Changes in Order Characteristics, Displayed Liquidity, and Execution Quality on the New York Stock Exchange around the Switch to Decimal Pricing

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New York Stock Exchange Working Paper 2001-02
November, 2001

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Draft 1.3

We thank Katharine Ross and Julie Fryer for providing help in data collection. The comments and opinions expressed in this paper are the author's and do not necessarily reflect those of the directors, members, or officers of the New York Stock Exchange, Inc. or Goldman Sachs & Co.

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Abstract

This paper examines the apparent effects of trading in penny price increments on traders' order-placement strategies, the display of trading interests, and the execution quality of market orders at the New York Stock Exchange (NYSE). Finance theory suggests that a smaller minimum price increment may make limit order traders more cautious. Although the ratio of marketable orders to limit orders changes little around the switch to penny trading, limit orders are smaller, more aggressively priced, and more frequently cancelled. The resulting NYSE inside quote changes more frequently, has a 30% narrower spread, and has 70% less depth. There appears to be more competition in setting the National Best Bid and Offer prices, but the NYSE is still the dominant player for the sample NYSE-listed securities. Examining NYSE trading interests away from the inside quote reveals a substantially thinner limit order book after decimals. The decrease in committed liquidity does not seem to adversely affect traditional measures of execution quality, however. Depth improvement rates and price improvement rates increase and the effective spread falls in the post-decimal sample periods relative to the pre-decimal base period numbers.

Introduction

The optimum minimum price variation for trading financial securities has been the topic of much recent debate. A small minimum variation (tick size) encourages price competition among liquidity suppliers, which can reduce the quoted spread and lower investors' trading costs. However, as noted by Harris (1997) and (1999), a small minimum price variation also makes it less expensive for traders to step in front of displayed liquidity. Suppose, for example, that a public limit order bidding $20.00 is the best (highest) bid on the book. When the minimum price variation was $1/16, anyone wishing to gain priority over that standing order must better the price by $0.0625 per share. After the introduction of the penny price increment, the second-mover need bid only $20.01 (either in the form of a limit order or a non-displayed, oral bid on the exchange floor). This penny-better bid prevents the initial bidder from interacting with opposite-sided order flow. Furthermore, should the individual bidding $20.01 decide that owing the stock is not a good idea after acquiring it, he or she can sell into the original $20.00

bid, losing only $0.01 per share. If liquidity suppliers are "disadvantaged" frequently enough by penny-better bids and offers, then they might choose to not display their trading interests. This decrease in displayed liquidity, in turn, potentially reduces market quality.[1]

This paper provides descriptive statistics on characteristics of NYSE system orders, the quoting behavior of the national market system participants, the submission of limit orders with prices away from the inside quote on the NYSE, and the execution quality of NYSE market orders for a sample of NYSE-listed securities during sample periods before and after the reduction in the tick size from $1/16 to $0.01. Although the mix of marketable and limited orders remains approximately the same, we find that average limit order size decreases twice as much in percentage terms as does average market order size. Furthermore, the limit order cancellation rate increases by ten percentage points. This suggests that committed liquidity might be adversely affected by decimals. On the positive side, limit orders are more aggressively priced relative to contemporaneous quoted prices post-decimals, implying a narrower bid-ask spread. Examining inside NYSE quotes, we find that the bid-ask spread is 30% narrower and quoted size is 70% less post-decimals than the pre-decimal period. We also document a 10% increase in NYSE quote traffic when comparing the last post-decimal sample period to the pre-decimal period. Examining the national market system quotes for the sample stocks, we find that non-NYSE markets appear to offer increased competition in setting the best quotes in the post-decimal era (e.g., they quote more frequently and are more often at either the National Best Bid or the National Best Offer), but that the NYSE's quote still plays the dominant

[1] Ahn, Cao, and Choe (1996), Bacidore (1997), Bollen and Whaley (1998), Goldstein and Kavajecz (2001), Porter and Weaver (1997), and Ronen and Weaver (1999) are examples of work that examines previous reductions in tick size. Chakravarty, Harris, and Wood (2000) document decimalization effects similar to ours on quotes and trades, but do not have access to order data.

role in setting the National Best Bid and/or Offer (NBBO).[2] Specifically, the average NYSE quote is one-fifth as wide and for 7.5 times as many shares as its average competitor, and at both sides of the NBBO over 90% of the time. In addition to finding less depth at the inside quote, we document that there is considerably less depth throughout the limit order book. At prices more than a few cents away from the contemporaneous quote, there are one-half the number of shares in the limit order book after decimals relative to before. Despite less committed liquidity, traditional execution-quality measures find that system market orders enjoy better executions in the decimal environment than in the fractional environment. Depth improvement rates (the fraction of the shares in orders with sizes exceeding contemporaneous quoted sizes that receive the quoted prices) increase slightly after decimals. Because the fraction of orders exceeding the quoted size doubles in the post-decimal sample period, this result suggests that depth improvement is much more common after the switch to decimal pricing than before. The price improvement rate increases considerably after the switch to decimals, although the dollar amount of price improvement per share falls. Effective spreads (the difference between actual buying and selling prices) fall by 34% for system orders, suggesting that the cost of obtaining liquidity for system orders decreases after decimalization. We observe lower post-decimal effective spreads even when focusing on the large system orders or, in a separate analysis, on the large trades. This suggests that even institutional-sized order/trades enjoy lower traditional-measured execution costs in the decimal environment. The improvement in execution quality in the face of less displayed liquidity, suggests that the NYSE is a source of considerable non-displayed liquidity.

[2] The NBBO is the highest bid price across all market centers quoting a particular security and the lowest offer price across the same market centers.

Data

Decimalization on the NYSE occurred in four stages. Seven stocks, traded by one specialist, converted to decimal pricing on August 28, 2000. An additional 57 securities followed on September 25, 2000. The final pilot involved 94 more securities that began trading in pennies on December 4, 2000. All remaining securities converted to decimals on January 29, 2001. We choose 148 securities from the final group to be decimalized as our sample. Fifty of these securities are the most actively traded (highest share volume in the month prior to decimalization) securities that are not part of the decimal pilot program. We also randomly select 25 securities from each of four volume/price groups. To select the 100-stock random sample, we rank all NYSE-listed securities on share trading volume and, separately, on average NYSE trade price during the month prior to January 29, 2001. Each security is placed in one of four categories after comparing its share price to the median NYSE share price and its trading volume to the median NYSE trading volume. These four groups (of unequal numbers of stocks) are a high-volume:high-price group, a high-volume:low-price group, a low-volume: high-price group, and, a low-volume:low-price group. Within each group, we arrange securities alphabetically (by symbol) and choose every Nth security, where N is chosen to select 25 securities from that group. Because two of the 50 stocks with the highest trading volume (AIG and MRK) also are randomly chosen as part of the high volume groups, our final sample has 148 securities. The sample securities are listed in Table 1.

[Insert Table 1.]

We study four one-week time periods. The first is the week before decimals, January 22-26, 2001. During this week, all of the sample securities trade in $0.0625 increments. The

second and third sample periods are the first and fourth weeks of decimal trading; January 29 through February 2 and February 20-26, respectively. Finally, we examine the last full week in April, April 23-27, a week approximately three months after decimal trading begins for these securities.

We use two data sources. The Consolidated Quotation file has information on markets' quotes. This includes the time of the quote, the quoted prices and associated sizes, and a condition code indicating whether the quote is firm. We use these data to calculate the NBBO and to evaluate changes in the competitiveness of the quoting environment around the switch to decimals. The System Order Database (SOD) and its companion quote file (SODQ) provide the additional data we need. SOD contains order and execution information. Order data include security, order type, a buy-sell indicator, time in force, order size, date and time, and limit price (if applicable). Execution data include the date and time of the trade, the execution price, the number of shares executing, and cancel information (if applicable). SODQ contains the NYSE quote and the best non-NYSE quote existing at the time of order receipt and at trade time.

Quoting Intensity

Penny price increments provide an opportunity for market makers and traders to improve (or match) existing quotes less expensively. Furthermore, the spreading of trading interests across roughly six times the number of price points suggests that there might be more "holes" in the limit order book that traders can fill. Together, these points imply that market makers might find themselves updating quotes more frequently post-decimals (either for their own trading interests or to reflect limit orders received from other traders). In Panel A of Table 2, we report the average number of NYSE quotes and the total number of quotes placed on the Consolidated

Quote file per stock per trading day during each sample period. For each quote update from any market center, we determine whether the new quote improves either side (or both sides) of the NBBO. We do not count a change in the NBBO quoted size without a change in at least one of the quoted prices as a quote change. The numbers of resulting *changes* in NBBO quoted prices are shown in Panel B. To compute the averages displayed in Table 2, each stock in the indicated sub-sample receives equal weighting.

[Insert Table 2.]

The overall per stock per day average number of NYSE quotes actually falls immediately after decimals while the total number of quotes across all markets increases. Interestingly, these results are very similar to Chakravarty, Harris, and Wood (2000), who find that the number of NYSE quotes decrease by about 15% while the total number of quotes increases by more than 13% for the 87 common stocks included in the NYSE's decimal pilot program. However, we find that there are 10.4% more NYSE quotes in the final sample period than before decimals. A steeper increase in quote traffic at the non-NYSE venues results in 27.5% more quotes in total during the last week in April than in the sample pre-decimal week. Because the non-NYSE markets increase their quoting intensity more than does the NYSE, the NYSE's share of quotes declines from 40% in the sample pre-decimal week to 34% post-decimals. The low-volume, low-price stocks have the largest percentage increase in quotes (76% for the NYSE and 85% total). The highest activity stocks, however, experience the largest absolute increase in quote traffic (1,666 more quotes per stock per day). With a 6.5 hour trading day, the numbers reported in Panel A of Table 2 suggest that the NYSE updates its quote in the sample stocks every 21.4 seconds before decimals and every 19.4 seconds during the last week in April. Likewise, the

average time between quote updates from somewhere on the national market system decreases from 8.5 seconds to 6.6 seconds. For an average stock in the Top 50 group, the NYSE updates its quote every 8.3 seconds and there is a quote update from some market center every 2.9 seconds in the final sample period.

In Panel B, we report the number of NBBO quote changes resulting from the quote updating activity documented in Panel A. The proportional increase in the number of NBBO quote changes exceeds the proportional increase in quote frequency. Overall, the average number of NBBOs per stock per day doubles while the number of quotes increases only by 27%. This is consistent with a more competitive quoting environment in the post-decimal time period. Quote updates more frequently result in changes in the NBBO after decimals than before. For example, overall, about one quote update in ten causes a change in the NBBO (= 280 NBBO quote changes divided by 2,761 total quote updates). In the last post-decimal sample period, this increased to about one in six (562/3,520).

Another measure of quoting competitiveness is the frequency with which the different market centers are part of the NBBO. Traditionally, the NYSE provides the NBBO quotes most of the time (e.g., see Blume and Goldstein [1992]). If decimals create an environment where the non-NYSE markets can better compete with the NYSE, then we anticipate that the non-NYSE markets would more frequently post quotes setting (or equaling) the NBBO prices. Consistently with this argument, Chakravarty, Harris, and Wood (2000) find that the NYSE's quote is the NBBO less frequently post-decimals than before. Table 3 details the fraction of the average trading day that the NYSE and the non-NYSE markets post quotes equal to the national best

quoted prices. The "Others" column represents an equally weighted average of the non-NYSE markets (i.e., the regional stock exchanges and the Nasdaq InterMarket).

[Insert Table 3.]

Initially after decimalization, there is some evidence that the non-NYSE markets more effectively compete with the NYSE in setting the national best quotes. Although the fraction of time the NYSE is on at least one side of the NBBO remains relatively unchanged, the fraction of time that the NYSE is at *both* sides of the NBBO (Panel B) falls from 93% to 82% overall.[3] This suggests that non-NYSE markets are alone more frequently on one side of the NBBO. This is true despite the fact that the non-NYSE markets average less absolute time at one side of the NBBO (tied and alone) after decimals than before. In none of the sample periods do the non-NYSE markets, on average, provide both sides of the NBBO a substantial amount of time. The "Other" markets most effectively compete with the NYSE in the high volume stocks. By the end of the sample period, the NYSE is on both sides of the NBBO about the same amount of time as before decimals (e.g., 91% of the time overall as compared to 93%).

Order Information

A fundamental conclusion of Harris (1997, 1999) is that a smaller tick size will decrease the attractiveness of displaying trading interests. Because traders can more cheaply gain priority over limit orders, traders will become more cautious in placing limit orders. Thus, we might observe a shift from limited to marketable orders around the time security prices convert to decimals. Marketable orders consist of market orders and marketable limit orders. Marketable limit orders are limit orders with limit prices such that these orders can execute immediately

[3] This finding is similar to Chakravarty, Harris, and Wood (2000), who find that the NYSE is at the NBBO 78% of the time after their sample of 87 decimal-pilot common stocks convert to decimal pricing. We do not impose any

given the contemporaneous quotes. That is, a buy (sell) marketable limit order is an order with a limit price greater (less) than or equal to the existing quoted offer (bid) price. Table 4 reports on the relative frequencies of market and marketable limit orders.

[Insert Table 4.]

Decimalization appears to have only a minimal effect on the mix of marketable and limited orders. Overall, there is a slight shift toward marketable orders, with both market orders and marketable limit orders comprising an additional one percentage point of the NYSE's order flow post-decimal compared to pre-decimal. The increase in the frequency of marketable orders is consistent throughout all of the sub-samples with the exception of the low-volume, high-price portfolio. For that group, marketable orders fell from 39% to 30% of all orders. Generally speaking, however, the move to decimal pricing appears to have only minimally affected the trader's choice of order type.

Order type is the most basic order characteristic traders can vary in response to a change in the tick size. Order size is another variable that investors control. If the priority of limit orders is weakened by decimals, then limit order traders might decrease the size of their orders. Limit order traders also can change the aggressiveness with which they price their orders and can more frequently cancel limit orders in order to remove the trading option it provides other traders. To measure the aggressiveness of limit orders, we calculate the distance between the limit price and the midpoint of the contemporaneous bid-ask spread.[4] For buy limit orders, we subtract the spread's midpoint from the limit price. For sell limit orders, we subtract the limit price from the spread's midpoint. That is, the distance is signed based on whether the limit order

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quoted size requirement to consider a venue's quoted prices to be part of the NBBO.

[4] The spread midpoint is one-half the sum of the bid price and the offer price.

is a buy or a sell order. An aggressive order has a small (potentially negative) distance measure. In Table 5, we report these descriptive statistics.

[Insert Table 5.]

Both average market order size and average limit order size decrease after decimals for all portfolios examined. Average market order size falls 15.7% overall, with the high-volume, high-price group experiencing the greatest percentage decline at 31%. Average limit order size experiences a steeper, 33.4%, decrease post-decimals. Thus, although traders do not reduce their use of limit orders substantively, they do appear to lessen their exposure to traders trying to take advantage of their willingness to display a trading interest by decreasing the size of their commitments to trade. It is interesting to note that, for the overall sample and most sub-samples, the decrease continues throughout the sample period, with the last sample period having the smallest order size. This suggests that traders might still have been adjusting their trading strategies as the sample period concludes.

In Panel B of Table 5, we examine two additional characteristics of limit orders. The aggressiveness statistic (distance from spread midpoint to limit price) suggests that limit order traders, overall, became more aggressive after decimals. Limit prices are closer to the contemporaneous spread midpoint with decimals than with fractions. Limit order traders seem to use the increased flexibility of decimals to compete more intensely on price. This evidence is consistent with the primary argument for decreasing the tick size. Interestingly, this increased aggressiveness does not seem to be manifested in the limit prices used by traders in the low-volume stocks (although there appears to be substantial variability in the statistic). Finally, we find that cancellation rates generally rise after decimals. Overall, the cancellation rate increases

from 43% to 53%. All sub-samples experience an increased cancellation rate in at least two of the three post-decimal weeks.

Finally, traders might choose to alter their trading strategies by routing orders to the floor of the Exchange using floor brokers instead of SuperDOT (the Exchange's electronic order routing system). With floor brokers, traders can choose to not display their trading interests. By not committing to trade, traders avoid giving others the option to trade against them. Although the Exchange did not capture orders routed to floor brokers, we can track the ratio of system-order *volume* to total volume. In Table 6, we report the ratio of system buy volume plus system sell volume to twice total volume.

[Insert Table 6.]

With the caveat that we use trading volume to proxy for orders, we find no evidence that traders change their order routing decision from SuperDOT to floor brokers between the pre- and post-decimal sample periods. Overall, 71.1% of the total volume is system volume before decimals. That falls to 69.0% in the first week of decimals, but rises over the latter two post-decimal sample periods. Although the absolute level of fraction of volume from system orders varies by group (high volume stocks have relatively less system volume), each group experiences a small increase in that fraction except for the low volume groups.

Quoted Spreads and Quoted Depths

How are the changes in order submission strategy we document above reflected in the liquidity supply? The primary justification of reducing the tick size to a penny was to lower the quoted spread, which might reduce investors' trading costs. The fact that limit orders are priced more aggressively post-decimals suggests that this objective might have been met. The facts that

average limit order size decreases relative to average market order size and that limit orders are more frequently cancelled after the reduction in tick size mitigates that advantage and might lead to less displayed liquidity as found by Goldstein and Kavajecz (2001) and others when the tick size was reduced from $1/8 to $1/16. In Table 7, we report the time-weighted spreads and sizes for the NYSE and an equally-weighted average of the non-NYSE markets.

[Insert Table 7.]

The NYSE's quoted spread falls in all of the sub-samples, with the overall sample spread decreasing 30% by the end of the sample period. The greatest percentage decrease in spreads is in the highest volume stocks, where the post-decimal spreads are 52% of their pre-decimal levels. Non-NYSE spreads also generally decrease, albeit by relatively small amounts. In both the pre- and post-decimal sample periods, the NYSE offers substantially tighter spreads than its competitors. This latter finding is consistent with the evidence in the previous section that the non-NYSE markets are seldom at both sides of the NBBO (see, e.g., Blume and Goldstein [1992]). Relative to its competitors, the NYSE's spreads are tighter post-decimals than before.

As in Goldstein and Kavajecz (2001), we find substantial decreases in the size associated with quoted prices around the switch to decimals. Overall, NYSE quoted size falls 70.5%. The greatest percentage decrease in NYSE quoted size occurs in the high-volume, low-price group, which has the largest pre-decimal size (presumably due to the low price). For high volume stocks, the quoted size falls throughout the sample periods, with the final sample period's size being the smallest. Non-NYSE average size falls by 26.9% overall. Again, the greatest

percentage decrease occurs in the high-volume, low-price stocks. NYSE quoted depth dwarfs the average non-NYSE quoted depth.[5]

In Table 8, we show the time-weighted NBBO quoted spreads and sizes.

[Insert Table 8.]

Not surprisingly given the results of the previous section, changes in the NBBO spread and size mirror changes in the NYSE quotes. Overall, the NBBO quoted spread falls by 30.7%, a decrease that is slightly greater than the NYSE's spread decrease. As with the NYSE spreads, the greatest percentage spread decrease, about 52%, occurs in the highest volume group. NBBO size falls 61.5%, compared to a 70.5% decrease in the NYSE's quoted size, suggesting that the non-NYSE markets are more likely to add to the NBBO's depth. Once again, the high-volume, low-price stocks seem to suffer the largest decrease in quoted size. The NBBO quoted size appears to have stabilized by the final sample period.[6]

Displayed Liquidity away from the Inside Quote - The Limit Order Book[7]

The preceding analysis demonstrates that the displayed liquidity at the best quoted price fell dramatically around the switch to decimal prices. Is this just a repositioning of liquidity among the new price points? Or does it represent a true decrease in displayed liquidity (presumably due to the lower cost with which traders can gain priority over a displayed trading interest)? To investigate this issue, we re-create the NYSE's limit order book during the trading days in each sample period. This allows us to compute the cumulative displayed liquidity at

[5] Given the quoted spreads in Panel A of Table 6 and the times at the NBBO in Table 3, we also should note that the "Others" markets' quoted depth is probably not at the same price as the NYSE's quoted depth.
[6] The changes in the NBBO quoted spread and depth are quite similar to Chakravarty, Harris, and Wood (2000).
[7] In this section, we use the term "displayed" liquidity advisedly. Obviously, limit orders away from the contemporaneous quote are not currently displayed off of the NYSE floor. They are, however, displayed to the trading crowd and can be relayed back to traders off of the floor by floor brokers.

each distance from the quoted price and determine the average cost of buying or selling a given number of shares if there is no non-displayed liquidity available on the NYSE.

To re-create the limit order book, we start with the LOFOPEN file, which the NYSE produces daily. This file captures all limit orders remaining open after the close of trading. These are unfilled, good-'til-cancelled limit orders (day limit orders automatically expire at the close of trading). The file contains the stock symbol, a buy-sell indicator, the limit price, and the order's unfilled shares. This enables us to produce the limit order book prior to any activity the following day. We use the next day's SOD file to track new limit order arrivals, limit order executions (full or partial), and limit order cancellation. This information is used to construct on-the-hour snapshots of the limit order book for each sample stock for each sample day (17,760 snapshots = 148 stocks × 6 snapshots per day × 20 days). To aggregate the books across stocks, we convert the absolute limit price to a distance from the midpoint of the snapshot-time NYSE bid-ask spread. To conserve space, we average the bid and offer sides of the book.[8] The cumulative displayed size is a non-decreasing step-function of the distance from the spread midpoint - as one moves further up the offer side (down the bid side) of the book the cumulative displayed depth at that price or lower (higher) rises. The steps occur at half-tick intervals ($0.03125 before decimals and $0.005 afterwards) because the spread can be as narrow as one tick. The average cost of a trade of a given size takes into account the fact that some shares can be purchased (sold) at a lower (higher) price than the last shares needed to complete the trade.

Cumulative depth is displayed in Figure 1. The horizontal axis is measured in units of $0.005, so the translation to the fractional environment is not exact.

[Insert Figure 1.]

Overall, see Panel A of Figure 1, displayed liquidity falls dramatically with decimal pricing. Only small size is available at prices inside of the old half-tick (from $0.005 to $0.03 away from the spread midpoint). There is more quoted depth at the first fractional price point ($0.03125 represented by $0.035) than cumulative with decimals through $0.035. Further from the spread midpoint, there is substantially less displayed trading interest. To gauge the decrease in displayed depth note the vertical distance from the pre-decimal cumulative step-function to the post-decimal curve. The displayed size in decimals generally is less than one-half the displayed trading interest in fractions for all price points. For example, within $0.25 of the spread midpoint, there is approximately 60,000 shares of displayed liquidity, on average, pre-decimals. In the first week of decimal trading, that decreases to less than 30,000 shares. By the last sample period, cumulative depth at $0.25 from the spread's midpoint is only 20,000 shares. To find 60,000 shares of displayed liquidity during the last week of April requires going $1.00 into the book. The displayed depth continues to decrease throughout the sample periods.

All of the sub-samples, see Panels B through F, display much less displayed liquidity throughout the limit order book. The highest volume stocks' displayed liquidity falls monotonically as we move further away from the decimalization date, but the displayed depth of the other sub-samples appear to have stabilized. The high-volume, high-price stocks' books appear to be least affected by decimals and the high-volume, low priced stocks' books appear to be the most affected (in percentage terms). The latter observation is consistent with finding that the high-volume, low-priced stocks' quoted depth falls the most of all the sub-samples. The low-volume, low-priced stocks' books held their own in the first week of decimals, but fell

[8] Qualitatively similar results are found considering the bid and offer sides of the book separately.

dramatically thereafter. The fact that the effect appears to be greatest for the low-priced stocks is consistent with theory (e.g., Harris [1992] and [1997]).

Another statistic derivable from the limit order book is the average cost of trading a given number of shares if the only liquidity in the market is the liquidity displayed in the book. Assuming that the midpoint of the spread is a proxy for the value of a security, the cost of displayed liquidity for an order is the product of the additional shares available in the limit order book at each price point times the distance of the price point from the spread midpoint summed through the number of shares in the order of interest. Dividing that sum by the total number of shares in the order provides the per share cost of obtaining the displayed liquidity.[9] For example, assume that there are 500 shares available in the limit order book at $0.01 from the existing quote and another 500 shares available at $0.02 from the quote. Without additional liquidity, a 1,000 share trade using only the liquidity displayed in the limit order book has an average cost $0.015 per share (relative to the spread midpoint). This calculation requires the same information previously used to compute the cumulative depth at given price points (illustrated in Figure 1). Figure 2 provides the average cost schedules before and after decimals.

[Insert Figure 2.]

For an order of a given number of shares on the vertical axis, the horizontal distance between the price curves represent the difference in the average cost of trading pre- and post-decimals. For the overall sample and all sub-samples but the low-volume, high-price stocks, the costs of doing a trade of significant size greatly increase after decimals. For example, overall, the cost of displayed liquidity for a 50,000-share trade approximately doubles after decimal

[9] We do not mean to imply that this is the actual cost of obtaining liquidity. We are deliberately ignoring non-displayed liquidity in this calculation.

trading. The pre-decimal cost in Panel A is about $0.16 (i.e., the pre-decimal price function intersects the 50,000 share gridline at $0.16 on the vertical axis). Post-decimals, the average cost is approximately $0.33 in the first week and almost $0.50 in the thirteenth week. Furthermore, there are many trade sizes that appear quite feasible in the pre-decimal sample period that are not feasible post-decimals. Consider Panel A of Figure 2 once again. Pre-decimals, the cost of displayed liquidity for a 100,000 share order is about $0.30 per share. In the first week of decimals, the trade "costs" about $0.78. This "cost" increases to about $1.00 per share in week 4 of decimals. In week 13 of decimals, one cannot do a 100,000-share trade at any cost (within $1.00). The high-volume, low-price stocks (Panel D) seem particularly hard hit. A 60,000-share trade could have been done less than $0.15 from the spread midpoint in the pre-decimal period, but cannot be done at any price post-decimals. Only the low-volume, high-price stocks appear to hold up well with decimals (at least through a trade size of 2,500 shares).

Because it is difficult to determine costs from Figure 2 with any precision, we compute the average cost of doing some standard size trades before and after decimals. For this exercise, we select trade sizes of 3,000 shares, 5,000 shares, and 10,000 shares. Table 9 reports the average costs.

[Insert Table 9.]

Overall, the 2,000 share trade provides approximately the same average cost after decimals (at least in the fourth and thirteenth weeks) as pre-decimals. For the Top 50 stocks the 3,000-share trade produces lower average costs post-decimals in post-decimal weeks one and four, but approximately the same cost in the thirteenth week of decimals. Relative to the pre-decimal cost, the 5,000-share Top 50 trade costs less in week one of decimals, but more in week 13. The Top

50's 10,000-share trade is more expensive in every pre-decimal sample period; more than doubling in cost by the final sample period from $0.03125 to $0.075 per share). Except for the 500-share trade, the average cost associated with the high-volume, high-price stocks doubles for all three trade sizes examined. For the high-volume, low-price stocks, the effect on the average cost of the 3,000 share trade falls, the cost of the 5,000 share trade stays roughly constant, and the cost of the 10,000 share trade increases post decimals. The average cost of doing each of these trade sizes in the low-volume stocks increases after decimalization. For the low-volume, high-price stocks, there are insufficient shares in the book to do even a 5,000 share trade within $5.00 of the spread midpoint in every sample period. For the low-volume, low-price stocks, although there are sufficient shares in the book to do a 10,000-share trade before decimals, there is not in the post-decimal periods.

Execution Quality

Finally, we address the question of whether the fall in displayed liquidity has a deleterious effect on execution quality. There is ample evidence from the pre-decimal era that the floor of the NYSE provides substantial amounts of non-displayed liquidity. For example, Bacidore, Ross, and Sofianos (1999) find that 35.5% of eligible NYSE system market orders execute at prices better than the posted quotes (compared to 6.9% that execute at worse-than-quoted prices). Bacidore, Battalio, and Jennings (2001) document that 70% of eligible system market orders receive depth improvement (i.e., orders for more than the quoted number of shares execute at the quoted price or better). Both price improvement and depth improvement are signs of non-displayed liquidity, i.e., trading interests that are produced dynamically in the trading process. Thus, even though the previous section reports a substantial reduction in displayed

liquidity, it is possible that execution quality is unaffected (or even improves) with decimal trading.

Depth improvement is a market's ability to fill orders with more than the quoted number of shares at the quoted price or better. For example, consider a buy order for 800 shares arriving when the quoted offer price is $20.10 for 500 shares. The market maker is liable for only 500 shares at the quoted price. If the market maker decides to execute more than 500 shares at $20.10 (or less), then the market maker provides depth improvement. Suppose 600 shares trade at $20.10 and 200 shares trade at $20.15. In this case, 300 of the 800 shares are eligible for depth improvement and 100 shares out of 300 depth-improvement-eligible shares are depth improved. This example produces a 37.5% depth improvement eligibility rate (300 shares exceeding the quoted size out of 800 shares in the order) and a 33% depth improvement rate (100 shares improved out of 300 eligible). In Table 10, we present the depth improvement eligibility rate (both in orders and shares) and the depth improvement rate.

[Insert Table 10.]

Panel A provides the fraction of market orders and shares exceeding the order-receipt-time relevant quoted size (offer size for buy orders and bid size for sell orders). Consistently with the decrease in quoted size documented previously, the overall fraction of market orders with sizes exceeding the order-receipt-time quoted size more than doubles in the decimal environment. Because the average market order size decreases post-decimals, the fraction of shares eligible for depth improvement did not increase as much as the fraction of orders eligible for depth improvement. The low-volume, high-price group is the exception to the general increase in the

frequency with which order size exceeds quoted size. From Table 3 Panel A, we note that it also is the sub-sample with an increase in the proportion of limit orders.

Panel B provides the depth improvement rates. The overall depth improvement rate is slightly higher after the advent of decimal pricing (by 2.61 percentage points). Examining the sub-samples, we find that the high-volume, high-priced stocks experience a greater-than-average increase in depth improvement while the high-volume, low-priced stocks experience a decrease. Low-priced stocks also experience a decrease in the depth improvement rate. The small increase in the overall depth improvement rate, combined with the fact that the depth improvement eligible number of shares increases post-decimals, suggests that the number of shares receiving depth improvement increases.

Price improvement occurs when all or part of an order with size no greater than the relevant order-receipt-time quoted size receives an execution price better than the relevant order-arrival-time quoted price. Price disimprovement occurs when all or part of an order with size not exceeding the relevant order-receipt-time quoted depth receives an execution price that is worse than the relevant quoted price.[10] The relevant quote for a buy (sell) order is the offer (bid) price. Thus, buy (sell) orders with order sizes exceeding the quoted offer (bid) size are excluded from this calculation. The price improvement rate is the number of price-improvement-eligible shares receiving price improvement divided by the total number of price-improvement-eligible shares. As the cost of providing price improvement decreases (to as little as one penny), we anticipate that the price improvement rate will increase. We also anticipate increases in the frequency of both price improvement and in price disimprovement caused by the increase in the frequency of

[10] The size constraint is necessary because market makers are not obligated to provide the quoted prices for orders with greater-than-quoted size.

the NBBO changes. To the extent that market makers cannot observe the current NBBO when trading, we anticipate seeing an increase in both rates. The sample's price improvement and disimprovement rates are displayed in Table 11.

[Insert Table 11.]

In general, both price improvement and price disimprovement rates increase substantially after the tick size is reduced.[11] There appears to be very little price disimprovement in the low-volume groups. This likely reflects the fact that the NBBO the specialist sees agrees with the "official" NBBO because trading in these securities is less intense. The net price improvement rate (i.e., the price improvement rate less the price disimprovement rate) increases from 23.17% to 29.24%, suggesting an improvement in market quality.

It is possible that, although more frequent, the additional price points available with decimal trading result in less dollar improvement per share improved. To examine that, we calculate the dollar amount of price improvement per share in Panel B of Table 11. We compute the dollar amount of price improvement per share improved by multiplying the difference between the trade price and the quoted price times the number of shares in the trade for all price-improved shares, summing these products, and dividing by the total number of price-improved shares. For buy orders, we subtract the execution price from the quoted offer price. For sell orders, we subtract the quoted bid price from the trade price. The amount of price improvement per share improved falls dramatically in the decimal-price environment. In the pre-decimal period, the amount of price improvement per share exceeds seven cents for all sample groups.

[11] A portion of the price (dis)improvement rate is due to the fact that the researcher uses a different benchmark NBBO when measuring execution quality than the specialist uses when executing the trade. This is because of delays in the system presenting the quotes to the specialist. The more frequent changes in the NBBO documented earlier in the paper suggest that the specialist might have more difficulty in determining the contemporaneous NBBO, which suggests spurious increases in price (dis)improvement rates.

Afterwards, it is but three or four cents. By the final sample period, overall, per share price improvement is only 40.3% of what it is in the fractional environment. The low-volume groups experience less of a decline in the amount of price improvement than do the high-volume groups.

With decimal trading the depth improvement rate increases slightly, the price improvement rate rises, and the amount of price improvement per share falls. What is the net effect on execution quality? The effective spread allows us to address this issue. To compute the effective spread, we measure the distance between a market order's execution price and the order-receipt-time quoted NBBO midpoint and multiply by two. For buy (sell) orders, the effective spread is positive if the trade price exceeds (is less than) the spread's midpoint and negative otherwise. Taking the spread midpoint as a measure of the security's value, the effective spread measures the cost of liquidity to a market-order trader. Low effective spreads indicate that the cost of liquidity is low. Table 12 documents the changes in the effective spread around the switch to decimal pricing.

[Insert Table 12.]

The statistics indicate that the liquidity cost, on average, falls by 34% with the move to decimals. This is much greater than the 11% decrease in effective spreads around the switch to decimal prices documented by Chakravarty, Harris, and Wood (2000) using trade (instead of order) data. In the fractional environment, trades are about five cents worse than the spread's midpoint overall (with the low-volume groups' effective spreads being higher), giving an effective spread of about ten cents. With decimals, that distance shrinks to just over three cents, on average, for an effective spread of about six cents. The only group to not experience a decrease in liquidity

cost is the low-volume, low-price group. Overall, the effective spread suggests that the decrease in displayed liquidity does not adversely impact system market order traders.

In Table 12, we focus on system orders. This has the benefit of allowing us to determine the order-receipt-time benchmark NBBO, but the disadvantage of not being able to examine non-system orders. System orders tend to be easier to execute (at least in the minds of the traders involved) than non-system orders. Thus, it is possible that examining only system orders results in a downward-biased estimate of post-decimal liquidity costs. To address this issue, we expand our analysis to include an examination of all *trades* by using the Consolidated Trade tape. By switching to trades, we capture the execution of non-system orders, but lose the ability to distinguish orders and benchmark to the NBBO at order-receipt time. In Table 13, we present the effective spreads in the pre- and post-decimal sample periods conditional on *trade* size. To compute effective spreads, we use the trade-time NBBO and compute the absolute value of the difference between the trade price and the midpoint of the benchmark quoted spread. We report the share-weighted average effective spreads in Table 13.

[Insert Table 13.]

The trading volume numbers reported in Table 13 suggest that the average trade size fell between the pre-decimal sample period and the post-decimal sample periods. Overall, the frequency of observing a trade size between 1,001 and 5,000 shares increases and the frequency of observing a trade for more than 10,000 shares decreases.

With regard to average effective spreads, we find that the effective spreads reported in Table 13 from trades are consistently less than the effective spreads reported in Table 12 from orders. This is likely due to the fact that the benchmark quoted spread changes between order-

receipt time and trade time. Overall, effective spreads are lower after the switch to decimal pricing. By the final post-decimal period examined, the average share-weighted effective spread is 35% less than in the pre-decimal sample period. Generally, the smaller trade-size categories enjoy a larger proportional decrease in effective spreads than the larger trade-size categories. For trades of more than 10,000 shares, the overall effective spread decreases from 7.76 cents per share in the pre-decimal sample period to 5.67 cents per share in the final post-decimal sample period. This represents a 27% decrease in the effective spread. Because the overall figure is share-weighted, this result is driven primarily by the Top 50 stocks, but the 10,000+ share trades' effective spreads fall for all volume:price groups examined (with the exception of the first week of decimals for two of the subgroups). The fact that large trades are associated with a reduction in effective spreads suggests that institutional-sized orders also find the execution quality in the post-decimal environment better than in the fractional environment. This, of course, does not consider any alterations in institutional traders' strategies that contribute to this decrease.

It is possible that the lower dollar effective spreads documented in Table 13 are associated with a post-decimal decline in share prices. If this is the case, then concluding that execution quality is not adversely affected by the implementation of decimal pricing is premature. To control for share price level, we compute effective spreads as a percent of the quoted spread midpoint at execution time. These figures are reported in Table 14.

[Insert Table 14.]

For each sample category, the conclusions from the percentage spread are identical to the conclusions reached with dollar spreads. The measured reduction in effective spreads appears robust to whether we measure absolute spreads or spreads relative to share price.

Finally, we note that the averages displayed in Tables 13 and 14 are weighted equally across the stocks in the sample. Although this allows us to address questions about the typical stock, a natural extension is to address questions regarding the average share traded. Thus, we recalculate the average effective spread on a share-weighted basis. That is, we multiply the effective spread associated with each trade by the number of shares in the trade, sum these products, and divide by the total number of shares traded.

[Insert Table 15.]

Overall, the volume-weighted results look quite similar to the results in Table 13; effective spreads are lower after decimals for all trade sizes than before, both in cents and in basis points.[12] Generally speaking, smaller trades appear to benefit more from decimalization than larger trades.

Summary

We examine changes in order submission strategies, in quoting behavior, in displayed liquidity, and in market order execution quality around the switch to decimal pricing for a sample of NYSE-listed stocks. Quoting intensity, especially for the non-NYSE markets increases post-decimals. Much of this additional quoting appears to be concentrated around the NBBO quotes because we find that the percentage increase in the number of NBBO quote changes far exceeds the increase in the number of quotes. The fraction of time that NYSE

[12] We report results for the Top 50 stocks only since the vast majority of stocks did not have a sufficient number of trades to reliably estimate the average for all trade size buckets.

quotes are on both sides of the NBBO decreases after decimal pricing, suggesting that non-NYSE markets provide more effective competition. By the end of our sample period, however, the NYSE's time at both sides of the national best quote recover to nearly their pre-decimal levels. Consistently with finance theory predicting that limit orders are less attractive with a smaller minimum tick, we find a small increase in the proportion of marketable orders, a decrease in the size of limit orders relative to the size of market orders, and an increase in the cancellation rate of limit orders. Supporting the primary motive for the move to decimal pricing, we find an increase in the aggressiveness of limit order pricing, which appears to result in narrower quoted spreads (particularly on the NYSE). Quoted depth, however, fell dramatically around the switch to decimal pricing. Displayed depth fell at all prices available pre-decimals, producing a limit order book that generally is only one-half as "thick" post-decimals. This decrease in displayed liquidity does not appear to adversely affect system market order traders. Traditionally measured execution quality actually improves. Both the depth improvement rate and the net price improvement rate increase after stocks begin trading in decimals. In addition, the effective spread falls.

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Table 1

Sample Securities[1]

Panel A. Fifty highest trading volume stocks not part of the NYSE decimal pilot

AIG	MOT
AXP	MRK
BAC	MU
C	MWD
CNC	NOK
CPN	NT
DIS	ONE
EIX	PCG
EMC	PCS
F	PFE
FNM	Q
GE	SBC
GLW	SCH
GPS	SGP
GX	AA
HD	T
HWP	TGT
IBM	TXN
JPM	TYC
KM	VIAB
LMGA	VOD
LU	WFC
MCD	WMT
MER	XOM
MO	XOX

Panel B. High trading volume and High share price

AIG	FOE	PBR
AVB	GPT	PP
BK	HPT	RKY
CB	JBL	SJR
CMS	KWD	SUS
CUZ	MC	TMK
DRE	MRK	UDS
EQT	NKE	WB
		ZQK

Table 1 (continued)

Panel C. High trading volume and Low share price

ACG	GRP	OMX
AOT	HRC	PNK
BBV	IRT	RI
BRM	KGC	SKO
CHH	LTD	SZ
CQBPRA	MKT	TRP
DL	MXE	USI
ELY	NR	WMS
FMO		

Panel D. Low trading volume and High share price

ALS	FIGPRA	PLPRP
AXPPRA	GIGPRA	PSTPRA
BPL	HIPRT	ROMPR
CBA	JPMPRC	SJI
CLPPRA	LMCPRY	SSSPRB
CSDPRA	MWC	TLMPRB
DREPRA	NUI	UBT
ENEPRT	OUI	WMK
		ZNT

Panel E. Low trading volume and Low share price

AP	GNA	OFG
BKE	HIF	PFP
BZL	IMY	PTM
CM	JWB	SBPPRA
CWF	LNCPRG	SQMA
CEE	MIJ	TMNPRA
FCP	NAP	UMGPRY
FTD	NPC	VTP
		ZNH

[1] Trading volume and average New York Stock Exchange share price (i.e., trade price) are calculated in the 20 trading days prior to January 29, 2001.

Table 2

Quoting Intensity in the Sample Securities before and after the Switch to Decimal Prices on January 29, 2001[1]

The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. The thirteenth week of decimals is April 23-27, 2001. The Top 50 category contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001. The remaining lines refer to four randomly selected 25-stock portfolios selected based on trading volume (the first ranking) and share price (the second ranking). High and low are relative to the median for all NYSE securities. Thus, the low-high group is the 25-stock portfolio with below-median trading volumes and above-median share prices.

Panel A. Per Stock Number of NYSE Quotes and Total Number of Quotes – daily averages

	Pre-decimal		1st week decimals		4th week decimals.		13th week decimals	
	NYSE	Total	NYSE	Total	NYSE	Total	NYSE	Total
All 148	1,094	2,761	950	2,992	1,046	3,378	1,208	3,520
top 50	2,612	6,434	2,163	6,357	2,328	7,420	2,812	8,100
high-high	978	2,421	967	2,826	1,147	3,265	1,112	3,469
high-low	299	697	337	1,016	390	1,089	418	1,192
low-high	42	113	44	149	51	146	53	159
low-low	21	55	29	84	33	76	37	102

Panel B. Per Stock Number of NBBO quotes – daily averages

	Pre-decimal	1st week decimals	4th week decimals	13th week decimals
All 148	280.37	439.13	525.79	562.34
top 50	658.87	1,012.60	1,232.84	1,320.46
high-high	269.63	414.64	492.67	506.38
high-low	69.10	156.41	159.82	177.34
low-high	17.19	22.02	23.44	29.26
low-low	8.56	16.53	13.11	20.15

[1] Each number reported is an average that equally weights each stock in the sub-sample being examined and each day in the sample period. Thus, in the first row in each panel, we sum the number of quotes observed in the sample stocks during a given trading week and divide by 740 (= 148 stocks × 5 days).

Table 3

Fraction of Time Market Centers are Posting Quotes Equal to the National Best Quote in the Sample Securities before and after the Switch to Decimals on January 29, 2001[1]

The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. The thirteenth week of decimals is April 23-27, 2001. The Top 50 category contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001. The remaining lines refer to four randomly selected 25-stock portfolios selected based on trading volume (the first ranking) and share price (the second ranking). High and low are relative to the median for all NYSE securities. Thus, the low-high group is the 25-stock portfolio with below-median trading volumes and above-median share prices.

Panel A. Fraction of time at either the National Best Bid or the National Best Offer (but not both)

	Pre-decimal		1st week decimals		4th week decimals		13th week decimals	
	NYSE	Others	NYSE	Others	NYSE	Others	NYSE	Others
All 148	0.0710	0.2404	0.1718	0.1264	0.1138	0.1134	0.0880	0.0936
top 50	0.1096	0.2742	0.2637	0.1417	0.1675	0.1327	0.1339	0.1086
high-high	0.0483	0.2026	0.1478	0.0839	0.0634	0.0767	0.0458	0.0576
high-low	0.0794	0.2203	0.2206	0.1306	0.1793	0.1108	0.0314	0.0934
low-high	0.0167	0.2427	0.0307	0.0708	0.0170	0.0530	0.0132	0.0504
low-low	0.0621	0.1248	0.1042	0.0840	0.0839	0.0426	0.0658	0.0348

Panel B. Fraction of time at both the National Best Bid and National Best Offer prices

	Pre-decimal		1st week decimals		4th week decimals		13th week decimals	
	NYSE	Others	NYSE	Others	NYSE	Others	NYSE	Others
All 148	0.9275	0.0163	0.8174	0.0038	0.8770	0.0032	0.9065	0.0024
top 50	0.8871	0.0197	0.7175	0.0027	0.8146	0.0031	0.8561	0.0020
high-high	0.9511	0.0037	0.8479	0.0008	0.9351	0.0005	0.9537	0.0003
high-low	0.9192	0.0255	0.7573	0.0071	0.8065	0.0077	0.9568	0.0070
low-high	0.9829	0.0018	0.9688	0.0031	0.9823	0.0034	0.9868	0.0003
low-low	0.9377	0.0108	0.8952	0.0073	0.9130	0.0000	0.9338	0.0013

[1] The numbers reported are the time over which the indicated market center's quotes equal either the National Best Bid and/or the National Best Offer divided by the total time the NYSE is open for trading. Note that the total time that all market spend at either of both sides of the NBBO can exceed 100% because it is possible that more than one market has the best price. Quoted size is not considered for this analysis.

Table 4

Fraction of Market and Marketable Limit Orders in the Sample Securities before and after the Switch to Decimal Pricing on January 29, 2001[1]

The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. The thirteenth week of decimals is April 23-27, 2001. The Top 50 category contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001. The remaining lines refer to four randomly selected 25-stock portfolios selected based on trading volume (the first ranking) and share price (the second ranking). High and low are relative to the median for all NYSE securities. Thus, the low-high group is the 25-stock portfolio with below-median trading volumes and above-median share prices.

	Fraction Market Orders				Fraction Marketable Limit Orders			
Period[2]	Pre-Dec	Dec-wk1	Dec-wk4	Dec-wk13	Pre-Dec	Dec-wk1	Dec-wk4	Dec-wk13
All 148	.2909	.3072	.3304	.3007	.1294	.1218	.1391	.1432
Top 50	.3001	.3174	.3471	.3175	.1303	.1217	.1384	.1418
High-high	.2395	.2268	.2280	.2324	.1278	.1144	.1386	.1527
High-low	.1781	.1804	.1604	.1733	.1515	.1263	.1472	.1309
Low-high	.2469	.2527	.2461	.2089	.1478	.1524	.1287	.0930
Low-low	.2465	.2244	.2000	.2692	.1286	.1704	.0976	.1606

[1] Marketable limit orders are buy (sell) orders with limit prices greater (less) than the order-receipt-time offer (bid) price. The fractions reported are the number of orders of the indicated type divided by the total number of orders. The number reported is the equally-weighted average across the securities in the indicated sample.

[2] Pre-Dec indicates the pre-decimal sample period. Dec-wkN indicates the N^{th} week of decimal trading.

Table 5

Characteristics of Market and Limit Orders in the Sample of Securities before and after the Switch to Decimal Pricing on January 29, 2001[1]

The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. The thirteenth week of decimals is April 23-27, 2001. The Top 50 category contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001. The remaining lines refer to four randomly selected 25-stock portfolios selected based on trading volume (the first ranking) and share price (the second ranking). High and low are relative to the median for all NYSE securities. Thus, the low-high group is the 25-stock portfolio with below-median trading volumes and above-median share prices.

Panel A. Market Order and Limit Order Size[2]

	Market Order Size (shares)				Limit Order Size (shares)			
Period[3]	Pre-Dec	Dec-wk1	Dec-wk4	Dec-wk13	Pre-Dec	Dec-wk1	Dec-wk4	Dec-wk13
All 148	1,361	1,283	1,215	1,147	1,872	1,567	1,501	1,246
Top 50	1,356	1,285	1,232	1,144	1,923	1,623	1,570	1,273
High-high	1,241	998	871	858	1,066	890	861	822
High-low	1,603	1,718	1,254	1,325	2,343	2,164	1,638	1,728
Low-high	629	627	715	548	759	784	819	520
Low-low	805	953	831	646	1,487	1,512	1,164	1,153

Panel B. Limit Order Statistics

	Limit Order Aggressiveness[4]				Limit Order Cancellation Rate[5]			
Period	Pre-Dec	Dec-wk1	Dec-wk4	Dec-wk13	Pre-Dec	Dec-wk1	Dec-wk4	Dec-wk13
All 148	$0.177	$0.1921	$0.1561	$0.1571	43.29%	50.62%	51.46%	53.46%
Top 50	$0.178	$0.1961	$0.1530	$0.1697	42.32%	49.01%	50.34%	52.27%
High-high	$0.172	$0.1839	$0.2169	$0.1230	50.66%	60.26%	58.88%	59.09%
High-low	$0.133	$0.0887	$0.0857	$0.1037	48.78%	59.54%	58.23%	60.29%
Low-high	$0.077	$0.2665	$0.0804	$0.2313	46.30%	52.08%	53.54%	69.32%
Low-low	$0.091	$0.0566	$0.1638	$0.1216	44.38%	45.02%	55.71%	43.68%

[1] All reported numbers are the equally-weighted averages across the securities in the sample.

[2] Average order size is the sum of all shares in the orders for the indicated sample divided by the total number of orders in that sample.

[3] Pre-Dec indicates the pre-decimal sample size. Dec-wkN indicates the N^{th} week of decimal trading.

[4] Limit order aggressiveness is the distance between the limit price and the midpoint of the limit-order-receipt-time NBBO quoted spread. For buy limit orders, it is the spread midpoint minus the limit price. For sell limit orders, it is the limit price minus the spread midpoint.

[5] The limit order cancellation rate is the number of limit orders cancelled (either in whole or in part) in the indicated sub-sample divided by the total number of limit orders submitted in the indicated sub-sample.

Table 6

Fraction of System-Order Trading Volume in the Sample Securities before and after the Switch to Decimal Pricing on January 29, 2001[1]

The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. The thirteenth week of decimals is April 23-27, 2001. The Top 50 category contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001. The remaining lines refer to four randomly selected 25-stock portfolios selected based on trading volume (the first ranking) and share price (the second ranking). High and low are relative to the median for all NYSE securities. Thus, the low-high group is the 25-stock portfolio with below-median trading volumes and above-median share prices.

	Pre-decimal	1st week decimals	4th week decimals	13th week decimals
All 148	0.711	0.690	0.697	0.721
Top 50	0.603	0.617	0.618	0.657
High-high	0.731	0.693	0.709	0.723
High-low	0.721	0.668	0.759	0.756
Low-high	0.817	0.833	0.753	0.801
Low-low	0.771	0.712	0.723	0.722

[1] Ratio of system buy volume plus system sell volume divided by twice total volume.

Table 7

Time-weighted Quoted Spreads and Quoted Sizes in the Sample Stocks before and after the Switch to Decimals on January 29, 2001[1]

The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. The thirteenth week of decimals is April 23-27, 2001. The Top 50 category contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001. The remaining lines refer to four randomly selected 25-stock portfolios selected based on trading volume (the first ranking) and share price (the second ranking). High and low are relative to the median for all NYSE securities. Thus, the low-high group is the 25-stock portfolio with below-median trading volumes and above-median share prices.

Panel A. Time-weighted Bid-ask Spreads

	Pre-decimal		1st week decimals		4th week decimals		13th week decimals	
	NYSE	Others	NYSE	Others	NYSE	Others	NYSE	Others
All 148	$0.1733	$0.7038	$0.1462	$0.6437	$0.1423	$0.6509	$0.1214	$0.6488
top 50	$0.1012	$0.5259	$0.0644	$0.4888	$0.0663	$0.4576	$0.0531	$0.4544
high-high	$0.1341	$0.8630	$0.1083	$0.9925	$0.0957	$0.8685	$0.0813	$0.6765
high-low	$0.1058	$0.6553	$0.0925	$0.5800	$0.0841	$0.7014	$0.0759	$0.6265
low-high	$0.2535	$1.1149	$0.2207	$0.8639	$0.2082	$0.6874	$0.1834	$0.8816
low-low	$0.3440	$0.8412	$0.3268	$0.7232	$0.3358	$1.08325	$0.2926	$1.1446

Panel B. Time-weighted quoted depth (shares)

	Pre-decimal		1st week decimals		4th week decimals		13th week decimals	
	NYSE	Others	NYSE	Others	NYSE	Others	NYSE	Others
All 148	9,499	501	3,367	368	3,085	361	2,800	366
top 50	15,407	621	5,036	473	4,820	468	3,995	468
high-high	3,703	172	2,070	147	2,330	163	1,985	159
high-low	17,691	835	4,376	515	3,569	485	3,050	503
low-high	2,322	121	1,682	135	1,525	119	1,819	111
low-low	2,465	138	2,003	166	1,382	136	1,887	147

[1] The quoted spread is the difference between the quoted offer price and the quoted bid price. Time-weighed quoted spreads weight each observed spread by the number of seconds the quote exists and divides by the total number of seconds trading in the security is open on the NYSE. Quoted depth is the size associated with the quoted prices (bid and offer sizes are equally-weighted). Time-weighed quoted sizes weight each size observation by the number of seconds the quote exists and divides by the total number of seconds trading in the security is open on the NYSE. Non-NYSE markets are equally-weighted to form the "Others" average reported.

Table 8

Time-weighted NBBO Quoted Spreads and Quoted Sizes in the Sample Stocks before and after the Switch to Decimals on January 29, 2001[1]

The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. The thirteenth week of decimals is April 23-27, 2001. The Top 50 category contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001. The remaining lines refer to four randomly selected 25-stock portfolios selected based on trading volume (the first ranking) and share price (the second ranking). High and low are relative to the median for all NYSE securities. Thus, the low-high group is the 25-stock portfolio with below-median trading volumes and above-median share prices.

Panel A. Time-weighted NBBO bid-ask Spreads

	Pre-decimal	1st week decimals	4th week decimals	13th week decimals
All 148	$0.1675	$0.1387	$0.1361	$0.1160
top 50	$0.0922	$0.0539	$0.0558	$0.0444
high-high	$0.1298	$0.1007	$0.0918	$0.0782
high-low	$0.1006	$0.0856	$0.0776	$0.0708
low-high	$0.2521	$0.2190	$0.2064	$0.1825
low-low	$0.3378	$0.3190	$0.3319	$0.2910

Panel B. Time-weighted NBBO quoted depth (shares)

	Pre-decimal	1st week decimals	4th week decimals	13th week decimals
All 148	9,120	3,157	3,005	3,505
top 50	14,452	4,539	4,571	4,694
high-high	3,642	1,955	2,301	2,455
high-low	17,431	4,247	3,408	4,465
low-high	2,312	1,661	1,606	2,295
low-low	2,425	2,001	1,519	2.352

[1] The quoted NBBO spread is the difference between the quoted national best offer price and the quoted national best bid price. Time-weighed quoted spreads weight each observed spread by the number of seconds the quote exists and divides by the total number of seconds trading in the security is open on the NYSE. Quoted depth is the size associated with the quoted national best prices (national best bid and national best offer sizes are equally-weighted). Time-weighed quoted sizes weight each size observation by the number of seconds the quote exists and divides by the total number of seconds trading in the security is open on the NYSE.

Table 9

Average Cost of Trading Assuming that the Displayed Liquidity is the Only Liquidity Available in the Market for the Sample Stocks before and after the Switch to Decimal Pricing on January 29, 2001[1]

The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. The thirteenth week of decimals is April 23-27, 2001. The Top 50 category contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001. The remaining lines refer to four randomly selected 25-stock portfolios selected based on trading volume (the first ranking) and share price (the second ranking). High and low are relative to the median for all NYSE securities. Thus, the low-high group is the 25-stock portfolio with below-median trading volumes and above-median share prices.

Sample	Shares	Pre-decimal	Dec-week 1	Dec-week 4	Dec-week 13
All	500	$0.03125	$0.010	$0.015	$0.015
	1,000	$0.03125	$0.015	$0.020	$0.020
	2,000	$0.03125	$0.025	$0.030	$0.030
	3,000	$0.03125	$0.030	$0.035	$0.040
	5,000	$0.03125	$0.045	$0.050	$0.055
	10,000	$0.05625	$0.080	$0.085	$0.095
Top 50	500	$0.03125	$0.005	$0.010	$0.010
	1,000	$0.03125	$0.010	$0.010	$0.015
	2,000	$0.03125	$0.015	$0.020	$0.025
	3,000	$0.03125	$0.015	$0.025	$0.030
	5,000	$0.03125	$0.025	$0.035	$0.040
	10,000	$0.03125	$0.050	$0.060	$0.075
High-high	500	$0.03125	$0.025	$0.030	$0.020
	1,000	$0.03125	$0.040	$0.040	$0.030
	2,000	$0.03125	$0.060	$0.060	$0.055
	3,000	$0.03125	$0.075	$0.080	$0.070
	5,000	$0.06250	$0.115	$0.125	$0.105
	10,000	$0.09375	$0.220	$0.225	$0.190

Table 9 (continued)

High-low	500	$0.03125	$0.015	$0.010	$0.010
	1,000	$0.03125	$0.020	$0.015	$0.020
	2,000	$0.03125	$0.030	$0.025	$0.025
	3,000	$0.03125	$0.035	$0.030	$0.025
	5,000	$0.03125	$0.050	$0.040	$0.035
	10,000	$0.03125	$0.075	$0.060	$0.065
Low-high	500	$0.06250	$0.070	$0.065	$0.070
	1,000	$0.09375	$0.095	$0.095	$0.120
	2,000	$0.15625	$0.190	$0.190	$0.230
	3,000	$0.28125	$0.375	$0.380	n.a.[2]
	5,000	n.a.	n.a.	n.a.	n.a
	10,000	n.a.	n.a.	n.a.	n.a.
Low-low	500	$0.03125	$0.070	$0.050	$0.050
	1,000	$0.06250	$0.090	$0.080	$0.080
	2,000	$0.09375	$0.135	$0.130	$0.120
	3,000	$0.12500	$0.170	$0.165	$0.170
	5,000	$0.15625	$0.295	$0.260	$0.450
	10,000	$0.34375	n.a.	n.a.	n.a.

[1] We compute the average cost of liquidity by multiplying the number of shares available in the limit order book at each price by the price point, summing these products until the number of shares equals the number of shares in the order size of interest, and dividing by the number of shares in the order size of interest.
[2] n.a. = insufficient shares available at any price within $5.00 of the spread midpoint

Table 10
Depth Improvement in the Sample Securities before and after the Switch to Decimal Pricing on January 29, 2001

Depth improvement is the act of providing large orders executions for more than the order-receipt-time quoted number of shares at the quoted price or better. To be eligible for depth improvement a market buy (sell) order must have an order size exceeding the order-receipt-time quoted offer (bid) depth. The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. Thirteen weeks post-decimal is April 23-27, 2001. The 148-stock sample contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001 and to four randomly selected 25-stock portfolios selected based on trading volume and share price. High and low volume/price are relative to the median for all NYSE securities. The low-high portfolio are the 25 stocks with trading volumes less than the median NYSE volume and prices greater than the NYSE's median price.

Panel A. Fraction of Orders and Shares Eligible for Depth Improvement[1]

	Fraction of Orders with Size > Quoted Size				Fraction of Shares Eligible for Depth Imp.			
Period[2]	Pre-Dec	Dec-wk1	Dec-wk4	Dec-wk13	Pre-Dec	Dec-wk1	Dec-wk4	Dec-wk13
All 148	.1173	.2505	.2441	.2838	.3862	.4973	.4637	.4962
Top 50	.1149	.2472	.2440	.2889	.3765	.4922	.4639	.4858
High-high	.1522	.2983	.2771	.3008	.4889	.5245	.4711	.4923
High-low	.1219	.2696	.2305	.2182	.3797	.5248	.4615	.5415
Low-high	.2730	.2411	.2511	.2574	.2845	.2661	.4135	.3231
Low-low	.1924	.3014	.2843	.2972	.2167	.3701	.3241	.3113

Panel B. Depth Improvement Rate[3]

	Percent of Depth-Improvement Eligible Shares Receiving Depth Improvement			
Period	Pre-Decimal	Decimal-week 1	Decimal-week 4	Decimal-week 13
All 148	37.25%	36.76%	40.60%	39.86%
Top 50	38.46%	38.95%	40.78%	41.16%
High-high	25.06%	36.77%	45.68%	43.82%
High-low	46.36%	36.65%	31.86%	26.96%
Low-high	31.90%	34.58%	36.72%	28.86%
Low-low	51.53%	31.95%	34.79%	44.73%

[1] The fraction of orders eligible for depth improvement is the number of market orders with order size exceeding the relevant order-receipt-time quoted size divided by the total number of orders. The fraction of shares eligible for depth improvement is computed by totaling the number of size-exceeding shares in orders with size greater than the order-receipt-time relevant quoted size and dividing by the total number of shares in submitted market orders. The relevant side of the quote is the bid (offer) for sell (buy) orders.

2 Pre-Dec indicates the pre-decimal sample period. Dec-wkN indicates the N^{th} week of decimal trading.

[2] Depth improvement is trading at the quoted price (or better) for at least some of the depth-improvement-eligible shares in an order with size exceeding the relevant NBBO quoted size. For a buy (sell) market order the relevant size is that associated with the quoted NBO (NBB) price. A market order is eligible for depth improvement if the order size exceeds the relevant depth. The depth improvement rate is the number of depth-improvement-eligible shares receiving depth improvement divided by the total number of depth-improvement-eligible shares.

Table 11
Price Improvement in the Sample Securities before and after the Switch to Decimal Pricing on January 29, 2001[1]

Price (dis)improvement is an execution at a price (worse) better than the relevant order-receipt-time national best quote (i.e., the bid price for sell orders and the offer price for buy orders0. The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. The thirteenth week of decimals is April 23-27, 2001. The Top 50 category contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001. The remaining lines refer to four randomly selected 25-stock portfolios selected based on trading volume (the first ranking) and share price (the second ranking). High and low are relative to the median for all NYSE securities. Thus, the low-high group is the 25-stock portfolio with below-median trading volumes and above-median share prices.

Panel A. Price Improvement and Price Disimprovement Rates

	Price Improvement Rate				Price Disimprovement Rate			
Period[2]	Pre-Dec	Dec-wk1	Dec-wk4	Dec-wk13	Pre-Dec	Dec-wk1	Dec-wk4	Dec-wk13
All 148	31.21%	48.90%	48.31%	44.68%	8.04%	13.72%	18.20%	15.44%
Top 50	31.14%	49.28%	48.60%	44.86%	8.34%	14.09%	18.73%	16.17%
High-high	36.82%	50.49%	49.05%	43.43%	7.52%	11.91%	11.48%	9.25%
High-low	21.55%	35.99%	36.73%	36.60%	3.33%	6.26%	3.85%	4.96%
Low-high	26.53%	41.13%	42.95%	43.41%	0.80%	1.03%	0.13%	0.63%
Low-low	23.12%	45.03%	40.49%	46.26%	0.00%	0.42%	0.00%	1.10%

Panel B. Amount of Price Improvement per Share Improved[3]

	Amount of Price Improvement per Share Improved (dollars)			
Period	Pre-Decimals	Decimals-week 1	Decimals-week 4	Decimals-week 13
All 148	$0.0861	$0.0443	$0.0537	$0.0347
Top 50	$0.0862	$0.0438	$0.0546	$0.0350
High-high	$0.0854	$0.0616	$0.0491	$0.0387
High-low	$0.0794	$0.0352	$0.0292	$0.0308
Low-high	$0.0738	$0.0353	$0.0485	$0.0441
Low-low	$0.0751	$0.0399	$0.0408	$0.0451

[1] The price improvement rate is the number of price-improvement-eligible shares receiving price improvement divided by the total number of price-improvement-eligible shares. To be eligible for price improvement, an order must be for no more shares that the quoted size associated with the relevant quoted price. Thus, buy (sell) orders with order sizes exceeding the quoted offer (bid) size are excluded from this calculation.

[2] Pre-Dec indicates the pre-decimal sample period. Dec-wkN indicates the N^{th} week of decimal trading.

[3] To compute the dollar amount of price improvement per share we multiply the difference between the trade price and the quoted price times the number of shares in the trade, sum these products for all price-improvement-eligible orders, and divide by the total number of shares in price-improvement eligible orders. For buy orders, we subtract the execution price from the quoted offer price. For sell orders, we subtract the quoted bid price from the trade price.

Table 12

Effective Spreads for the Sample Securities before and after the Switch to Decimal Pricing on January 29, 2001[1]

The effective spread is the distance between the trade price and the order-receipt-time NBBO spread midpoint multiplied by two. For buy orders, we subtract the spread midpoint from the trade price. For sell orders, we subtract the trade price from the midpoint. The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. The thirteenth week of decimals is April 23-27, 2001. The Top 50 category contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001. The remaining lines refer to four randomly selected 25-stock portfolios selected based on trading volume (the first ranking) and share price (the second ranking). High and low are relative to the median for all NYSE securities. Thus, the low-high group is the 25-stock portfolio with below-median trading volumes and above-median share prices.

	Effective Spread			
Period	Pre-decimal	Decimals-week 1	Decimals-week 4	Decimals-week 13
All 148	$0.0962	$0.0880	$0.0836	$0.0632
Top 50	$0.0930	$0.0848	$0.0835	$0.0600
High-high	$0.1300	$0.1222	$0.0722	$0.1182
High-low	$0.1192	$0.1168	$0.0892	$0.0828
Low-high	$0.2472	$0.1818	$0.1928	$0.1850
Low-low	$0.1274	$0.1366	$0.1520	$0.1316

[1] The effective spread is the average distance from the trade price to the midpoint of the order-submission-time bid-ask spread for market orders times two. For buy (sell) orders it is the trade price less the order-receipt-time spread's midpoint (spread's midpoint less the trade price). If the spread's midpoint represents the value of the security, then the effective spread represents (twice) the amount paid for immediacy of execution (i.e., the amount less than the midpoint a seller receives and the amount greater than the midpoint a buyer pays). A small number is preferable to a large number as it indicates the cost of liquidity is low. To compute the effective spread, we calculate the indicated difference for each market order execution, multiply by the number of shares in the trade, total across all trades, and divide by the total number of market-order shares trading.

Table 13

Effective Spreads using Trades for the Sample Securities before and after the Switch to Decimal Pricing on January 29, 2001[1]

The effective spread is the distance between the trade price and the trade-time NBBO spread midpoint multiplied by two. The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. The thirteenth week of decimals is April 23-27, 2001. The Top 50 category contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001. The remaining lines refer to four randomly selected 25-stock portfolios selected based on trading volume (the first ranking) and share price (the second ranking). High and low are relative to the median for all NYSE securities. Thus, the low-high group is the 25-stock portfolio with below-median trading volumes and above-median share prices.

Table 13 (continued)

Order size category (shares)	Pre-Decimals		Decimals - Week 1		Decimals - Week 4		Decimals - Week 13	
	Millions of shares	Effective Spread – cents	Millions of shares	Effective Spread - cents	Millions of shares	Effective Spread - cents	Millions of shares	Effective Spread - cents
All 148 stocks								
< 501	54.12	6.026	53.38	3.802	55.83	3.839	63.63	3.170
501-1,000	70.22	6.160	71.02	4.002	80.92	4.059	85.21	3.382
1,001-5,000	367.35	6.635	369.84	4.605	422.77	4.675	391.24	3.833
5,001-10,000	299.08	7.107	287.31	5.655	331.95	5.668	271.01	4.438
> 10,000	1,096.95	7.764	879.77	7.300	1,078.51	8.294	770.81	5.671
All trade sizes	**1,887.72**	**7.331**	**1,661.31**	**6.163**	**1,969.98**	**6.775**	**1,581.90**	**4.781**
High Volume High Price								
< 501	7.26	7.302	7.39	5.627	9.06	5.013	9.38	4.204
501-1,000	8.68	7.653	8.26	5.955	10.42	5.386	9.61	4.426
1,001-5,000	32.06	8.540	29.45	7.108	36.16	6.238	33.18	5.116
5,001-10,000	17.47	9.203	15.61	9.822	18.96	7.633	16.42	6.215
> 10,000	36.56	10.374	30.28	14.072	31.65	9.073	33.15	7.181
All trade sizes	**102.03**	**9.147**	**90.99**	**9.666**	**106.25**	**7.144**	**101.73**	**5.817**
High Volume Low Price								
< 501	1.55	6.322	1.93	4.727	2.36	4.042	2.46	3.881
501-1,000	2.21	6.477	2.65	4.864	2.93	4.383	2.83	4.193
1,001-5,000	10.64	6.871	11.39	5.373	9.96	4.711	10.39	4.626
5,001-10,000	7.72	7.238	6.55	6.267	5.04	5.223	5.44	4.898
> 10,000	29.31	7.908	16.59	7.495	12.37	6.112	15.25	6.380
All trade sizes	**51.43**	**7.483**	**39.11**	**6.357**	**32.66**	**5.243**	**36.37**	**5.318**
Low Volume High Price								
< 501	0.35	13.811	0.31	12.820	0.33	10.863	0.34	10.983
501-1,000	0.31	13.466	0.26	12.400	0.24	12.053	0.26	13.204
1,001-5,000	0.44	15.675	0.31	14.207	0.41	17.121	0.36	13.597
5,001-10,000	0.05	20.459	0.00	NA	0.10	10.399	0.06	18.362
> 10,000	0.04	36.538	0.03	14.957	0.13	26.936	0.06	19.455
All trade sizes	**1.18**	**15.450**	**0.91**	**13.253**	**1.21**	**14.922**	**1.07**	**13.242**
Low Volume Low Price								
< 501	0.16	10.795	0.23	10.106	0.18	7.884	0.27	9.077
501-1,000	0.19	10.690	0.24	10.764	0.20	9.664	0.27	9.327
1,001-5,000	0.39	12.266	0.65	12.814	0.38	13.072	0.43	11.379
5,001-10,000	0.06	14.123	0.24	12.939	0.05	19.210	0.11	12.686
> 10,000	0.29	10.966	0.12	8.216	0.13	10.149	0.10	13.414
All trade sizes	**1.10**	**11.543**	**1.48**	**11.712**	**0.95**	**11.266**	**1.18**	**10.667**
Top 50								
< 501	46.82	5.733	45.35	3.400	46.13	3.566	53.52	2.846
501-1,000	61.53	5.888	62.01	3.677	70.08	3.838	75.20	3.139
1,001-5,000	337.97	6.443	340.08	4.386	389.24	4.548	359.89	3.653
5,001-10,000	283.20	6.999	272.28	5.462	315.85	5.603	256.05	4.305
> 10,000	1,051.85	7.707	846.46	7.121	1,044.51	8.307	735.87	5.573
All trade sizes	**1,781.37**	**7.240**	**1,566.20**	**5.994**	**1,865.81**	**6.780**	**1,480.53**	**4.665**

Table 14

Percentage Effective Spreads using Trades for the Sample Securities before and after the Switch to Decimal Pricing on January 29, 2001

The percentage effective spread is the distance between the trade price and the trade-time NBBO spread midpoint multiplied by two and divided by the spread midpoint. The reported numbers are converted to basis points by multiplying the percentage by 1000. The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. The thirteenth week of decimals is April 23-27, 2001. The Top 50 category contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001. The remaining lines refer to four randomly selected 25-stock portfolios selected based on trading volume (the first ranking) and share price (the second ranking). High and low are relative to the median for all NYSE securities. Thus, the low-high group is the 25-stock portfolio with below-median trading volumes and above-median share prices.

Table 14 (continued)

Order size category (shares)	Pre-Decimals		Week 1 - Decimals		Week 4 - Decimals		Week 13 - Decimals	
	Millions of Shares	Effective Spread - Basis Points	Millions of Shares	Effective Spread Basis Points	Millions of shares	Effective Spread - Basis Points	Millions of shares	Effective Spread - Basis Points
All 148 stocks								
< 501	54.12	16.726	53.38	10.511	55.83	11.850	63.63	9.945
501-1,000	70.22	17.566	71.02	11.350	80.92	12.609	85.21	10.636
1,001-5,000	367.35	18.456	369.84	12.661	422.77	14.085	391.24	12.192
5,001-10,000	299.08	20.047	287.31	15.120	331.95	16.933	271.01	14.686
> 10,000	1,096.95	24.029	879.77	21.341	1,078.51	26.256	770.81	22.960
All trade sizes	**1,887.72**	**21.864**	**1,661.31**	**17.558**	**1,969.98**	**21.104**	**1,581.90**	**17.692**
High Volume High Price								
< 501	7.26	15.879	7.39	12.852	9.06	12.186	9.38	10.369
501-1,000	8.68	16.200	8.26	13.014	10.42	12.818	9.61	10.542
1,001-5,000	32.06	16.783	29.45	14.425	36.16	13.747	33.18	11.663
5,001-10,000	17.47	17.235	15.61	19.507	18.96	16.341	16.42	13.697
> 10,000	36.56	19.107	30.28	28.943	31.65	19.889	33.15	15.889
All trade sizes	**102.03**	**17.579**	**90.99**	**19.872**	**106.25**	**15.816**	**101.73**	**13.143**
High Volume Low Price								
< 501	1.55	55.126	1.93	39.774	2.36	34.280	2.46	31.724
501-1,000	2.21	65.526	2.65	44.368	2.93	40.290	2.83	37.540
1,001-5,000	10.64	74.132	11.39	51.219	9.96	47.097	10.39	44.746
5,001-10,000	7.72	85.607	6.55	60.006	5.04	53.034	5.44	51.599
> 10,000	29.31	86.587	16.59	79.823	12.37	57.217	15.25	60.012
All trade sizes	**51.43**	**82.010**	**39.11**	**63.796**	**32.66**	**50.312**	**36.37**	**50.734**
Low Volume High Price								
< 501	0.35	51.550	0.31	46.258	0.33	39.922	0.34	41.298
501-1,000	0.31	51.982	0.26	46.796	0.24	44.945	0.26	52.337
1,001-5,000	0.44	59.849	0.31	51.936	0.41	60.771	0.36	51.648
5,001-10,000	0.05	72.969	0.00	NA	0.10	38.031	0.06	72.271
> 10,000	0.04	80.837	0.03	53.225	0.13	102.885	0.06	81.059
All trade sizes	**1.18**	**56.633**	**0.91**	**48.601**	**1.21**	**54.642**	**1.07**	**51.205**
Low Volume Low Price								
< 501	0.16	71.673	0.23	80.335	0.18	56.031	0.27	57.142
501-1,000	0.19	77.728	0.24	95.358	0.20	72.486	0.27	65.312
1,001-5,000	0.39	108.564	0.65	115.606	0.38	93.952	0.43	83.350
5,001-10,000	0.06	178.198	0.24	135.983	0.05	120.580	0.11	95.481
> 10,000	0.29	78.501	0.12	123.238	0.13	60.472	0.10	68.152
All trade sizes	**1.10**	**93.995**	**1.48**	**110.664**	**0.95**	**78.814**	**1.18**	**73.105**
Top 50								
< 501	46.82	14.715	45.35	8.080	46.13	9.961	53.52	8.137
501-1,000	61.53	15.227	62.01	9.020	70.08	10.861	75.20	9.021
1,001-5,000	337.97	16.278	340.08	10.785	389.24	12.910	359.89	10.892
5,001-10,000	283.20	18.040	272.28	13.536	315.85	16.180	256.05	13.667
> 10,000	1,051.85	22.195	846.46	19.781	1,044.51	25.929	735.87	22.195
All trade sizes	**1,781.37**	**19.975**	**1,566.20**	**15.977**	**1,865.81**	**20.602**	**1,480.53**	**16.795**

Table 15

Volume-weighted Effective Spreads using Trades for the Top 50 Securities before and after the Switch to Decimal Pricing on January 29, 2001[1]

The percentage effective spread is the distance between the trade price and the trade-time NBBO spread midpoint multiplied by two and divided by the spread midpoint. The reported numbers are converted to basis points by multiplying the percentage by 1000. The pre-decimal period is the week of January 22, 2001. The first week of decimals is the week of January 29, 2001. The fourth week of decimals is February 20-26, 2001. The thirteenth week of decimals is April 23-27, 2001. The Top 50 category contains the 50 stocks not in the decimal pilot with the highest trading volume the month before January 29, 2001.

A. Effective spreads in cents

Order size category	Pre-Decimals	Decimals-Week 1	Decimals-Week 4	Decimals-Week 13
Top 50				
<500 shares	0.057	0.031	0.032	0.027
501-1000 shares	0.058	0.034	0.034	0.029
1001-5000 shares	0.065	0.043	0.042	0.035
5001-10000 shares	0.071	0.054	0.052	0.042
10000-24999 shares	0.076	0.065	0.063	0.050
25000-49999 shares	0.082	0.078	0.072	0.055
50000+ shares	0.086	0.090	0.088	0.064

B. *Effective spreads in* basis points

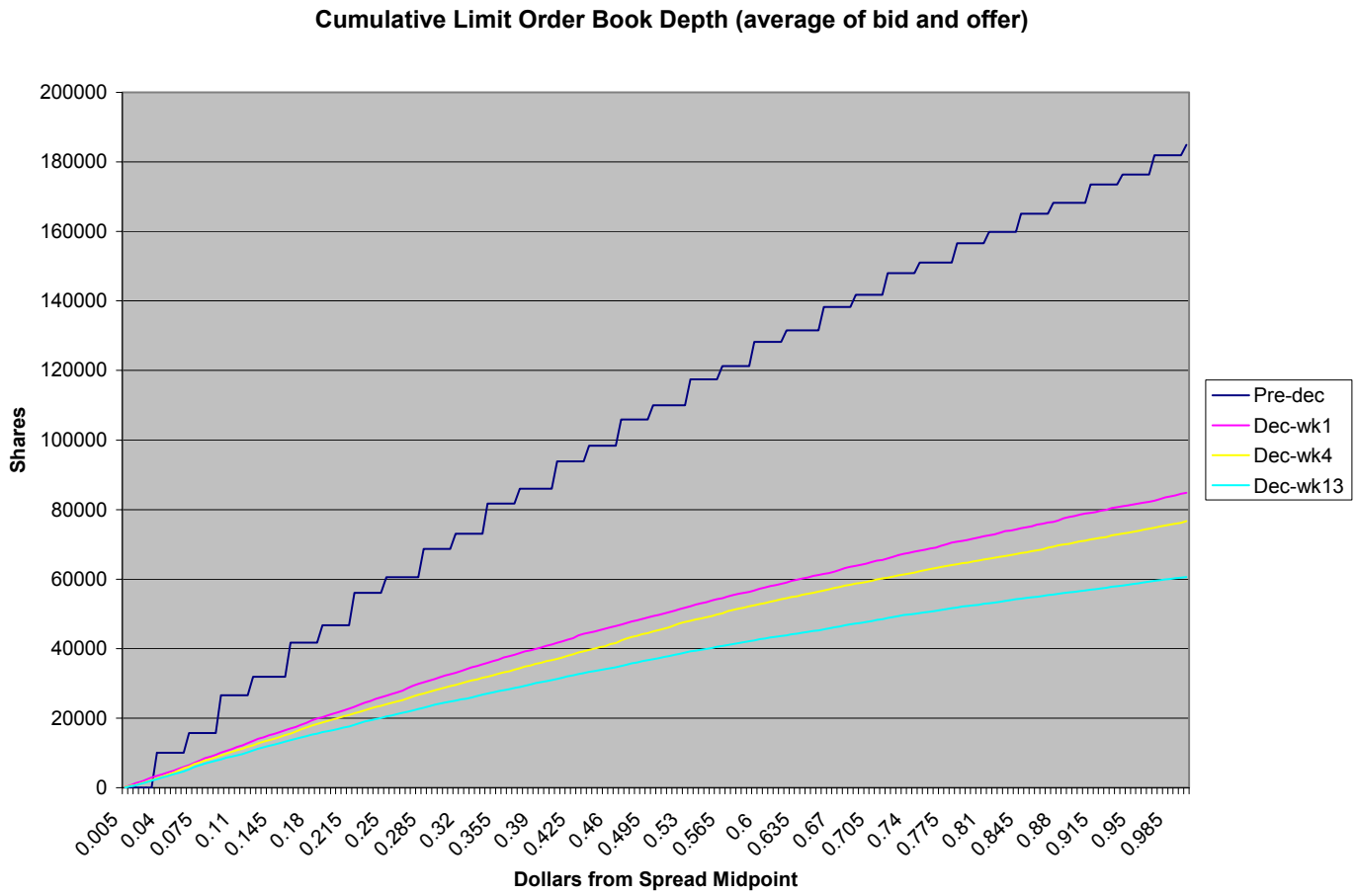
Order size category	Pre-Decimals	Decimals-Week 1	Decimals-Week 4	Decimals-Week 13
Top 50				
<500 shares	18.4	8.7	10.3	8.9
501-1000 shares	18.4	9.4	10.9	9.8
1001-5000 shares	19.9	11.6	13.2	11.4
5001-10000 shares	21.5	14.2	15.8	13.3
10000-24999 shares	22.7	17.2	19.0	16.0
25000-49999 shares	23.9	20.6	22.3	18.4
50000+ shares	25.3	24.8	26.7	20.6

Figure 1

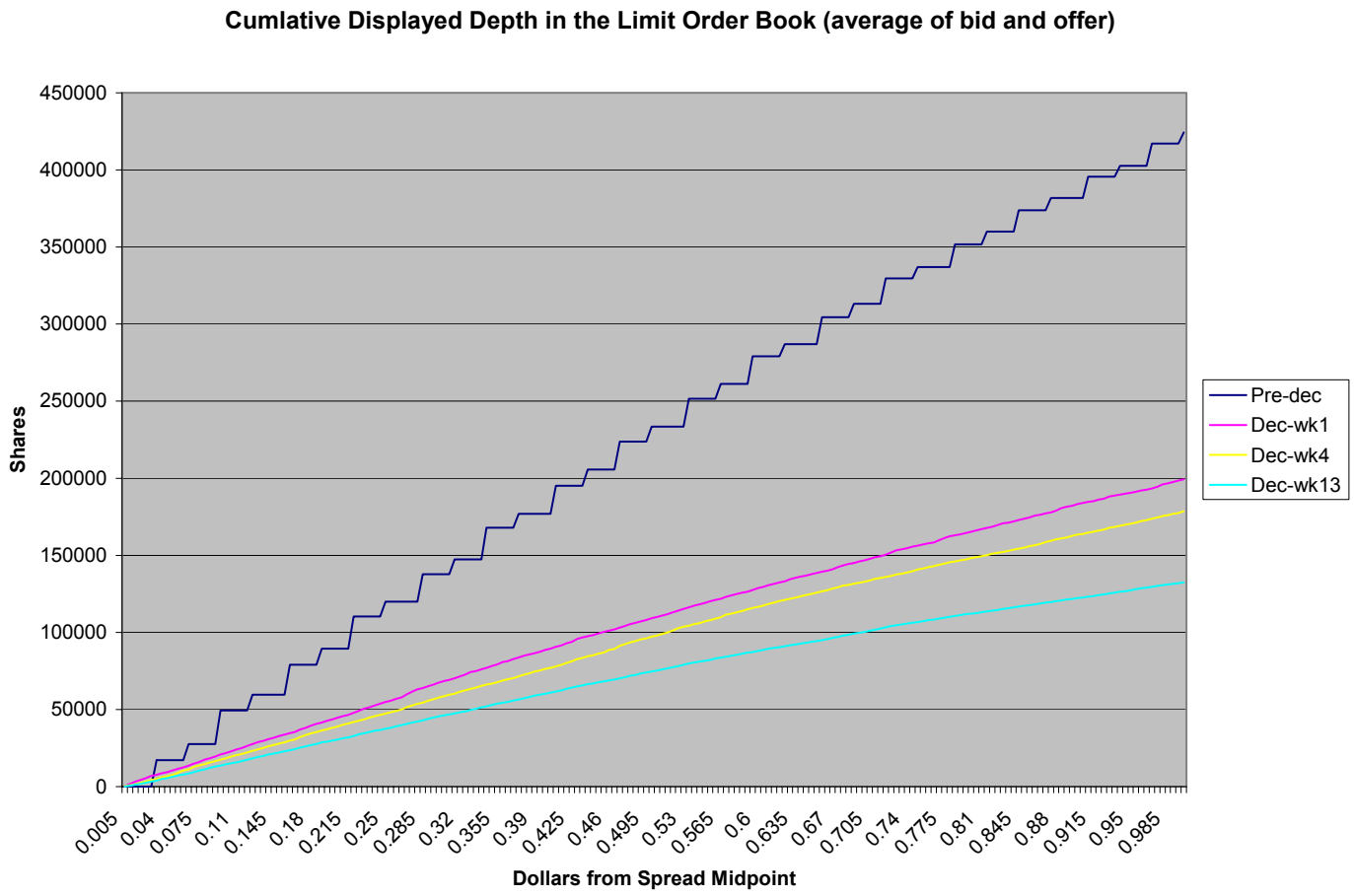
Cumulative Limit Order Book Depth

A snapshot calculation of the cumulative number of shares in the limit order book conditional on the distance of the limit price from the midpoint of the quoted spread at the time of the snapshot. Snapshots are taken daily on the hour (i.e., 10:00, 11:00, 12:00, 1:00, 2:00, 3:00, 4:00). All snapshots are equally weighted in the figures below. To estimate the limit order book, we begin the day with the unfilled good-'til-canceled limit orders in the limit order book at the close of trading the prior day (the NYSE provides the LOFOPEN file). For each day, we add to that beginning position all limit orders arriving before the snapshot is taken and subtract from that all shares cancelled or executed prior to the snapshot. The remaining limit order shares comprise the book. These shares are cumulated as we move up in price from the current offer price for sell limit orders and down in price from the current bid price for limit buy orders. For this presentation, we equally-weight the buy and sell sides of the book.

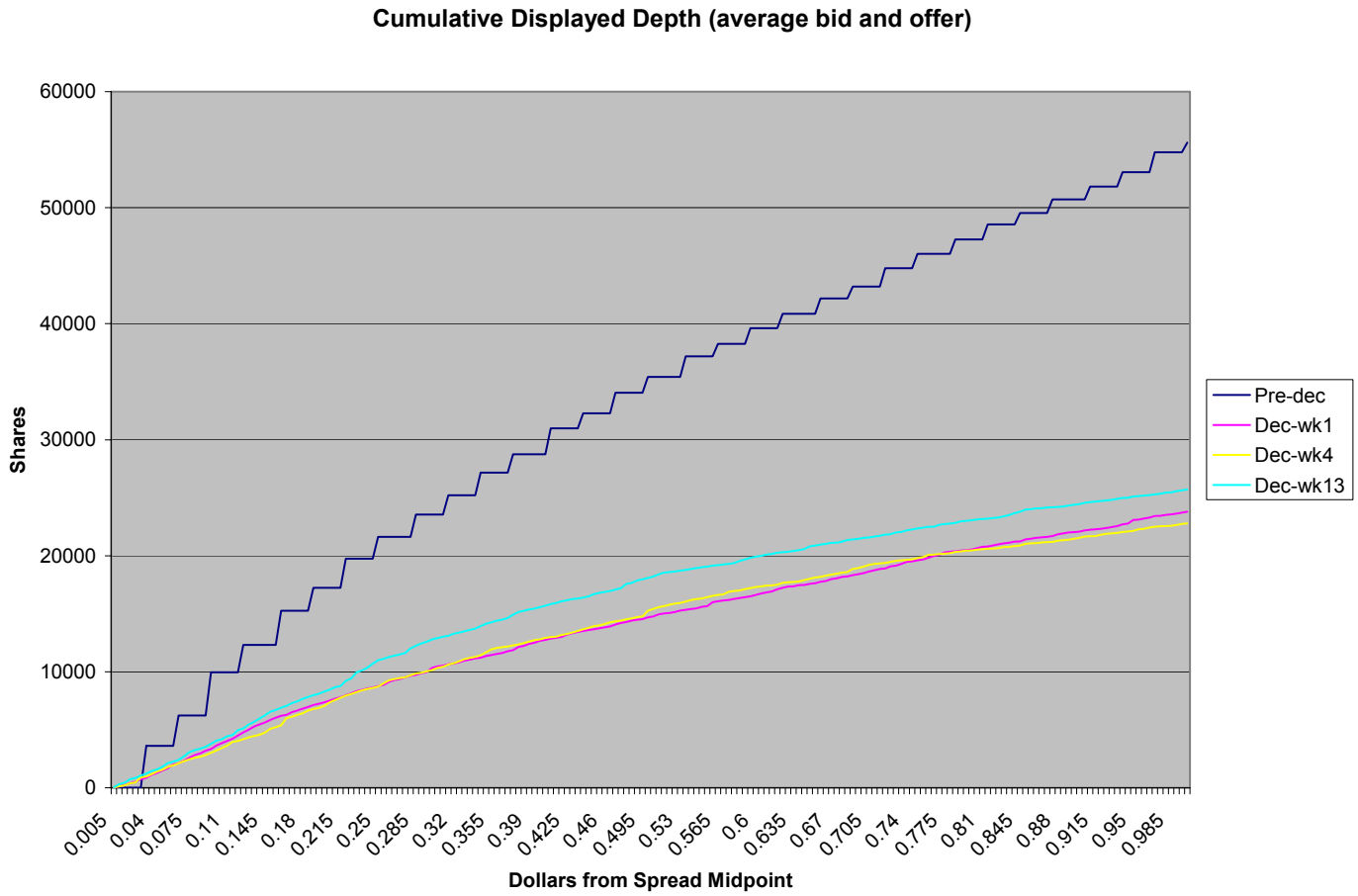
Panel A. All 148 Stocks



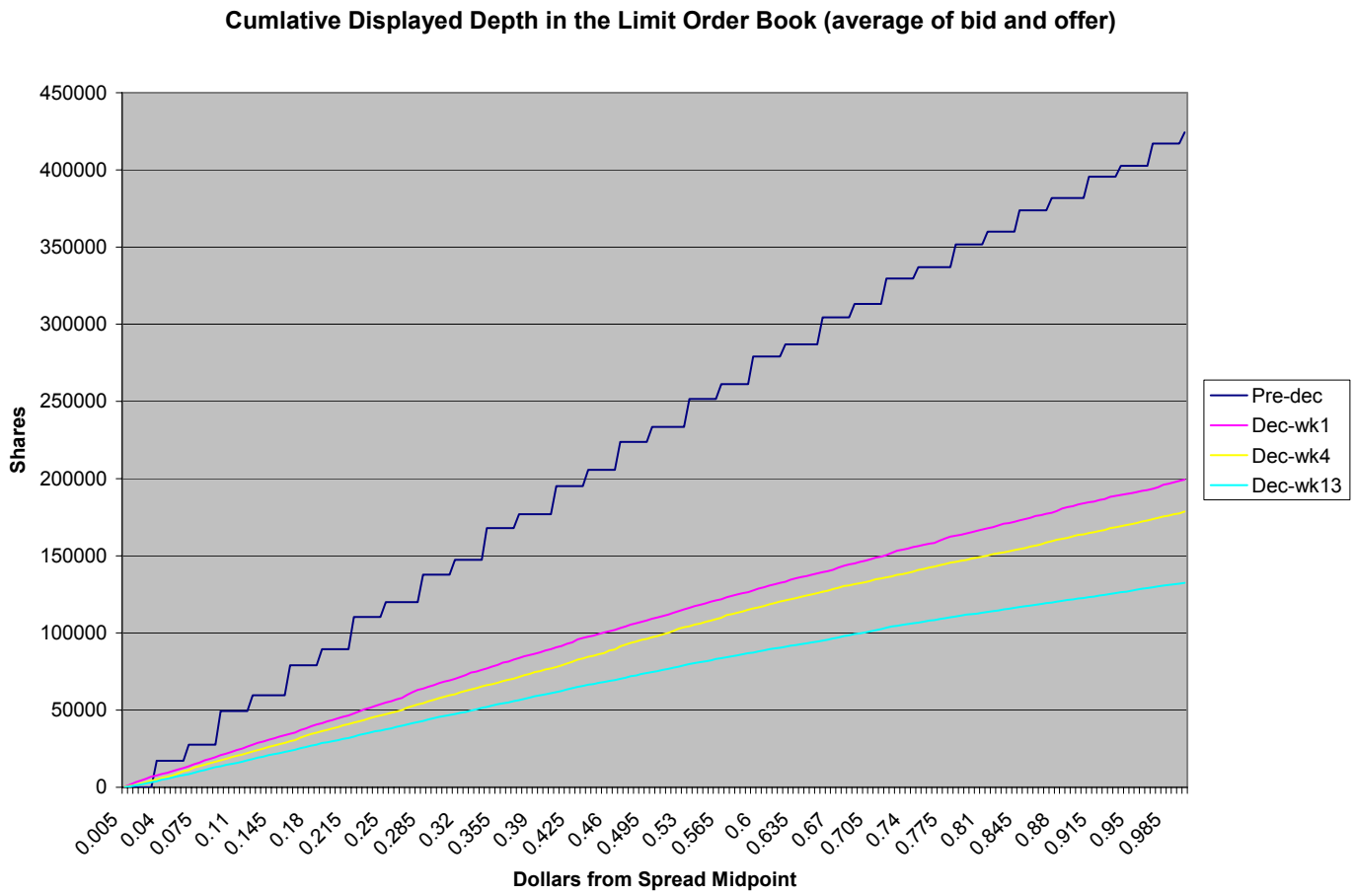
Panel B. Top 50 Stocks



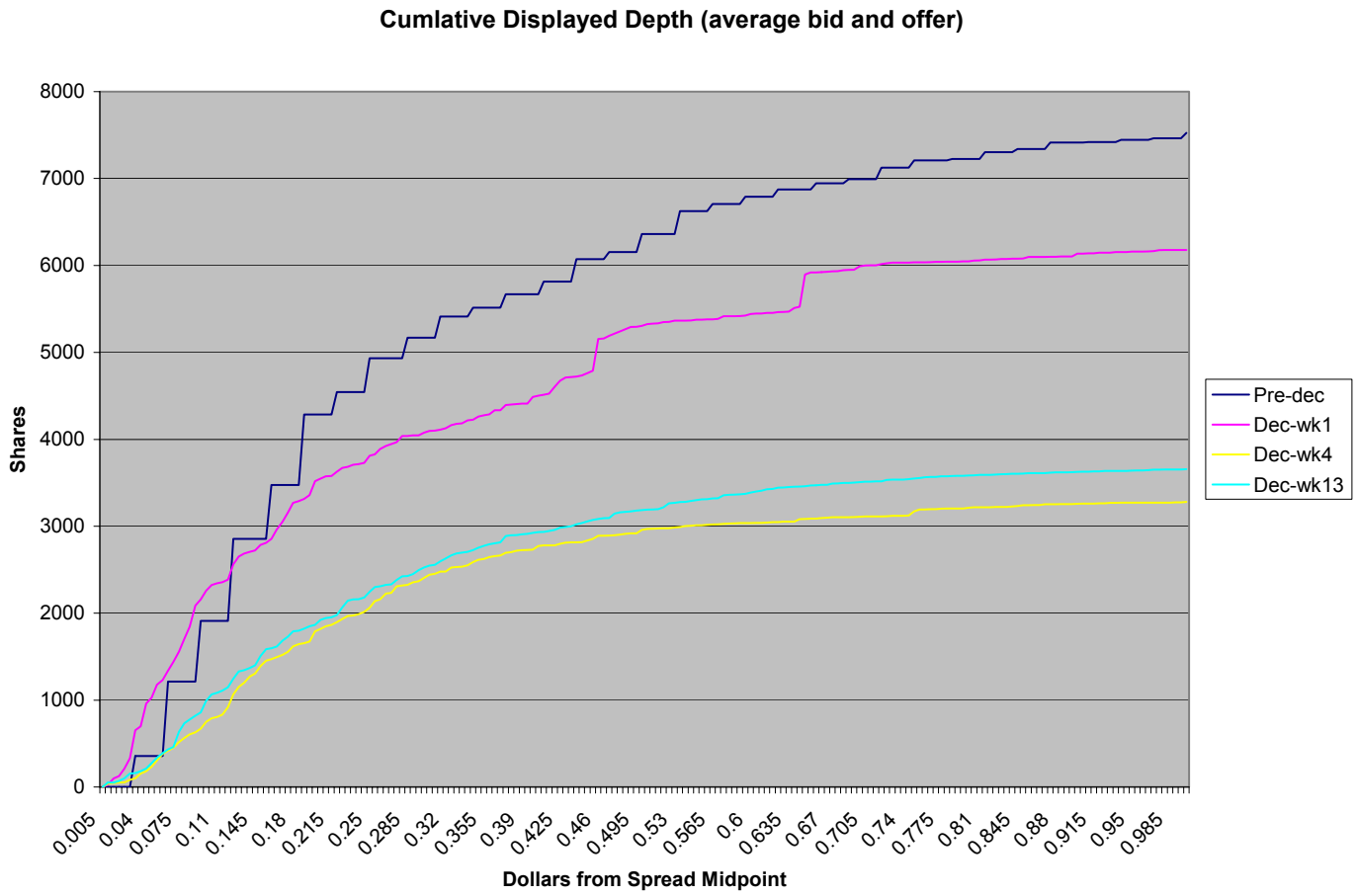
Panel C. High volume-high price Stocks



Panel D. High volume-low price stocks



Panel E. Low volume-high price stocks



Panel F. Low volume-low price stocks

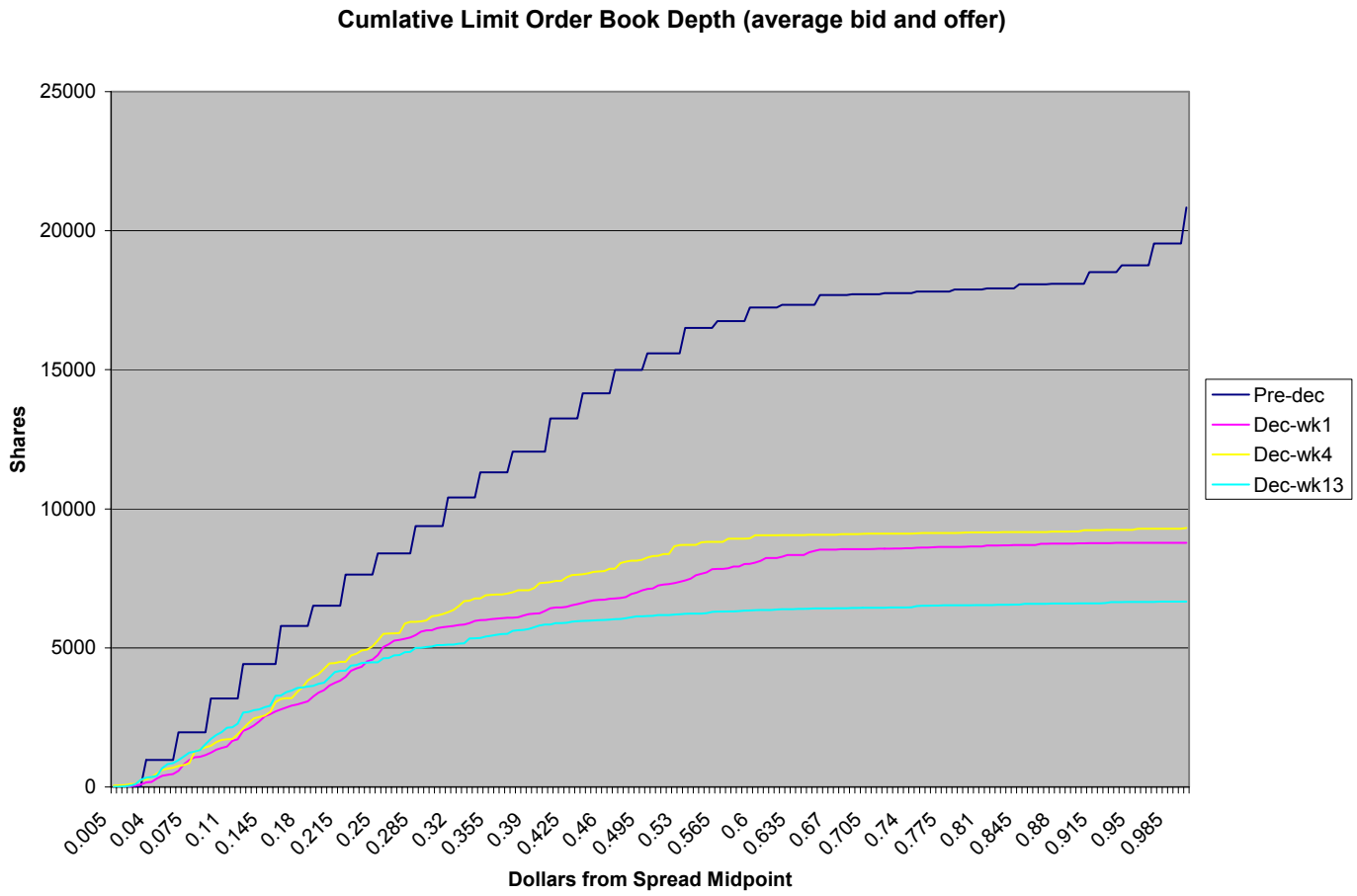
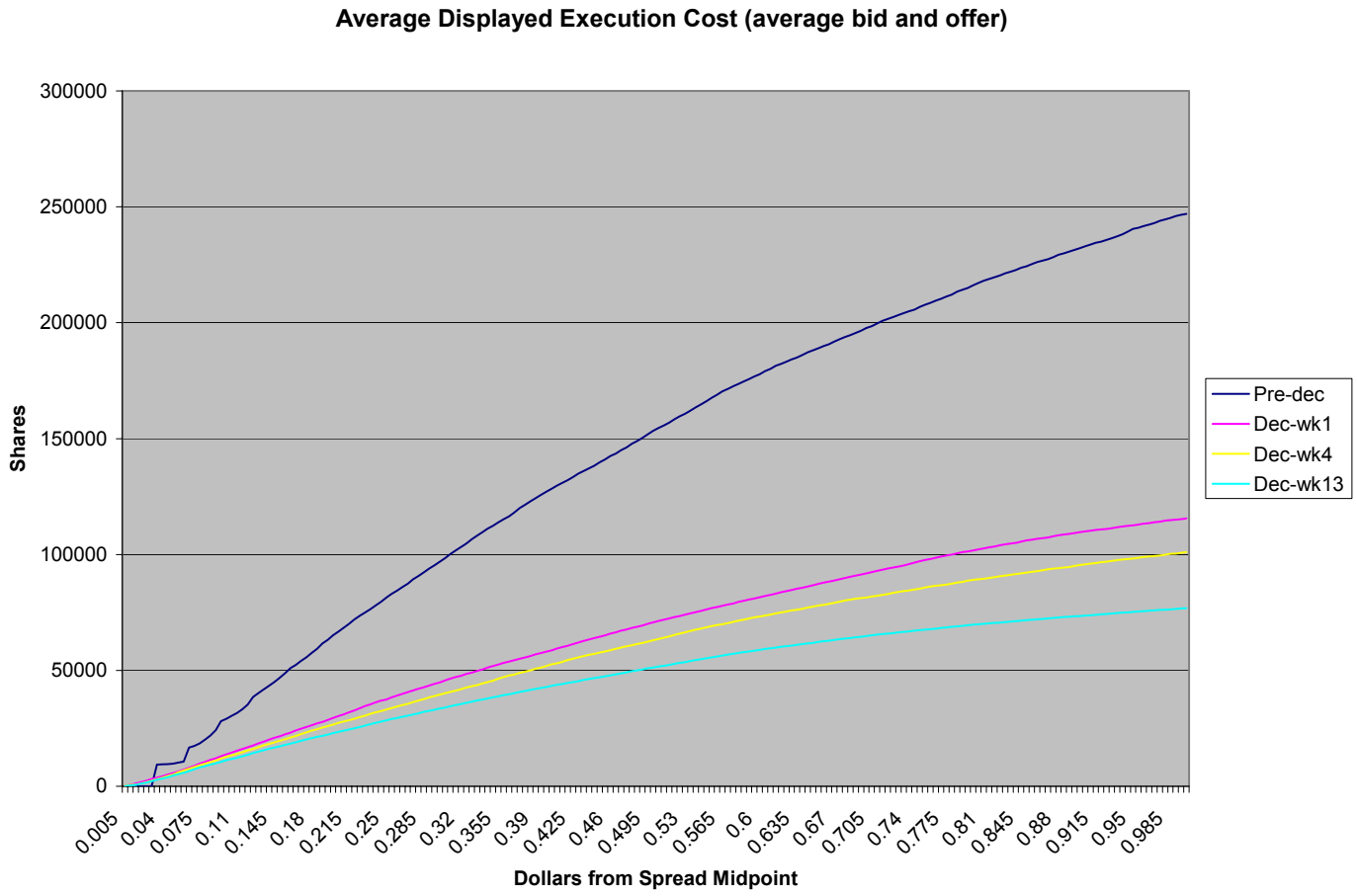


Figure 2

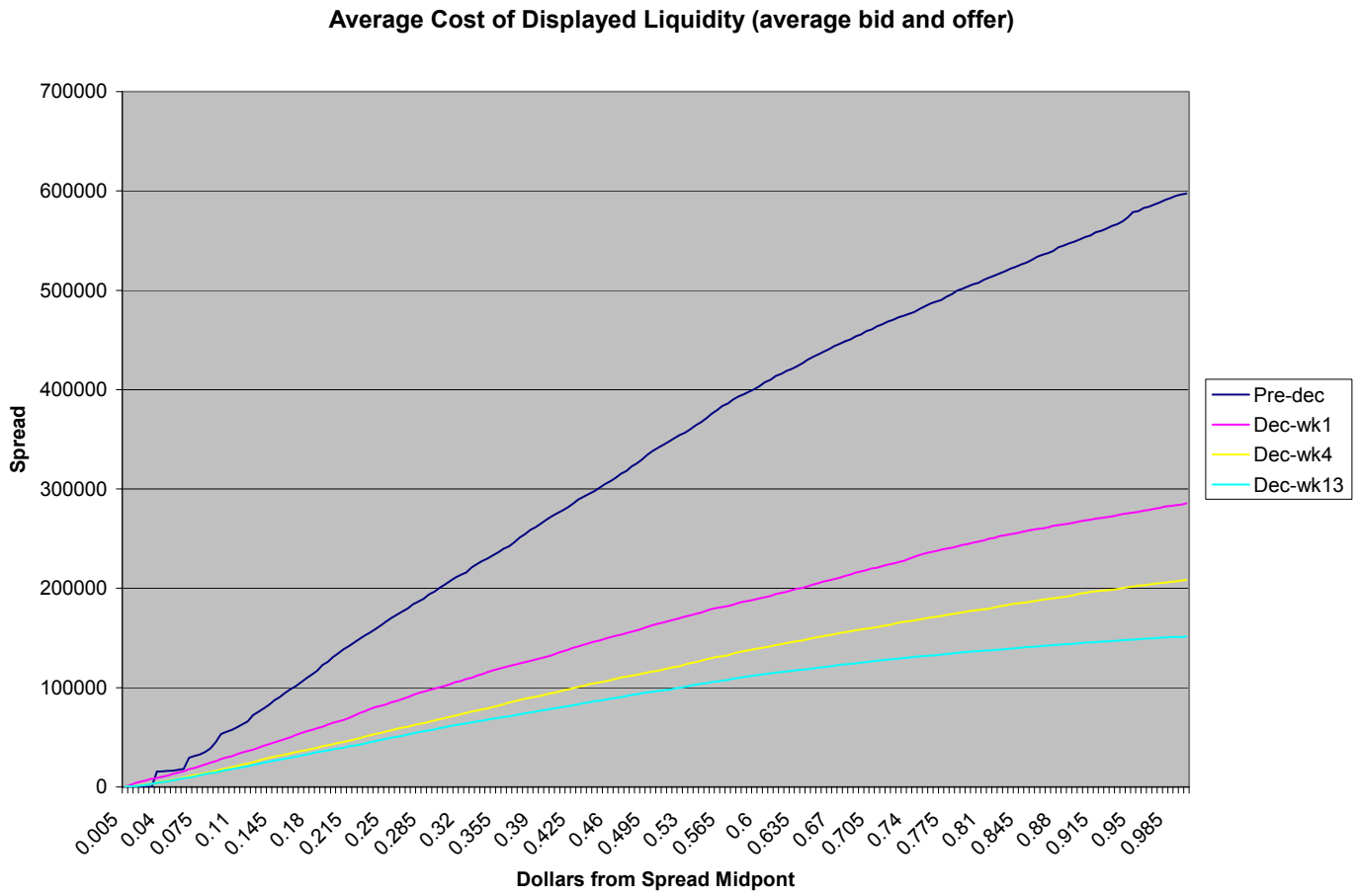
Average Cost of Executing a Trade of a Given Size Assuming that only Displayed Liquidity is Available for the Sample Stocks before and after the Switch to Decimal Pricing on January 29, 2001

To compute average cost, we begin with the cumulative displayed depth at different price points (as illustrated in Figure 1). Beginning at the displayed size closest to the contemporaneous spread, we move up the offer side of the book or down the bid side of the book. At each price point, we multiply the additional shares available at that price point times the distance from the price point to the spread midpoint. When we reach the number of shares in the order, we sum the products from the previous calculations and divide by the total number of shares. For example, suppose that 500 shares are offered at \$0.01 from the contemporaneous best offer, 250 more shares are offered \$0.015 away, and another 250 shares are offered at \$0.02. A 1,000 share buy order faces an average cost of \$0.01375 (= [500 shares × \$0.01 + 250 shares × \$0.015 + 250 shares × \$0.02]/1,000 shares).

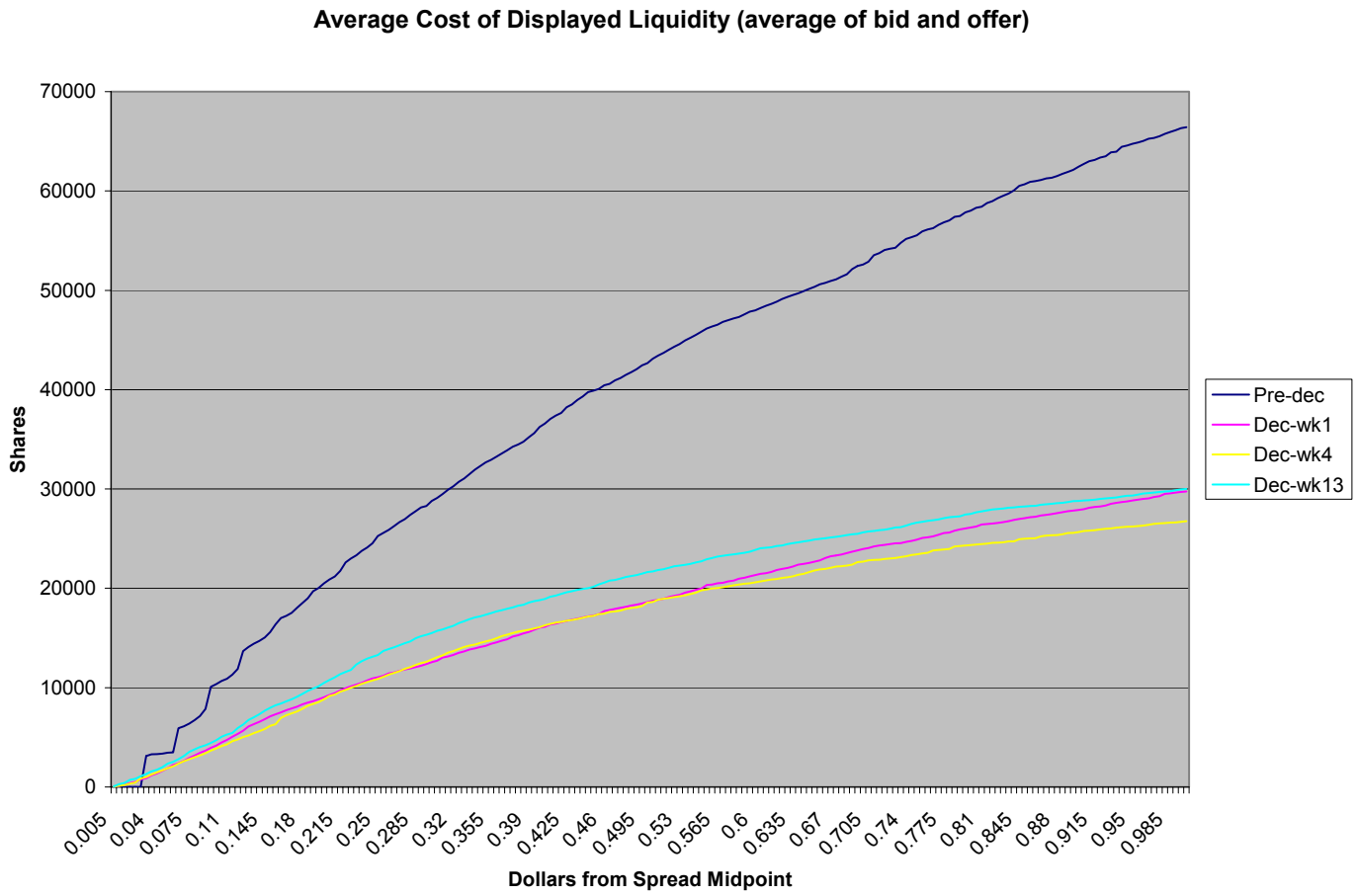
Panel A. All 148 stocks



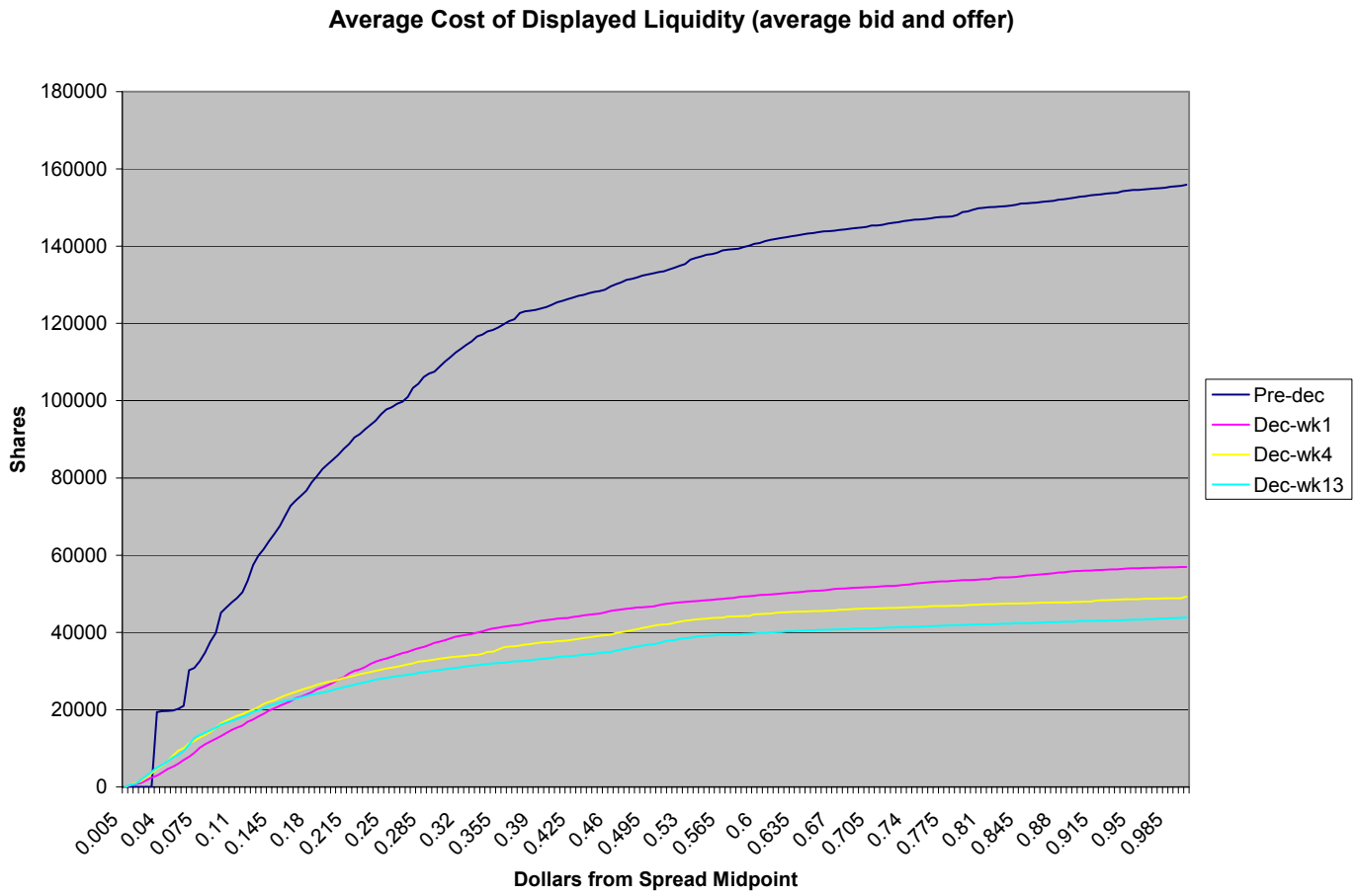
Panel B. Top 50 stocks



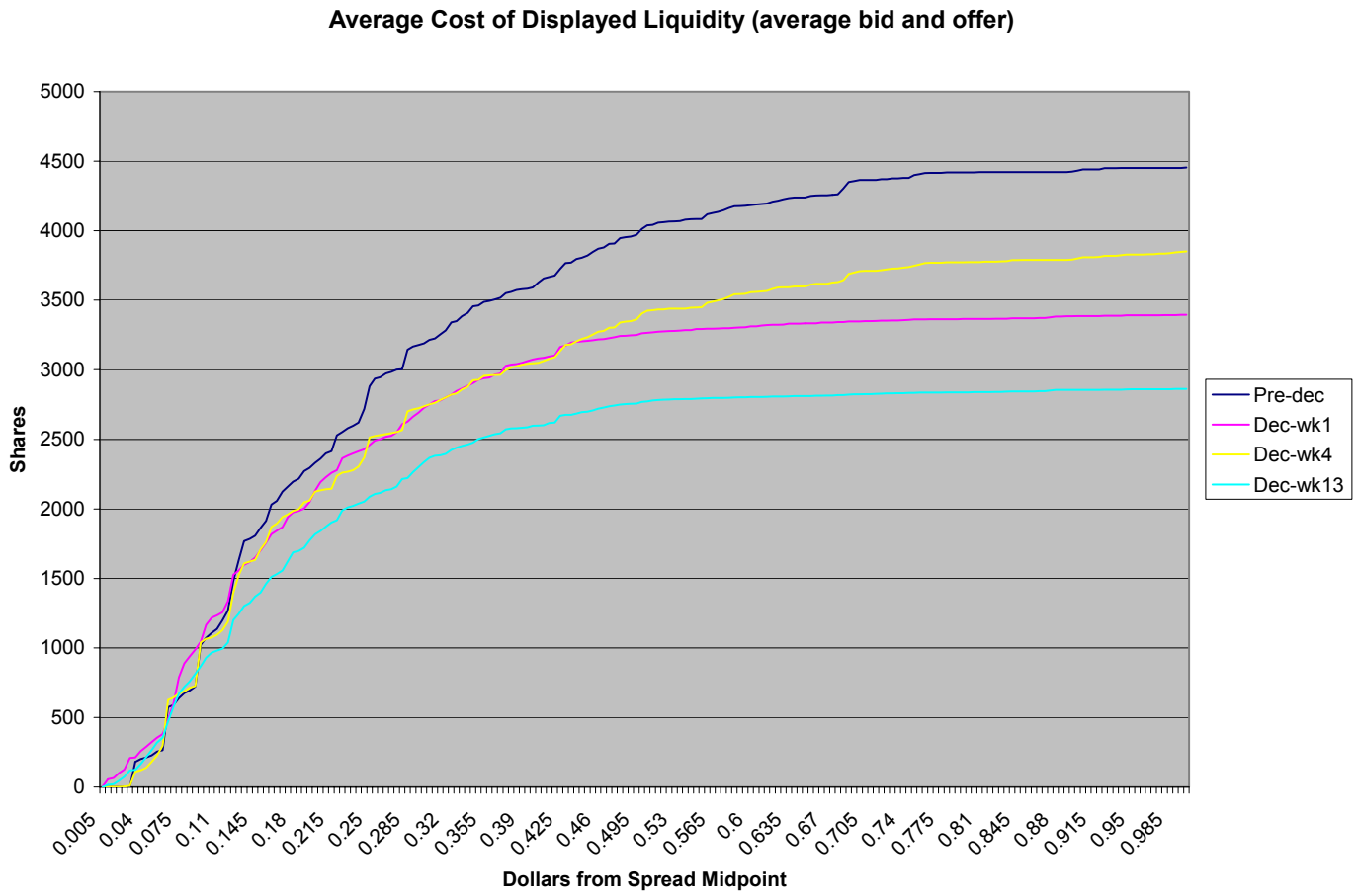
Panel C. High volume-high price stocks



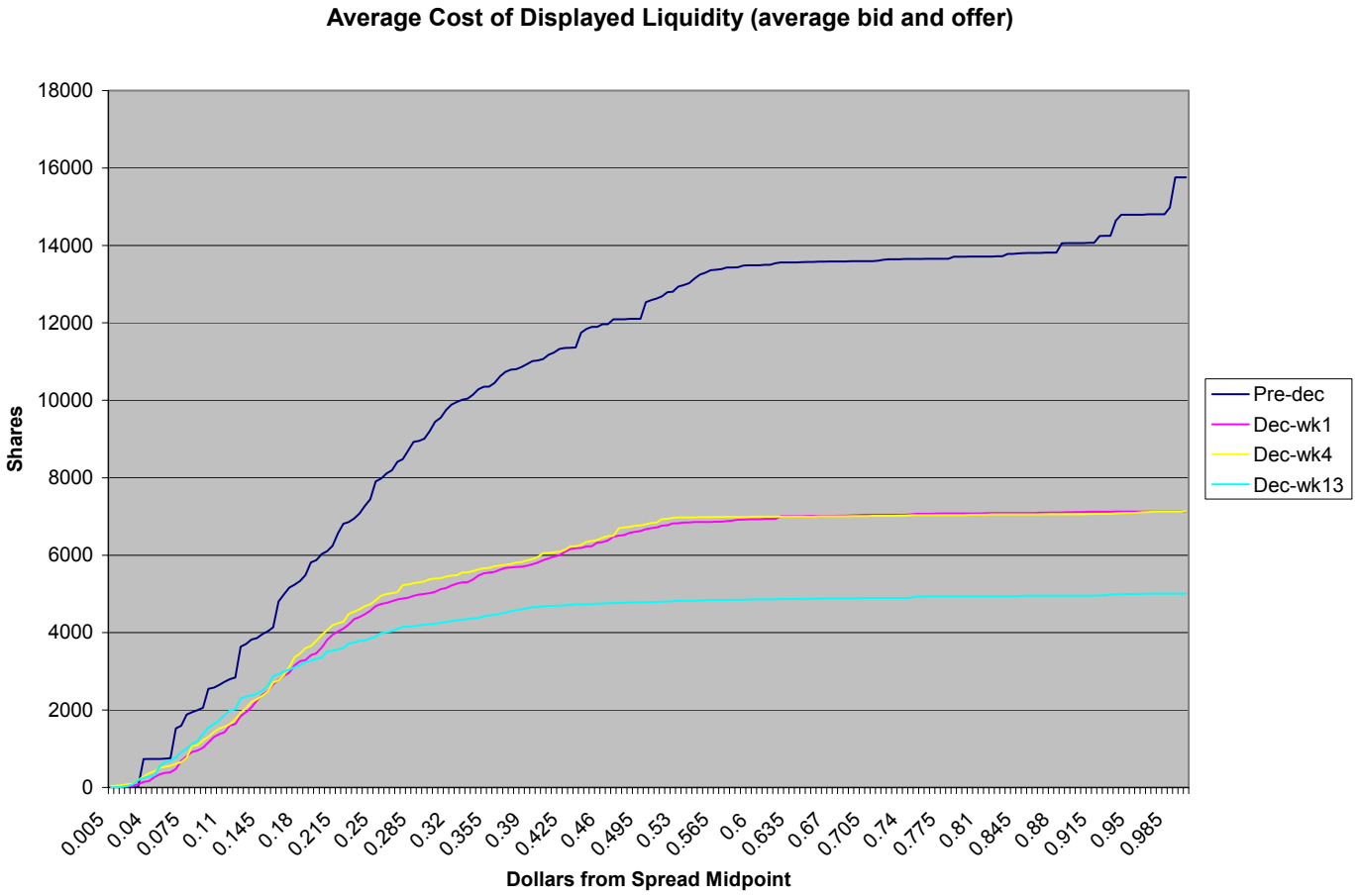
Panel D. High volume-low price stocks



Panel E. Low volume-high price stocks



Panel F. Low volume-low price stocks


Average Cost of Displayed Liquidity (average bid and offer)
Shares
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0.005
0.04
0.075
0.11
0.145
0.18
0.215
0.25
0.285
0.32
0.355
0.39
0.425
0.46
0.495
0.53
0.565
0.6
0.635
0.67
0.705
0.74
0.775
0.81
0.845
0.88
0.915
0.95
0.985
Dollars from Spread Midpoint
Pre-dec
Dec-wk1
Dec-wk4
Dec-wk13