferences and therefore meet with less resistance than quoting on the odd-eighth.

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Table 1
Sample Selection

Description of the selection criteria for the sample of limit orders. Limit orders are obtained from the SOD file in the NYSE's TORQ database. This database covers 144 NYSE firms over a three-month period from November 1, 1990 to January 31, 1991. Limit orders to buy and sell common stock of the 144 firms are identified with a value of "1" or "9" for the SOD variable *OCOND* and "L" for the second character of variable *OCODE*. Limit orders with obvious data errors are eliminated from the sample, leaving 476,394 "good" limit orders on the SOD file (264,310 buy limit orders and 212,084 sell limit orders). The table details the number of limit orders eliminated because the firm's stock traded below $5 per share during our sample period, limit order prices that were not set on the eighth of a dollar, limit orders carried over from a previous day, and limit orders placed after 4 p.m.

	All limit orders	Buy limit orders	Sell limit orders
Number of "good" limit orders for the 144 firms in the SOD file	476,394	264,310	212,084
Eliminate 36 firms with stock that trades below $5 per share	-48,444	-29,317	-19,127
Eliminate limit orders with prices that are not in eighths	-12	-10	-2
Eliminate limit orders carried over from a previous day	-61,570	-37,370	-24,200
Eliminate any limit orders placed after 4 p.m.	-276	-103	-173
Final sample	366,092	197,510	168,582
Limit orders placed prior to the first quote	51,468	28,664	22,804
Limit orders placed after the first quote	314,624	168,846	145,778

Table 2
Descriptive Statistics for the Sample of Stocks

Descriptive statistics for *stock price* (Panel A) and *equity capitalization* (Panel B) for all 144 firms in the TORQ database and for the 108 firms in our sample. *Stock price* is the closing stock price on October 31, 1990. *Equity capitalization* is equal to the closing stock price on October 31, 1990 times shares outstanding on that date. Stock price and shares outstanding are collected from the *Center for Research in Securities Prices (CRSP)* database.

	All TORQ Firms (N = 144)	Sample Firms (N = 108)
Panel A: Mean stock price		
Maximum	$135.75	$135.75
Median	14.69	18.81
Minimum	0.05	6.00
Mean	18.59	23.96
Panel B: Equity capitalization (in millions of dollars)		
Maximum	$61,106.38	$61,106.38
Median	238.67	397.91
Minimum	0.23	1.81
Mean	2,608.95	3,465.83

Table 3
Descriptive Statistics for the Sample of Limit Orders by Investor Type

Total number of limit orders, mean shares per limit order, and mean dollar value per limit order in thousands of dollars (limit price times the number of shares in the limit order divided by 1000) for 51,468 limit orders placed before the posting of the day's first quote by the NYSE specialist (Panel A) and 314,624 limit orders placed after the posting of the first quote, but before the close of the market (Panel B). Limit orders to buy and sell common stock of the 108 firms were placed over a sample period of November 1, 1990 to January 31, 1991. Statistics are provided for four subsamples:

1) *Proprietary* - Limit orders placed by NYSE member firms for their own account
2) *Agency* - Limit orders placed by NYSE member firms for the account of another party
3) *Individual* - Limit orders placed by individual investors
4) *Unidentified* - Limit orders for which the SOD file does not identify the investor

	Proprietary	Agency	Individual	Unidentified
Panel A: Limit orders placed before the posting of the first quote				
Number of limit orders	3,386	16,248	15,946	15,888
Mean shares per limit order	1,893	1,615	677	5,491
Mean dollar value per limit order (000's of dollars)	$71.02	$63.31	$20.56	$202.43
Number of buy limit orders	1,894	9,468	9,367	7,935
Mean shares per buy limit order	1,959	1,475	636	5,608
Mean dollar value per buy limit order (000's of dollars)	$73.73	$59.53	$17.93	$211.14
Number of sell limit orders	1,492	6,780	6,579	7,953
Mean shares per sell limit order	1,809	1,574	737	5,375
Mean dollar value per sell limit order (000's of dollars)	$67.59	$68.58	$24.30	$193.74
Panel B: Limit orders placed after the posting of the first quote				
Number of limit orders	43,931	106,951	113,580	50,162
Mean shares per limit order	1,523	1,414	688	5,449
Mean dollar value per limit order (000's of dollars)	$69.98	$57.51	$21.02	$189.75
Number of buy limit orders	23,399	59,083	62,729	23,635
Mean shares per buy limit order	1,624	1,407	635	5,440
Mean dollar value per buy limit order (000's of dollars)	$73.22	$55.50	$18.02	$183.29
Number of sell limit orders	20,532	47,868	50,851	26,527
Mean shares per sell limit order	1,407	1,423	754	5,457
Mean dollar value per sell limit order (000's of dollars)	$66.29	$30.00	$24.73	$195.50

Table 4
Analysis of Limit Orders Placed Before the Posting of the First Quote

Panel A: The number of limit orders with whole-dollar, half-dollar, quarter-dollar, and odd-eighth limit prices for the 51,468 limit orders placed before the posting of the day's first quote by the NYSE specialist. The Z-statistic is for the null hypothesis that the percentages of even-eighth limit orders equals 50 percent. Panel B: The mean dollar value of the 51,468 limit orders in thousands of dollars (limit price times the number of shares in the limit order divided by 1000). Ratio is equal to the mean dollar value for even-eighth limit orders divided by the mean dollar value for odd-eighth limit orders. The *t*-statistic is for a null hypothesis of equal means for even-eighth and odd-eighth limit orders. Significance at the 5 percent level is indicated with a *.

	All limit orders	Buy limit orders	Sell limit orders
Panel A: Number of limit orders			
\$0 / 8	15,242 (29.6%)	8,383 (29.2%)	6,859 (30.1%)
\$4 / 8	8,653 (16.8%)	4,886 (17.0%)	3,767 (16.5%)
\$2 / 8 or \$6 / 8	11,965 (23.2%)	6,567 (22.9%)	5,398 (23.7%)
\$1/8, \$3/8, \$5/8, or \$7/8	15,608 (30.3%)	8,828 (20.8%)	6,780 (29.7%)
Total Observations	51,468	28,664	22,804
Percent even-eighth	69.67%	69.20%	70.27%
Z-statistic	89.27*	65.02*	61.21*
Panel B: Mean dollar value of limit orders (000's of dollars)			
\$0 / 8	\$95.73	\$93.63	\$98.29
\$4 / 8	92.04	86.33	99.44
\$2 / 8 or \$6 / 8	96.43	93.17	100.40
\$1/8, \$3/8, \$5/8, or \$7/8	89.94	82.47	99.68
Combined Sample	93.52	88.84	99.39
Even-eighth sample	95.07	91.68	99.27
Ratio	1.06	1.11	1.00
t-statistic	2.33*	2.93*	-0.13

Table 5
Frequency Distribution of Limit Orders Placed After the Posting of the First Quote

The distribution of the 314,624 limit orders placed after the posting of the first quote, but before the close of the market. The distribution is calculated by comparing the limit price to the time-matched quote. Buy limit order prices are compared to the bid price (Panel A) and sell limit order prices are compared to the ask price (Panel B). The first column of numbers gives information for all limit orders. The sample is then split in the second and third columns based on whether the current quote is at the even-eighth or odd-eighth. The fourth column gives the percentage of even-eighth limit orders. If the quote is even, even-eighth limit orders are in $0.25 increments above and below the quote. If the quote is odd, odd-eighth limit orders are in $0.25 increments above and below the quote. The last column reports the Z-statistic for the null hypothesis that the percent even equals 52.68 percent for buy limit orders and 52.74 percent for sell limit orders. (In our sample, 52.68 percent of bid prices and 52.74 percent of ask prices are at the even-eighth.) Significance at the 5 percent level is indicated with a *. Limit orders to buy and sell common stock of the 108 sample firms were placed over the period November 1, 1990 to January 31, 1991.

Limit price	All buy limit orders	Even bid	Odd bid	Percent even	*Z*-statistic
Panel A: Number of buy limit orders					
$6/8 + $2N/8 above bid (N = 0,?)	467	365	102	78.16%	11.03*
$5/8+ $2N/8 above bid (N = 0,?)	515	178	337	65.44	5.80*
$4/8 above bid	739	569	170	77.00	13.24*
$3/8 above bid	1,921	846	1,075	55.96	2.88*
$2/8 above bid	10,533	6,564	3,969	62.32	19.81*
Total buy limit orders inside the bid	14,175	8,522	5,653	NA	NA
$1/8 above bid	51,841	24,797	27,044	52.17	(2.34)*
At current bid	60,569	33,147	27,422	54.73	10.09*
$1/8 below bid	13,765	5,560	8,205	59.61	16.28*
Total buy limit orders within $1/8 of the bid	126,175	63,504	62,671	NA	NA
$2/8 below bid	5,920	4,189	1,731	70.76	27.86*
$3/8 below bid	3,222	872	2,350	72.94	23.03*
$4/8 below bid	2,330	1,809	521	77.64	24.13*
$5/8 below bid	1,464	321	1,143	78.07	19.46*
$6/8 below bid	1,274	1,041	233	81.71	20.75*
$7/8 below bid	1,035	216	819	79.13	17.04*
$8/8 below bid	918	749	169	81.59	17.54*
$9/8 + $2N/8 below bid (N = 0,?)	6,326	877	5,449	86.14	53.30*
$10/8 + $2N/8 below bid (N = 0,?)	6,007	5,264	743	87.63	54.26*
Total buy limit orders outside the bid	28,496	15,338	13,158	NA	NA
Total buy limit orders	168,846	87,364	81,482	NA	NA

Limit price	All sell limit orders	Even ask	Odd ask	Percent even	*Z*-statistic
Panel B: Number of sell limit orders					
$6/8 + $2N/8 below ask (N = 0,?)	673	563	110	83.66%	16.06*
$5/8+ $2N/8 below ask (N = 0,?)	613	151	462	75.37	11.22*
$4/8 below ask	483	422	61	87.37	15.24*
$3/8 below ask	1,205	394	811	67.30	10.13*
$2/8 below ask	7,105	4,966	2,139	69.89	28.96*
Total sell limit orders inside the ask	10,079	6,496	3,583	NA	NA
$1/8 below ask	39,842	18,371	21,471	53.89	4.60*
At current ask	58,042	33,014	25,028	56.88	19.98*
$1/8 above ask	14,507	5,504	9,003	62.06	22.48*
Total sell limit orders within $1/8 of the ask	112,391	56,889	55,502	NA	NA
$2/8 above ask	6,385	4,749	1,636	74.38	34.63*
$3/8 above ask	3,355	920	2,435	72.58	23.02*
$4/8 above ask	2,416	1,925	491	79.68	26.52*
$5/8 above ask	1,632	336	1,296	79.41	21.58*
$6/8 above ask	1,233	1,029	204	83.45	21.60*
$7/8 above ask	991	216	775	78.20	16.06*
$8/8 above ask	870	723	147	83.10	17.94*
$9/8 + $2N/8 above ask (N = 0,?)	3,298	511	2,787	84.51	36.54*
$10/8 + $2N/8 above ask (N = 0,?)	3,128	2,744	384	87.72	39.19*
Total sell limit orders outside the ask	23,308	13,153	10,155	NA	NA
Total sell limit orders	145,778	76,538	69,240	NA	NA

Table 6
Average Dollar Value of Limit Orders Placed After the Posting of the First Quote

The mean dollar value in thousands of dollars (limit price times the number of shares in the limit order divided by 1000) of the 314,624 limit orders placed after the posting of the first quote, but before the close of the market. Means are calculated after subsamples are formed based on the comparison of the limit order price to the time-matched quote. Buy limit order prices are compared to the bid price (Panel A) and sell limit order prices are compared to the ask price (Panel B). The first column of numbers gives information for all limit orders. The sample is then split in the second and third columns based on whether the current quote is at the even-eighth or odd-eighth. The fourth column gives a ratio equal to the mean for even-eighth limit orders divided by the mean for odd-eighth limit orders. If the quote is even, even-eighth limit orders are in $0.25 increments above and below the quote. If the quote is odd, odd-eighth limit orders are in $0.25 increments above and below the quote. The last column reports the *t*-statistic for the null hypothesis of equal means for columns two and three. Significance at the 5 percent level is indicated with a *. Limit orders to buy and sell common stock of the 108 sample firms were placed over the period November 1, 1990 to January 31, 1991.

Limit price	All buy limit orders	Even bid	Odd bid	Ratio	*t*-statistic
Panel A: Mean dollar value of buy limit orders (in 000's of dollars)					
$6/8 + $2N/8 above bid (N = 0,?)	$104.38	$109.52	$86.00	1.2735	1.03
$5/8+ $2N/8 above bid (N = 0,?)	71.41	60.84	77.00	1.2655	1.12
$4/8 above bid	54.32	54.95	52.22	1.0524	0.34
$3/8 above bid	49.34	42.90	54.41	1.2682	2.68*
$2/8 above bid	46.56	46.96	45.90	1.0231	0.47
Mean for buy limit orders inside the bid	50.15	50.06	50.29	NA	NA
$1/8 above bid	49.12	48.86	49.35	1.0099	0.44
At current bid	68.52	67.49	69.78	0.9672	-2.23*
$1/8 below bid	96.73	97.33	96.32	0.9897	-0.29
Mean for buy limit orders within $1/8 of the bid	63.63	62.83	64.44	NA	NA
$2/8 below bid	104.40	107.74	96.32	1.1186	1.82
$3/8 below bid	81.91	90.52	78.71	0.8696	-1.70
$4/8 below bid	73.77	72.41	78.50	0.9224	-0.76
$5/8 below bid	73.13	79.86	71.25	0.8922	-0.84
$6/8 below bid	71.97	69.14	84.63	0.8170	-1.11
$7/8 below bid	58.69	84.60	51.86	0.6129	-1.94
$8/8 below bid	53.56	52.98	56.13	0.9439	-0.22
$9/8 + $2N/8 below bid (N = 0,?)	28.02	32.40	27.31	0.8430	-1.63
$10/8 + $2N/8 below bid (N = 0,?)	29.26	28.56	34.26	0.8337	-1.17
Mean for buy limit orders outside the bid	60.20	64.91	54.72	NA	NA
Mean for all buy limit orders	61.92	61.95	61.89	NA	NA
Limit price	All sell limit orders	Even bid	Odd bid	Ratio	*t*-statistic
Panel B: Mean dollar value of sell limit orders (in 000's of dollars)					
$6/8 + $2N/8 below ask (N = 0,?)	$53.78	$56.63	$39.16	1.4463	1.72
$5/8+ $2N/8 below ask (N = 0,?)	32.59	43.90	28.90	0.6583	-1.58
$4/8 below ask	68.65	73.95	31.99	2.3117	2.97*
$3/8 below ask	38.06	44.44	34.96	0.7867	-1.66
$2/8 below ask	41.99	41.51	43.11	0.9628	-0.68
Mean for sell limit orders inside the ask	43.01	45.16	39.12	NA	NA
$1/8 below ask	49.14	49.71	48.65	0.9786	-1.09
At current ask	82.44	80.35	85.19	0.9432	-3.94*
$1/8 above ask	105.80	109.08	103.79	0.9515	-1.58
Mean for sell limit orders within $1/8 of the ask	73.65	73.24	74.07	NA	NA
$2/8 above ask	102.28	100.32	107.95	0.9293	-1.28
$3/8 above ask	93.81	94.69	93.48	0.9873	-0.15
$4/8 above ask	99.33	96.97	108.60	0.8929	-0.91
$5/8 above ask	90.19	104.52	86.48	0.8274	-1.05
$6/8 above ask	84.97	81.93	100.31	0.8168	-1.01
$7/8 above ask	69.72	81.53	66.42	0.8147	-1.19
$8/8 above ask	82.98	76.06	117.04	0.6499	-1.73
$9/8 + $2N/8 above ask (N = 0,?)	57.56	81.53	53.16	0.6520	-2.07*
$10/8 + $2N/8 above ask (N = 0,?)	55.92	52.43	80.91	0.6480	-2.40*
Mean for sell limit orders outside the ask	84.34	85.74	82.52	NA	NA
Mean for all sell limit orders	73.24	73.00	73.50	NA	NA

Table 7
Analysis by Investor Type of Limit Orders Placed within $1/8 of the Quote

The distribution of the 238,566 limit orders placed within one-eighth of the quote by investor type. The distribution is calculated by comparing the limit price to the time-matched quote. Evaluation is made of the percentage of limit orders placed at the quote as compared to those placed $0.125 on either side of the quote for each of four different investor types.

1) *Proprietary* - Limit orders placed by NYSE member firms for their own account
2) *Agency* - Limit orders placed by NYSE member firms for the account of another party
3) *Individual* - Limit orders placed by individual investors
4) *Unidentified* - Limit orders for which the SOD file does not identify the investor

Buy limit order prices are compared to the bid price (Panel A) and sell limit orders are compared to the ask price (Panel B). The first column of numbers gives information for all limit orders. The sample is then split in the second and third columns based on whether the current quote is at the even-eighth or odd-eighth. The Z-statistic is for the null hypothesis that the percent even equals the percentages listed in the first column (e.g., 53.84 percent for proprietary buy limit orders). Significance at the 5 percent level is indicated with a *. Limit orders to buy and sell common stock of the 108 sample firms were placed over the period November 1, 1990 to January 31, 1991.

Panel A: Buy limit orders	All buy limit orders	Even-eighth bid	Odd-eighth bid
Proprietary			
Number of buy limit orders within $1/8 of the bid	20859	10654	10205
Number of buy limit orders at the bid	11230	5830	5400
Percent at the bid	53.84%	54.72%	52.92%
Z-statistic	NA	1.83	-1.87
Agency			
Number of buy limit orders within $1/8 of the bid	46674	23565	23109
Number of buy limit orders at the bid	22120	11877	10243
Percent at the bid	47.39%	50.40%	44.32%
Z-statistic	NA	9.25*	-9.34*
Individual			
Number of buy limit orders within $1/8 of the bid	40111	19736	20375
Number of buy limit orders at the bid	15055	8714	6341
Percent at the bid	37.53%	44.15%	31.12%
Z-statistic	NA	19.21*	-18.90*
Unidentified			
Number of buy limit orders within $1/8 of the bid	18531	9549	8982
Number of buy limit orders at the bid	12164	6726	5438
Percent at the bid	65.64%	70.44%	60.54%
Z-statistic	NA	9.87*	-10.17*
Panel B: Sell limit orders	All sell limit orders	Even-eighth ask	Odd-eighth ask
Proprietary			
Number of sell limit orders within $1/8 of the ask	19038	9870	9168
Number of sell limit orders at the ask	11006	5832	5174
Percent at the ask	57.81%	59.09%	56.44%
Z-statistic	NA	2.57*	-2.67*
Agency			
Number of sell limit orders within $1/8 of the ask	38985	19841	19144
Number of sell limit orders at the ask	20068	11021	9047
Percent at the ask	51.48%	55.55%	47.26%
Z-statistic		11.47*	-11.68*
Individual			
Number of sell limit orders within $1/8 of the ask	32711	15940	16771
Number of sell limit orders at the ask	12204	7885	4319
Percent at the ask	37.31%	49.47%	25.75%
Z-statistic	NA	31.74*	-30.94*
Unidentified			
Number of sell limit orders within $1/8 of the ask	21657	11238	10419
Number of sell limit orders at the ask	14764	8276	6488
Percent at the ask	68.17%	73.64%	62.27%
Z-statistic	NA	12.45*	-12.93*

Table 8
Limit Order Execution Rates

An analysis of the execution of the 51,468 limit orders placed before the posting of the day's first quote and the 314,624 limit orders placed after the posting of the first quote, but before the close of the market. The sample of limit orders placed before the posting of the day's first quotes is split into two subsamples based on whether the limit order is to buy or sell stock. The sample of limit orders placed after the posting of the day's first quotes is split into ten subsamples based on a comparison of the limit price to the time-matched quote and whether the limit order is to buy or sell stock. Buy limit order prices are compared to the bid price (Panel A) and sell limit order prices are compared to the ask price (Panel B). The first column of numbers gives information for all limit orders. The sample is then split in the second and third columns based on whether the limit order was placed at the even- or odd-eighth. The figure in brackets is the number of limit orders that fully execute on the day that the limit order was placed. The percentage that fully execute is given in parenthesis. The last column reports the Z-statistic [in brackets] for the null hypothesis that the number of even-eighth limit orders that fully execute is equal to the number of odd-eighth limit orders that fully execute. The *Z*-statistic (in parentheses) is for the null hypothesis that the percentage of limit orders that fully execute is the same for even- and odd-eighth limit orders. Significance at the 5 percent level is indicated with a *. Limit orders to buy and sell common stock of the 108 sample firms were placed over the period November 1, 1990 to January 31, 1991.

Panel A: Buy limit orders	Total buy limit orders	Even-eighth buy limit orders	Odd-eighth buy limit orders	*Z*-statistics
Limit orders submitted before the posting of the first quote				
Number of buy limit orders	28,664	19,836	8,828	
[Number that fully execute]	[9,787]	[6,105]	[3,241]	[29.63*]
(Percentage that fully execute)	(34.1%)	(30.8%)	(36.7%)	(-9.75*)
Limit orders submitted after the posting of the first quote				
Number of buy limit orders more than $1/8 above the bid	14,175	8,910	5,265	
[Number that fully execute]	[10,570]	[6,642]	[3,928]	[26.40*]
(Percentage that fully execute)	(74.57%)	(74.55%)	(74.61%)	(-0.08)
Number of buy limit orders $1/8 above the bid	51,841	27,044	24,797	
[Number that fully execute]	[42,391]	[22,466]	[19,925]	[12.34*]
(Percentage that fully execute)	(81.77%)	(83.07%)	(80.35%)	(8.00*)
Number of buy limit orders at the bid	60,569	33,147	27,422	
[Number that fully execute]	[30,020]	[16,517]	[13,503]	[17.40*]
(Percentage that fully execute)	(49.56%)	(49.83%)	(49.24%)	(1.44)
Number of buy limit orders $1/8 below the bid	13,765	8,205	5,560	
[Number that fully execute]	[3,886]	[2,416]	[1,470]	[15.18*]
(Percentage that fully execute)	(28.23%)	(29.45%)	(26.44%)	(3.87*)
Number of buy limit orders more than $1/8 below the bid	28,496	22,813	5,683	
[Number that fully execute]	[2,176]	[1,599]	[577]	[21.91*]
(Percentage that fully execute)	(7.64%)	(7.01%)	(10.15%)	(-7.23*)
Total number of buy limit orders	168,846	100,119	68,727	
[Total number of buy limit orders that fully execute]	[89,043]	[49,640]	[39,403]	[34.31*]
(Total percentage of buy limit orders that fully execute)	(52.74%)	(49.58%)	(57.33%)	(-31.50*)

Table 8
Continued

Panel B: Sell limit orders submitted during the day	Total sell limit orders	Even-eighth sell limit orders	Odd-eighth sell limit orders	*Z*-statistics
Limit orders submitted before the posting of the first quote				
Number of buy limit orders	22,804	16,024	6,780	
[Number that fully execute]	[10,019]	[6,692]	[2,948]	[38.13*]
(Percentage that fully execute)	(43.9%)	(41.8%)	(43.5%)	(-2.40*)
Limit orders submitted after the posting of the first quote				
Number of sell limit orders more than $1/8 below the ask	10,079	7,224	2,855	
[Number that fully execute]	[8,448]	[5,990]	[2,458]	[38.43*]
(Percentage that fully execute)	(83.82%)	(82.92%)	(86.09%)	(-4.05*)
Number of sell limit orders $1/8 below the ask	39,842	21,471	18,371	
[Number that fully execute]	[33,663]	[18,406]	[15,257]	[17.16*]
(Percentage that fully execute)	(84.49%)	(85.72%)	(83.05%)	(7.32*)
Number of sell limit orders at the ask	58,042	33,014	25,028	
[Number that fully execute]	[31,816]	[18,314]	[13,502]	[26.98*]
(Percentage that fully execute)	(54.82%)	(55.47%)	(53.95%)	(3.66*)
Number of sell limit orders $1/8 above the ask	14,507	9,003	5,504	
[Number that fully execute]	[5,054]	[3,256]	[1,798]	[20.51*]
(Percentage that fully execute)	(34.84%)	(36.17%)	(32.67%)	(4.32*)
Number of sell limit orders more than $1/8 above the ask	23,308	18,463	4,845	
[Number that fully execute]	[3,518]	[2,710]	[808]	[32.07*]
(Percentage that fully execute)	(15.09%)	(14.68%)	(16.68%)	(-3.36*)
Total number of sell limit orders	145,778	89,175	56,603	
[Total number of sell limit orders that fully execute]	[82,499]	[48,676]	[33,823]	[51.71*]
(Total percentage of sell limit orders that fully execute)	(56.59%)	(54.58%)	(59.75%)	(-19.50*)

Table 9
Regressions

Results for cross-sectional OLS regressions of the difference in the percentage of even and odd limit orders on stock price and proxies for investor uncertainty. Variables are defined as follows:

Dependent variables

- *Percent difference early buy (sell) limit orders* = the proportion of early even-eighth buy (sell) limit orders minus the proportion of early odd-eighth buy (sell) limit orders (e.g., 0.70 – 0.30 = 0.40). Early limit orders are those limit orders placed before the posting of the day's first quote by the NYSE specialist.
- *Percent difference day buy (sell) limit orders* = the proportion of early even-eighth buy (sell) limit orders minus the proportion of early odd-eighth buy (sell) limit orders (e.g., 0.70 – 0.30 = 0.40). Day limit orders are those limit orders placed after the posting of the day's first quote by the NYSE specialist.

Independent variables

- *Stock price* = the average of the closing stock prices from November 1, 1990 to January 31, 1991.
- *Return volatility* = the standard deviation of daily stock returns calculated over the period from November 1, 1990 to January 31, 1991.
- *STD? P* = The standard deviation of the overlapping five-day stock price changes from October 25, 1990 (five trading days before November 1, 1990) to January 31, 1991.
- *LMV* = the natural log of the average market value of equity calculated at October 31, 1990 and January 31, 1991.
- *SqrtInvTrans* = one divided by the average number of daily NYSE transactions over the period from November 1, 1990 to January 31, 1991.
- *CEF Dummy* = 1 if the stock is a closed end fund and 0 otherwise.

Stock prices, returns, stock price changes, and the market values of equity are gathered from CRSP. Sias (1999) identifies the list of closed-end funds in the TORQ sample. The average daily number of transactions is gathered from TORQ. Panel A presents regression results for early limit orders and Panel B for day limit orders. There are 108 stocks in the sample. Regression coefficients are followed by *t*-statistics in parentheses. Significance at the 5 percent level is indicated with a *.

Table 9
Continued

	Panel A: Early Limit Orders			
	Percent difference early buy limit orders (Regression 1)	Percent difference early buy limit orders (Regression 2)	Percent difference early sell limit orders (Regression 3)	Percent difference early sell limit orders (Regression 4)
Intercept	0.1430	0.0201	0.0911	0.2036
	(1.993)*	(0.071)	(1.416)	(0.784)
Stock Price	0.0030	-0.0006	0.0056	0.0027
	(2.732)*	(-0.401)	(5.672)*	(2.019)*
Return volatility	5.4572		7.0639	
	(1.993)*		(2.876)*	
STD? P		0.0386		0.0487
		(1.549)		(2.124)*
LMV		0.0186		-0.0005
		(0.955)		(-0.029)
SqrtInvTrans		0.2749		0.3357
		(1.455)		(1.932)
CEF Dummy		-0.2517		-0.1854
		(-4.080)		(-3.267)
F-stat	4.386	6.155	16.626	10.283
(*p*-value)	(0.0148)	(0.0001)	(0.0001)	(0.0001)
Adj. R^2	5.95%	19.41%	22.60%	30.26%
Observations	108	108	108	108

Table 9
Continued

	Panel B: Day Limit Orders			
	Percent difference day buy limit orders (Regression 1)	Percent difference day buy limit orders (Regression 2)	Percent difference day sell limit orders (Regression 2)	Percent difference day sell limit orders (Regression 2)
Intercept	0.0689	0.0846	0.0939	-0.0038
	(1.492)	(0.609)	(1.901)	(-0.024)
Stock Price	0.0035	0.0034	0.0037	0.0031
	(5.003)*	(4.666)*	(4.975)*	(3.845)*
Return volatility	2.0714		2.7614	
	(1.175)		(1.465)	
STD? P		0.0105		0.0059
		(0.860)		(0.428)
LMV		-0.0073		0.0026
		(-0.757)		(0.248)
SqrtInvTrans		0.5512		0.6133
		(5.931)		(5.840)
CEF Dummy		-0.1257		-0.1532
		(-4.143)		(-4.469)
F-stat	12.655	31.739	12.399	26.078
(*p*-value)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Adj. R^2	17.89%	58.96%	17.56%	53.96%
Observations	108	108	108	108

Table 10
Limit Orders and Stock Quotes

Panel A gives the percentage of buy limit orders placed \$2/8 above, \$1/8 above, and at the bid quote and the percentage of sell limit orders placed \$2/8 below, \$1/8 below, and at the ask quote, for eight subsamples. The eight subsamples are based on whether the bid quote (for buy limit orders) or ask quote (for sell limit orders) is at the \$0/8, \$1/8, … , \$7/8. Percentages are calculated by dividing the number of observations in each cell by the corresponding number of observations for the row. The null hypothesis is that each cell has 12.5 percent of the number of observations for the row. Cells with percentages statistically different that 12.5 percent are indicated with a *.

Panel B shows mean normalized depth (column one) for even- versus odd-eighth quotes. Normalized depth for each of the 320,375 bid quotes is calculated as the depth for a particular quote divided by the average quoted depth across all bid quotes for a particular stock. Normalized depth for ask quotes is computed in a similar manner. Mean normalized limit order depth and specialist depth is provided in the second and third columns. Depths are normalized in a manner similar to that used for calculating the normalized bid (and ask) depth. However, instead of dividing by average bid (or ask) depth for the stock, we divide by the average limit order bid (or ask) depth for the stock when calculating normalized limit order depth and divide by the average specialist bid (or ask) depth for the stock when calculating normalized specialist depth. *T*-statistics test the null hypothesis that the normalized depth for an even quote equals the normalized depth for an odd quote. Significance at the 5 percent level is indicated with a *.

Panel A

	Percent of limit orders submitted when quote price ends with								
	\$0/8	\$1/8	\$2/8	\$3/8	\$4/8	\$5/8	\$6/8	\$7/8	Observations
Buy limit orders									
\$2/8 above bid	15.2%*	9.9%*	14.9%*	8.7%*	13.9%*	10.9%*	18.3%*	8.2%*	10,533
\$1/8 above bid	11.8%*	11.9%*	10.7%*	11.7%*	12.0%*	12.7%	13.4%*	15.7%*	51,841
At bid	15.5%*	11.4%*	12.3%	10.2%*	13.2%*	11.7%*	13.7%*	12.0%*	60,569
Sell limit orders									
\$2/8 below ask	14.4%*	5.5%*	24.6%*	8.7%*	14.4%*	7.5%*	16.4%*	8.5%*	7,105
\$1/8 below ask	11.7%*	16.1%*	11.5%*	12.0%*	11.2%*	12.9%*	11.7%*	12.9%*	39,842
At ask	17.5%*	9.9%*	12.8%*	11.3%*	13.6%*	10.5%*	13.0%*	11.5%*	58,042

Panel B

	Normalized depth	Normalized limit order depth	Normalized specialist depth	Observations
Bid Quotes				
Even bid quote	108.07%	107.85%	108.25%	168,776
Odd bid quote	91.02%	91.26%	90.82%	151,599
t-statistic	44.43*	35.09*	21.25*	320,375
Ask Quotes				
Even ask quote	110.57%	111.67%	110.04%	168,955
Odd ask quote	88.20%	86.97%	88.80%	151,420
t-statistic	56.11*	48.07*	28.31*	320,375

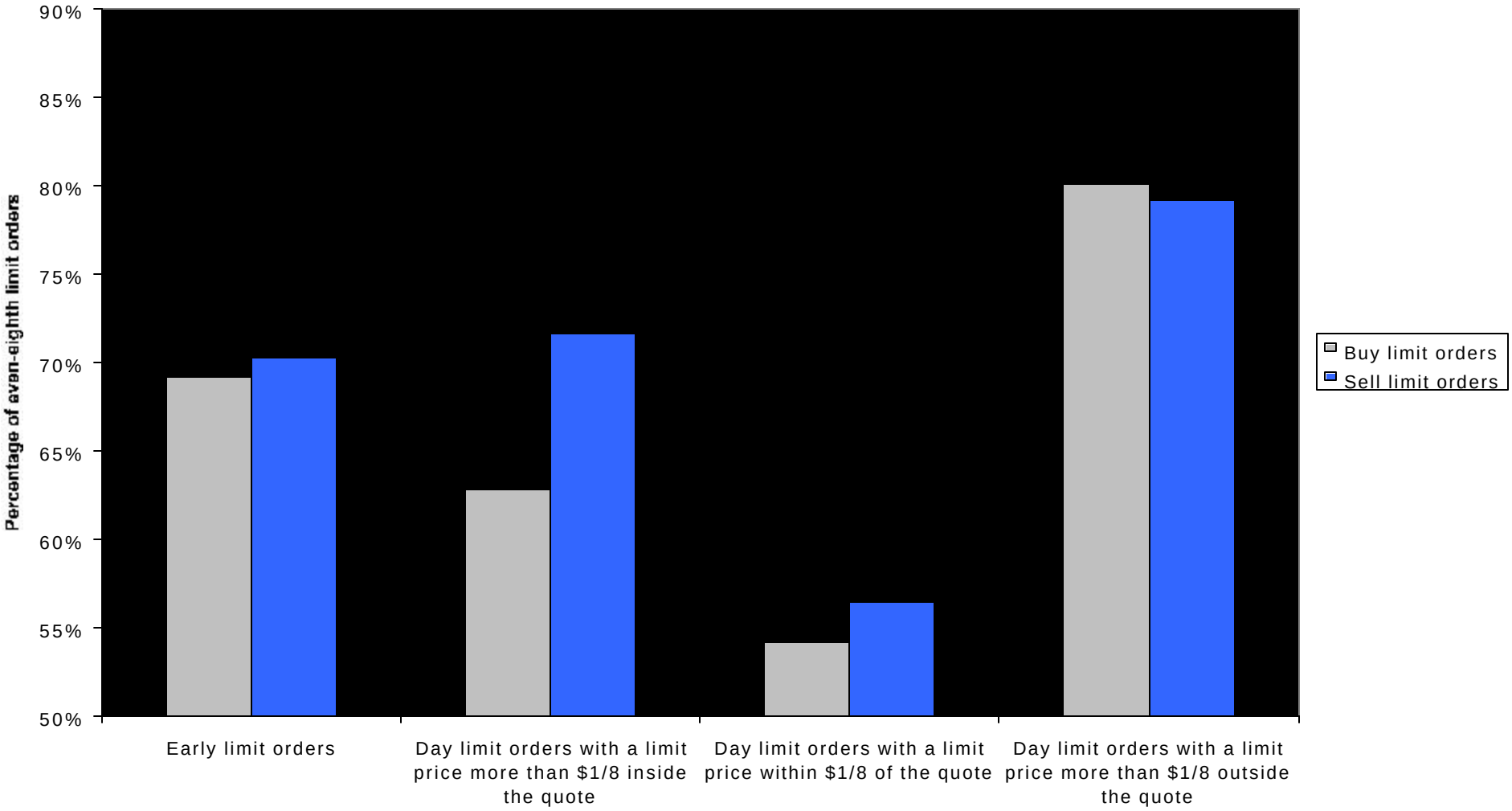

Figure 1. Percentage of limit orders placed at the even-eighth. The percentage of even-eighth limit orders for limit orders placed before the posting of the first quote of the day (Early limit orders) and limit orders placed after the posting of the first quote of the day, but before the close of the market (Day limit orders). Buy limit orders with limit prices inside (outside) the quote refer to limit prices set above (below) the bid price. Sell limit orders with limit prices inside (outside) the quote refer to limit prices set below (above) the ask price. The percentage of limit orders with even-eighth prices is calculated as the number of buy (sell) limit orders with even-eighth limit prices in that subsample divided by the total number of buy (sell) limit orders in that subsample.

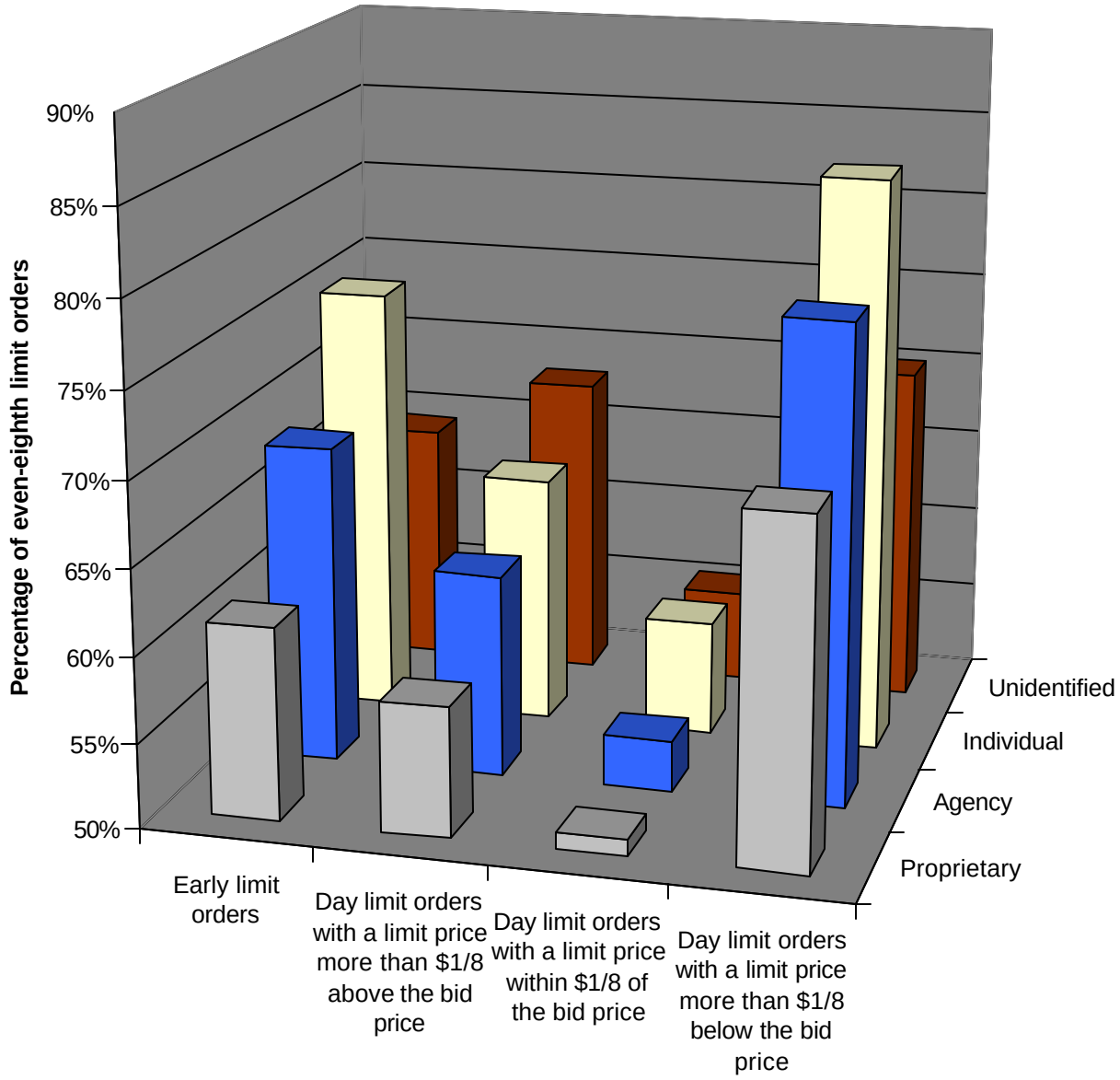

Figure 2A. Buy Limit Orders by Investor Type. The percentage of even-eighth buy limit orders for limit orders placed before the posting of the first quote of the day (Early limit orders) and limit orders placed after the posting of the first quote of the day, but before the close of the market (Day limit orders). The percentage of buy limit orders with even-eighth prices is calculated as the number of buy limit orders with even-eighth limit prices in that subsample divided by the total number of buy limit orders in that subsample.

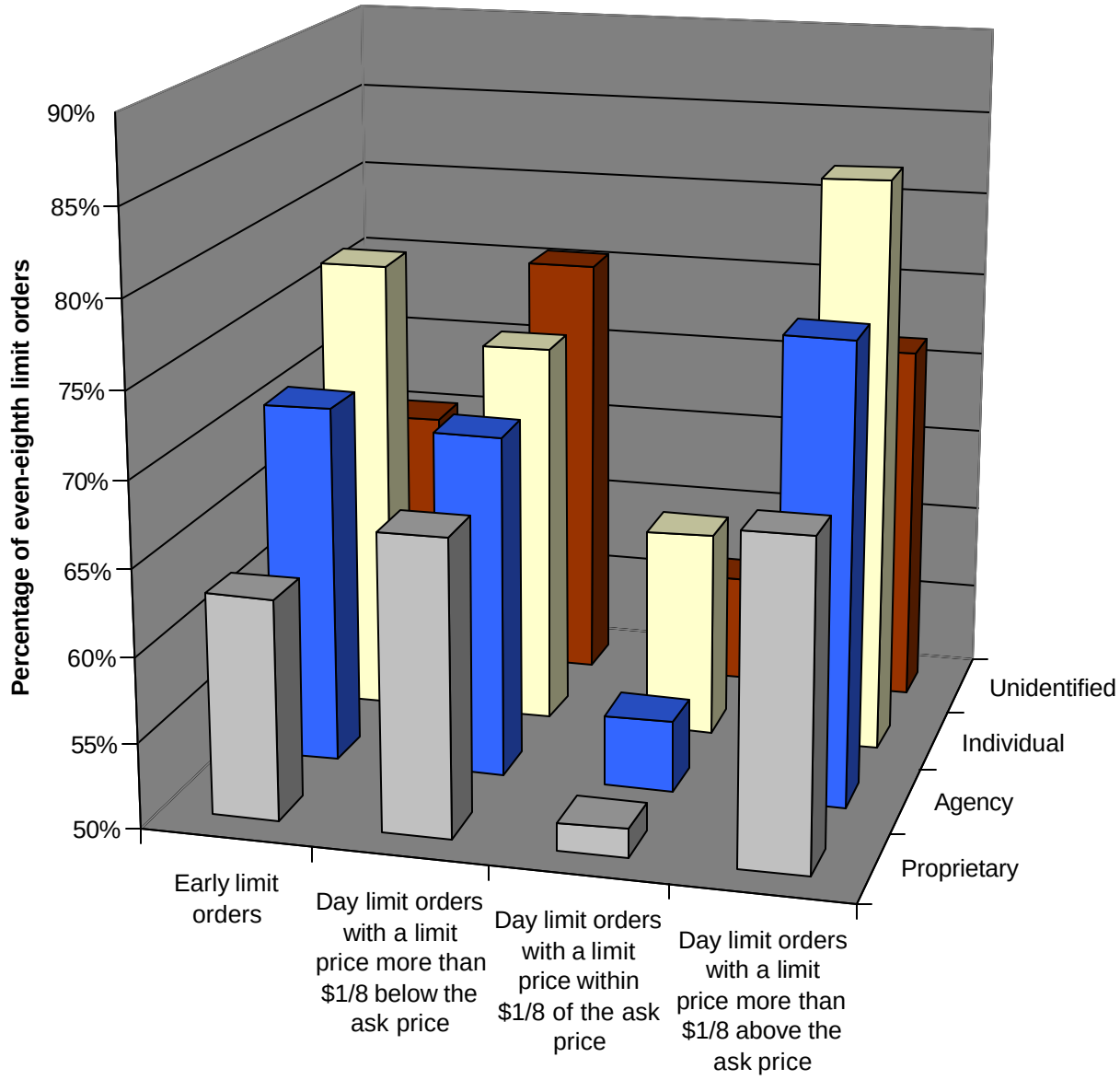

Figure 2B. Sell Limit Orders by Investor Type. The percentage of even-eighth sell limit orders for limit orders placed before the posting of the first quote of the day (Early limit orders) and limit orders placed after the posting of the first quote of the day, but before the close of the market (Day limit orders). The percentage of sell limit orders with even-eighth prices is calculated as the number of sell limit orders with even-eighth limit prices in that subsample divided by the total number of sell limit orders in that subsample.