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Decimal Trading and Market Impact

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Abstract

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JEL classification:
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Abstract

Using high-frequency data and a carefully constructed 1-1 matched sample of control (non decimal) stocks, we isolate the effects of decimalization for a sample of NYSE-listed common stocks trading in decimals. We find that both quoted and effective bid-ask spreads and depths have declined significantly following decimalization. Both trades and trading volume have declined significantly in all trade size, as well as in all stock size, categories. Stock return volatilities display an initial increase but a decline over the longer term – probably as traders become more comfortable in their new milieu. Finally, although there is some evidence of increased presence among regional stock exchanges in the wake of decimalization, the NYSE still appears to be very much in the lead in all categories. Our results have important research and policy implications.

"The theory is straightforward: As prices are quoted in smaller and smaller increments, there are more opportunities and less costs for dealers and investors to improve the bid or offer on a security. As more competitive bidding ensues, naturally the spread becomes smaller. And this means better, more efficient prices for investors."

Arthur Levitt, Chairman SEC.
March, 2000.

1. Introduction

Between August 28, 2000, and January 29, 2001, the New York Stock Exchange (NYSE), through a series of incremental steps, began trading and quoting all its listed securities in increments of a penny.[1] Decimalization had finally arrived in Wall Street! A two-hundred-year tradition of trading in fractions was history. We use this act of decimalization in the NYSE as a natural experiment to determine its effect on variables related to market liquidity.

According to the NYSE, the reduction in minimum price increment to sixteenths, in June 1997, was but an interim step in a move toward the decimalization of prices and price increments (Jones and Lipson (2001)). And while it is tempting to think of decimalization as merely a continuation in the process of tick size reduction, it is actually much more than just that. While the move to sixteenths resulted in a doubling of the price points or "ticks", the move to decimals (from sixteenths) resulted in a six-fold increase in ticks. Also, a unique, and potentially dangerous, aspect of decimalization is that for as little as 1 cent per share (as compared to about 6.25 cents a share under sixteenths), intermediaries can step in front of public limit orders in what amounts to "front running." If the stock heads down after this purchase, these investors could simply sell to the public limit orders and be none the worse for it. It is, therefore, conceivable that the supply of liquidity from the investing public in the form of public limit orders may dry up as a result. It can also be easier for institutional investors to jump in front of the queue with limit orders, supplying liquidity rather than demanding it (thereby acting as pseudo-dealers) and, in the process, earning the spread rather than paying it.

The NYSE's board approved conversion to decimal pricing in June 1997 with the goal of making prices more easily comprehensible by investors, reducing spreads and bringing the

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[1] Specifically, the NYSE lowered the minimum tick size to a penny for seven securities on August 28, 2000, 57 more securities on September 25, 2000, and an additional 94 securities on December 5, 2000. All remaining securities began trading in decimals on January 29, 2001.

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United States into conformity with international practices. Market liquidity is of paramount importance to both suppliers and demanders of capital as well as regulators entrusted with the mandate of maintaining a fair and orderly market. Other related benefits of decimalization include savings for investors through narrower spreads and easily understood numbers. While there is little debate that prices are easily understood under the decimal system where one does not have to pause momentarily and wonder if 5/8 is greater than 9/16, for example, whether or not this has actually impacted market liquidity (and its various facets) is an empirical issue and is a focus of the current paper.

The fact that the NYSE converted to decimal pricing via a phased, pilot program allows us to form a matched, non-decimal control sample. We use the matched securities to control for market effects that might occur coincidentally with the decimalization of the pilot securities' prices. In addition, we use the decimal-pilot securities as a control sample when trading in the matched (non-decimal) securities was decimalized on January 29, 2001, by examining the behavior of both groups of stocks up to March 30, 2001. Our final decimal sample of 79 common stocks (out of 158 total securities included in the decimal pilot) is arrived at after filtering out all non-common stocks (like preferred stocks, closed end funds, ADRs, etc.) and ensuring certain minimum price and trading conditions are satisfied. These filters are incorporated to minimize confounding effects and are detailed later. The 79 common stocks from the decimal pilot are denoted "decimal stocks," while the 79 corresponding (non-decimal) stocks created by matching each decimal stock to are labeled "control stocks". We then use tick-by-tick (TAQ) data for these stocks to investigate the impact of decimal trading on the various facets of market liquidity. Our investigation period comprises three distinct periods surrounding the decimal pilot in the NYSE: (1) a pre-decimal period (before any NYSE stock was trading in decimals); (2) a decimal-trial period (when only securities in the NYSE's decimal pilot were trading in decimals); and (3) an all-decimal period (when all NYSE stocks were trading in decimals). Including the latter period enables us to study the long-term effects of decimalization on the stocks in our sample.

Our main results can be summarized as follows. We find that both bid and ask quote increments of 5 cents or less appear to be used actively by the market, and that both the quoted and effective bid-ask spreads and depths have declined significantly, following decimalization. We find that both trades and trading volume have declined significantly in all trade size

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categories as well as in all stock size categories. Stock return volatilities display an initial increase but a decline over the longer term – probably as traders become more comfortable in their new milieu. Although there is some evidence to suggest increased activity among the regional stock exchanges with regard to bid-ask quote adjustment frequencies, autoquotes[2] and BBO times, in the wake of decimalization, the evidence is not strong and the NYSE appears to be still very much in the lead in all these categories.

Our results have important policy implications as the debate continues over the judiciousness of decimalization. The fact that quote increments of five cents or less appear to be used actively following decimalization may imply the fact that minimum prices increments of $1/8 or $1/16 may have represented barriers to price competition. Furthermore, the proponents of decimalization argue that decimals allow for more efficient price discovery without adversely affecting the supply of liquidity. Opponents claim that decimals will result in less liquid, high volatility markets. Our results, however, provide a mixed verdict on the issue of liquidity and volatility. Overall, the results suggest that we have moved to a new phase in security transactions – one in which participants will have to learn new rules to play the game effectively. Whether or not they do so, will determine, in large part, the success of decimalization in keeping prices efficient and markets liquid. At the very least, information about the available supply and demand schedule outside the BBO will be have to be made available to market participants. Interestingly, the NYSE has already started publicly providing information on the depth of the limit order book.[3]

The current research falls into a large body of research on tick-size reductions. And despite such efforts – both theoretical and empirical, its appropriateness remains an open question.[4] Most relevant to our work, however, is a complementary research by Chakravarty,

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[2] Autoquote is a bid ask quote generated automatically by computers in regional exchanges positioned just outside the prevailing highest price to buy and the lowest price to sell (otherwise known as the best bid and offer or BBO). The presence of autoquotes usually mean that the regional specialists are willing to be market participants for orders but not by paying as aggressive a price as the BBO.

[3] Specifically, the NYSE, beginning March 19, 2001, started disseminating "depth indications" on eight of its stocks. Its purpose is to show investors that there is a meaningful number of shares of a given stock available beyond the best price being bid and offered for the stock (WSJ, March 15, 2001, C1). This has now been expanded to all NYSE-listed securities.

[4] Examples of theoretical research include Grossman and Miller (1988), Brown, Laux and Schachter (1991), Hart (1993), Chordia and Subrahmanyam (1995), Peake (1995), Bernhardt and Hughson (1996), Kandel and Marx (1996), Cordella and Foucault (1996), O'Connell (1997), Harris (1994, 1997), Seppi (1997), and

Panchapagesan and Wood (2001) that examines institutional trade execution costs around decimalization in the NYSE using proprietary data and finds no evidence of increased trade execution costs following decimalization. An important implication of their study is that the available supply and demand of shares outside the best bid and offer prices remains undiminished. Our results, combined with those of Chakravarty, Panchapagesan and Wood, should allay the fears of regulators, academics and practitioners, who are afraid that decimalization may have decreased liquidity in the NYSE.

2. Data and Methodology

2.1 The Sample Stocks

The stocks in the decimal pilot were chosen based on several criteria developed by the NYSE, along with a securities-industry committee. These criteria include stocks having varying levels of daily trading activity, that trade on multiple exchanges, are part of an index, are underlying issues for multiply listed options; and may have corporate action pending. To avoid introducing confounding effects, we eliminate all preferred and convertible preferred stocks, closed end funds, ADRs, stocks with abnormally low average daily trading volume and stocks with no trading in at least one day over the study period. We also exclude all common stocks below $5 and above $150, and those stocks in the decimal pilot that moved from Nasdaq to NYSE during the period of the study. Our final sample comprises 79 NYSE-listed common stocks selected for trading in decimals under the three phases of the decimal pilot.

2.2 Selection of Control Stocks

Investigating the impact of decimalization on the pilot stocks after (relative to before) the event is valid under the assumption that the market remains constant over the entire examination period. In the presence of market trends, however, it is impossible to tell if an effect is due to decimalization or due to market trends. One way to isolate the effect of decimalization, independent of market trends, is to examine a matching sample of stocks, identical to the control stocks in every way, except that they do not trade in decimals.

Anshuman and Kalay (1998). Examples of empirical research include Crack (1994), Ahn, Cao and Choe (1996), Bacidore (1997), Bessembinder (1997), Huson, Kim and Mehrotra (1997), Porter and Weaver (1997) and Ahn, Cao and Choe (1998), Ronen and Weaver (1998), Bollen and Whaley (1998), Ricker (1998), Goldstein and Kavajecz (2000), Jones and Lipson (2001)).

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Accordingly, the control stocks are selected from the NYSE stocks with the same industry codes and security types (e.g. common stock) as the particular decimal stock. The precise control stock is now chosen to minimize the expression, $\Sigma_k \, (c_j^k - c_i^k)^2 / [(c_j^k + c_i^k)/2]$, where c_i^k (c_j^k) is the decimal (matched) stock measurement of characteristic k. Characteristics controlled include stock price, equity market capitalization, and trading volume. In addition to minimizing the sum, no single element of the summation is allowed to exceed unity. Bacidore et al. (2001) use a similar approach to select their control sample. It should be noted, however, that we go beyond them by employing an optimization model that *simultaneously* considers all possible (decimal-control) pairs, and selects only those pairs that minimize the overall distances. Further details of the procedure are provided in McInish and Wood (1986). The appendix provides a listing (and other details) of each decimal stock in our sample and the corresponding matched control stock.

We obtain tick-by-tick transaction and quote data for each stock in our decimal and control stock sample over the three distinct periods of study: October 2, 2000, to January 26, 2001 (the *decimal-trial* period, when only some chosen stocks in the NYSE were trading in decimals, with the remaining stocks trading in sixteenths);[5] January 29, 2001 – March 30, 2001 (the *all-decimal* period, when all NYSE stocks were trading in decimals); and April 1, 2000 – June 30, 2000 (the *pre-decimal* period, when no NYSE stocks were trading in decimals but, rather, trading in sixteenths).

3. Decimalization and Bid and Ask Quotes

The quote data, used below, is extensively error filtered and all quotes with missing values, with negative and zero spreads, and with quoted spreads greater than $2, are eliminated. This removes less than 1% of the quotes.[6] The corresponding transactions prices

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[5] We choose the start date of the decimal-trial period from October 2 -- i.e., week 6 onwards, relative to the start of Phase I decimal pilot in August 28, 2000 -- to provide enough time for market participants to have found an equilibrium trading pattern, since private communications with professional traders confirm that significant "learning" took place in the first few weeks of commencement of the decimal pilot as traders freely experimented with the new system.

[6] The comparison of trades and quotes also requires that data from CTA and CQS be merged by time. For various technical reasons (see Blume and Goldstein (1997), Hasbrouck and Soesbee (1992)), not only can the time stamps be in error, but also the very sequencing of trades in the same stock can be wrong. We considered using the Blume and Goldstein (1997) formula to adjust our quote time stamps the same

are also examined (and filtered) for potential errors. We begin our investigation by providing, in the following section, some metrics related to bid-ask quotes, based on the NYSE-listed decimal and control stocks in our sample, over the three distinct periods of study. These metrics are of interest to practitioners and regulators as an indicator of the overall health of the equity markets.

3.1 BBO quotes and quote change characteristics

There exists, at any point in time, a set of bid and ask quotes that represent the highest price to buy and the lowest price to sell. This is known as the best bid and offer (BBO). In a continuous auction market, such as the NYSE, a specialist posts quotes in stocks, comprising of a combination of own interest as well as the interest of the public limit orders competing directly with the specialist. Such competition can also come from the regional stock exchanges, posting quotes simultaneously in those stocks. In short, BBOs are generated by public limit orders originating both in the primary market as well in the regional stock exchanges, and dictate which exchange at any point in time has the best bid and offer quotes. The fraction of time that any particular exchange has the BBO is an indication of its dominance in terms of a supplying liquidity as well as price discovery – arguably the two most important roles of a modern financial exchange.

We begin by investigating the fraction of total trading time that a BBO is in effect across the regional exchanges for decimal and control stocks over all three periods of interest. We find that NYSE dominates the BBO times in both decimal and control stocks over all three periods. Thus, for example, over the pre-decimal period, NYSE had about 95% of the BBO times for both decimal and control stocks; about 94% and 96% of the BBO times for decimal and control stocks over the decimal-trial period; and about 94% of the BBO times for both decimal and control stocks over the all-decimal period. Thus, the dominance of the NYSE, in this regard, is clear.

Next, we move on to investigate the frequency of changes in the BBOs. The purpose is to see if all penny increments are being hit after decimalization or if the BBO quote changes are

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trading day. But the quote adjustment algorithm Blume and Goldstein develop is based upon 10-year old data contained in the NYSE TORQ database. Extensive improvements in trade recording systems have been implemented in the intervening years and there is currently a sense that adjusting quote time stamps is no longer appropriate.

loading up only on certain penny increments. Specifically, we sum the number of times the best prevailing bid (ask) changes by 1 cent, 2 cents, and so on, for all the decimal and control stocks in our sample and over the decimal-trial and all-decimal periods.

Over the decimal-trial period, we find that while about 25% (40%) of quote changes in control (decimal) stocks occur at 1/16ths (6 cents or less) and 52% (76%) at 1/8ths (12 cents or less), and only about 6% of the changes in decimal stocks occur at one penny. Over the all-decimal period, in comparison, 36% (34%) of quote changes in control (decimal) stocks occur at 6 cents or less and 70% (68%) at 12 cents or less, and only about 5% of the changes in both decimal stock and control stocks occur at one penny. Thus, while quote increments of less than 6 cents appear to be used actively by the market in decimal stocks, the evidence is by no means overwhelming. Also, over time, the relative frequency of using quote increments of 6 cents or less appears to have diminished significantly. This evidence flies in the face of those who believe that a minimum tick size of $1/16 may have represented a significant barrier to price competition, which would be ameliorated with decimal pricing.

Given the reasonable use of increments of 5 cents or less in the BBOs noted above, a related question to investigate is which regional exchanges are responsible for this narrowing of the BBOs. Specifically, we examine 1-5 cents quote changes (at the best bid and at the best ask) classified by the regional exchanges quoting them over both decimal-trial and all-decimal periods. Not surprisingly, we find that the NYSE has by far the greatest number of 1-5 cent changes, while the NASDAQ is competitive in all five-cent categories. Overall, it appears that even though the regional exchanges are actively contending for quote changes, the NYSE is still leading the way.

We now turn to the issue of dynamic quote behavior addressed by various researchers both in the context of increased fragmentation of U.S. equity orders and in the context of price discovery (see, for example, Garbade and Silber (1979), Shapiro (1993) and Hasbrouck (1995)). The NYSE and the regional exchanges are electronically linked and all trades and quotes are disseminated by a central transmission authority (the Consolidated Tape Association (CTA)). Although the regional exchanges sometimes establish the BBO, frequently they will choose to extract themselves from active quote competition in listed stocks by programming a computer to intercept all NYSE/AMEX quotes and immediately generate a new quote of their own by adding a delta to the ask and subtracting a delta from the bid, with 100 shares bid and 100

shares offered (the bid and ask depths). The mechanism(s) by which the regional quotes default to the BBOs, widened by a small arbitrary amount, are known as "autoquotes". Thus, an autoquote is effectively a non-quote whereby regional specialists signal that they are willing to supply liquidity but not at the best prices. Trades occur on the regional exchanges during periods of autoquoting, but those trades must match (or improve upon) the existing BBO. Our algorithm identifies an autoquote as any regional or third-market quote that brackets the existing NYSE or AMEX quote.

With the advent of decimalization it is reasonable to anticipate a change in the pattern of posting of quotes off the BBO by serious liquidity providers wising to earn more than a 1-2 cent spread. With the relatively thin book that naturally results from tighter spreads, significant buy/sell programs could easily march up/down the book and hit limit orders away from the minimum tick size.

We examine the percentage of time the NYSE-listed decimal and control stocks are autoquoted, over the three periods of interest, in the various regional exchanges. Specifically, we compute a simple percentage of all autoquotes from a given regional over all quotes from the regionals and the NYSE. While tests reveal (results not presented formally) that the percentage of autoquoting is statistically similar between decimal and control stocks in the pre-decimal period, autoquoting increased significantly over the decimal-trial period in decimal stocks, relative to control stocks, in most regional exchanges. Specifically, Cincinnati, Pacific and Chicago, among the regionals, appear to have the highest increases of autoquoting in decimal stocks. This increase in autoquoting is perhaps an indication of the uncertainty felt by these regionals in their effort toward efficient price discovery and their role as liquidity suppliers in a post-decimal world.

3.2   Quoted and Effective bid/ask spreads

A traditional measure of market liquidity has been the quoted bid-ask spread capturing the ex ante transactions cost. Petersen and Fialkowski (1994) and others have, however, argued for a related measure, the effective spread[7], which measures the ex post transaction cost, contending that the quoted bid-ask spread is no longer an accurate measure of transaction costs when trades are executed inside the prevailing quoted spread.

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[7] Effective spread is formally defined as twice the absolute difference between the transaction rice and the midpoint of the prevailing best bid and ask (BBO) prices.

We begin our investigation into spreads by examining, in Table 1A, the distribution of *all* quoted spreads originating from the national and regional exchanges in terms of odd and even ticks for decimal and control stocks, over both the decimal-trial and all-decimal periods. Over the decimal-trial period, the decimal stocks are almost even split between even and odd ticks in every exchange, while the control stock spreads, over the same period, appear to be overwhelmingly on even ticks. Recalling that the control stocks over this period were trading in sixteenths, the implication is that the smallest possible spread in those stocks was $2/16 or $1/8. Interestingly, over the all-decimal period, when all stocks were trading in decimals, the quotes for both the decimal and control stocks originating in the regionals were almost evenly divided into even and odd ticks. The exceptions were the NYSE (NASDAQ), which shows significantly more odd (even) ticks in all stocks. Thus, for example, about 61% (45%) of all ticks from the NASDAQ (NYSE) appear to be at even ticks.

Table 1B refines the examination of quoted spreads by investigating the distribution of only the BBO spreads (in cents) for decimal and control stocks over the decimal-trial and all-decimal periods. Decimal stocks display a higher frequency of spreads at six cents or less relative to the control stocks (51% versus 42%) over the decimal-trial period. Decimal stocks continue to display a greater dispersion even at spreads of 25 cents (or below). In examining the performance of decimal stocks over the all-decimal period, we see that the spread dispersion at 12 cents or below declines, while it improves at 13 cents or above, both relative to the decimal-trial period. Interestingly, the dispersion of the control stock spreads shows a marked improvement over the all-decimal period relative to the decimal-trial period when they were trading in sixteenths. Thus, for example, about 42% (52%) of the spreads in control stocks were at 6 cents or below over the decimal-trial (all-decimal) period. Furthermore, 73% (78%) of the spreads in control stocks were at 12 cents or below over the decimal-trial (all-decimal) period. Overall, it should be comforting to the supporters of decimal pricing that quote increments of 5 cents or less appear to be used actively by the market in a post-decimal world.

Tables 2 and 3 provide information on the quoted and the effective bid/ask spreads, in cents, on the NYSE-listed decimal stocks and the corresponding control stocks over all three periods considered in the study – the pre-decimal, decimal-trial and all-decimal periods. Both the quoted and effective bid/ask spreads are calculated on the basis of the best bid and offer (BBO) quotes available at the time of trade. Thus, autoquotes, which simply bracket an existing

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BBO, are automatically eliminated from consideration. We compute spreads of stock portfolios formed on the basis of the average daily dollar volume of trade of stocks over the pre-decimal period. Stocks in portfolio 1 (5) comprise the smallest (largest) dollar volume stocks. The reported spreads in Table 2 (and in Panel A of Table 3) for each dollar volume portfolio are computed by weighting, for a given stock within a given day, by the time each spread is outstanding, and weighted across stocks, by their daily average pre-decimal dollar trading volume.

Table 2 reveals that the decrease (over the decimal-trial period) in quoted spreads for decimal stocks is significant across all five dollar volume portfolios, and ranges from 26% to 36%, while the (dollar-volume weighted) average decline over all portfolios is about 35%. The corresponding decline in the control stock portfolios ranges from a 2% to 16%, with an overall average decline of about 16%. Thus, decimalization appears to have significantly reduced quoted spreads, in comparison to control stocks. On continuing our examination over the all-decimal period we find that quoted spreads in the decimal stocks have increased a little only in the smallest size portfolio. In the remaining portfolios, the quoted spreads continue to trend downwards.

To isolate the effect of decimalization on the quoted spreads of decimals stocks, the net difference in quoted spreads in decimal stocks is calculated as the difference between the daily average quoted spread of each decimal stock and its paired control stock in a particular size rank. For each portfolio, the average of these differences over each (pre-decimal, decimal-trial and all-decimal) period is then computed. The average of the differences, (trial - pre) and (all - pre), within each portfolio, is reported in Table 2. These reveal that decimalization itself may have resulted in quoted spreads declining by an average of about 2.2 cents. The last column of Table 2 confirms that the difference in quoted spreads between decimal and control stocks is statistically insignificant over the all-decimal period, which is what we would expect if the control stocks are similar to the decimal stocks and both groups are trading in decimals. The last column, therefore, serves as a robustness check of the efficacy of our control stock selection.

Table 3 Panel A reports the effective spreads of portfolios, once again classified by their average daily pre-decimal dollar volume. The reduction in effective spreads in decimal stocks ranges from 19% (portfolio 5) to 30% (portfolio 1). Not surprisingly, the greatest reductions occur in the lower dollar volume portfolios, which, as Table 2 indicates, have relatively wider

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quoted spreads. The overall (dollar volume weighted average) decrease is about 16%. The control portfolios also show a decline in effective spreads in almost all portfolio size categories with an overall (dollar volume weighted average) decrease of about 13%. Furthermore, the trend of declining effective spreads continues over the all-decimal period – especially in the higher dollar volume portfolios. To isolate the effect of decimalization on the effective spreads of decimal stocks, the net difference variable is reported. Only portfolios 2 and 4 show a significant decline while the rest are insignificantly different from zero.

To get a sense of the relationship between effective spreads and trade size, we further compute the effective spreads corresponding to trades in each of five trade size categories: all trades less than 500 shares (small trades), all trades between 500 and 999 shares (medium1 trades), all trades between 1,000 and 4,999 shares (medium2 trades), all trades between 5000 and 9999 shares (medium3 trades), and all trades of 10000 shares or greater (large trades). Table 3 panel B presents the average effective spreads in each trade size category, for decimal and control stocks, over the three periods of study.

We see that while the spreads in each trade size category are statistically similar between decimal and control stocks over the pre-decimal period, there are significant declines in effective spreads in almost every trade size category in decimal stocks (relative to control stocks) over the decimal-trial period. Specifically, the spread decreases monotonically from 33% in small trades to about 15% in large trades. In contrast, the decline is much more muted in control stocks over the same period. The net difference variable indicates that decimalization itself has resulted in reduction of effective spreads ranging from 2.8 to 3.1 cents in all but the largest trade size category. For large size trades, however, the net difference variable is not statistically significant at the 10% level, indicating no significant effective spread change ascribable to decimalization itself.

On following the path of effective spreads over the all-decimal period, we see a continuation in the downward trend in all trade size categories. This provides further support of improving liquidity in asset markets in the wake of decimalization.

In sum, decimalization appears to have significantly reduced both quoted and effective spreads in all but the largest size stocks and that this decline continues significantly beyond the start of the decimal pilot, indicating that the decline is not just a temporary phenomenon. Our conclusion holds even after accounting for effects other than decimalization, through the net

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difference variable, and are consistent with those reported in Goldstein and Kavajecz (2000) and Jones and Lipson (2001) following the conversion to sixteenths. Decimalization appears to have also enabled relatively smaller size trades to obtain better prices and execute deeper inside the quoted spreads, compared to relatively larger trades.

3.3 Changes in bid and ask depths

Following Harris (1990), it is now widely accepted that a complete characterization of market liquidity encompasses both the bid/ask spreads and the corresponding bid and ask depths. When liquidity is defined along these two dimensions, it is entirely likely that a reduction in liquidity could occur through a reduction in the bid and/or ask depth even though the bid/ask spread itself remains unchanged. Having examined spreads in the prior section, we now turn to the depths to see if, collectively, we could say anything conclusive about market liquidity following decimalization.

From a theoretical standpoint, it is reasonable to expect that quoted depths will decline, the closer a bid or offer is to the "true" price, consistent with the shape of the supply-demand curves. Further, the likelihood of a quote becoming stale increases as the spread narrows, so the option cost implicit in quotes will increase correspondingly.[8] Table 4 provides information on depths of the decimal and control stocks over the three distinct periods of interest, where depth is reported as the average of the bid and ask depths, in 100-share units. As in the case of spreads, we report depths based on the five portfolios (1-5) formed on the basis of the average daily dollar volume of trade of the sample stocks over the pre-decimal period. Consistent with the spread table, the reported depths in Table 4 for each dollar volume portfolio are computed by averaging across stocks in a portfolio, by their daily average dollar trading volume over the pre-decimal period.

We see that depths decreased significantly during the decimal-trial, relative to pre-decimal, period. The average decline in decimal stocks over the decimal-trial period is about

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[8] Consider, for example, a stock trading at 20 - 20 1/8 where a trader has posted a limit order to sell at 20 1/8. If the quote then jumps to 20 1/4 - 20 3/8 while the limit order is left unchanged, one could buy the stale limit order at 20 1/8 and immediately resell it at 20 1/4 ("picking it off"). With decimal trading, if a stock is quoted at 20 - 20.01, a 20.01 sell limit order could be picked off with a much smaller upward spread movement. Thus, the likelihood of the option being exercised against the limit-order provider is greater with decimal trading, but the expected value of the payoff price is smaller. The net effect of these two counteracting forces is indeterminate but could discourage the placement of limit orders in a decimal environment.

69%. Not surprisingly, the decline is the greatest (least) in the more active (less active) higher (lower) dollar volume stock portfolios. As the Table indicates, the prevailing depths in the lowest dollar volume portfolio are the smallest to begin with. There is, thus, less room for improvement in the smallest stocks. In contrast, the control stock portfolios, over the same period, show an overall increase in depths (by about 14%). Once again, the net difference variable isolates the impact of decimalization on the depths of decimal stocks following decimalization. From here, we see that decimalization itself has lead to a reduction in depth of about 9,742 shares. This trend of declining depths over the decimal-trial period continues into the all-decimal period especially in the lower dollar volume stocks. Also, the difference in depth between the decimal stocks and control stocks is statistically insignificant over the all-decimal period, which is what we would expect given that these are two matched groups of stocks trading in decimals.

In summary, after controlling for market trends (other than decimalization), there appears to be a significant decline in depth at the BBO and that this decline continues long after the commencement of the decimal pilot – especially for the relatively less active stocks. Goldstein and Kavajecz (2000) report an average quote depth decline of about 48% following conversion to sixteenths. While a decline in quoted and effective spreads indicates an increase in market liquidity, a simultaneous decrease in the corresponding depths (i.e., the corresponding order sizes that these improved quotes are valid for) implies a drop in liquidity. The overall effect of decimalization on market liquidity is therefore uncertain.

4. Decimalization and Transaction-related Variables

4.1 Trades and trading volume

An issue of interest to regulators and practitioners is the relative behavior of institutions compared to individual investors. It is generally perceived that institutions are "smart" or informed traders while individuals are uninformed investors. Evidence that institutional investors are more likely to use larger size trades than individuals, appears in Chakravarty (2001). Support that large trades are more likely to be from informed traders than small trades comes from Easley and O'Hara (1987). To investigate the relative activity of large (informed) trades versus small (uninformed) trades around decimalization, we investigate the frequency of trades and trading volume in the five trade size categories described earlier: small, medium1,

medium2, medium3 and large.

Table 5 reports results both for decimal and control stocks over the usual three periods of interest. Panel A presents the average daily trading volume results classified by trade size; panel B provides the corresponding daily average trade frequency statistics.

From Table 5, we see a decrease in average daily trades and trading volume in all trade size categories among decimal stocks in the decimal-trial period. The control stocks display the same pattern and a similar magnitude of decline. On tracking the trade and trading volume pattern through the all-decimal period, we see a further decline in both in all trade size categories. To isolate the effects of decimalization, we report the net difference in trade volume (or trade frequency) in decimal stocks, calculated, in the usual way, as the difference between the daily average volume (or trade frequency) of each decimal stock and its paired control stock in a particular trade size category. These numbers indicate that decimalization has led to a significant decrease in trades and trading volume in medium trades. There is evidence that the frequency of large trades has also declined following decimalization.

4.2 Volatility

In this section we examine volatility in decimal and control stocks. If the risk of trading in decimal stocks has increased significantly (relative to the control stocks) following decimalization, we would expect a greater price impact (or higher volatility) for a trade of a given size in decimal stocks.

To study volatility, we use the same five (quintile) portfolios of decimal and control stocks separately, based on the average daily dollar trading volume over the pre-decimal period. We form a minute-by-minute return series for the stocks within these portfolios, where each return is weighted by its corresponding share volume. Portfolio returns are then formed by weighting each stock in a portfolio by its pre-decimal average daily dollar volume. Overnight returns are discarded. Volatility for portfolio returns is calculated daily and the average volatility across days is reported.

Table 6 reveals a clear pattern of increase in volatility across all decimal stock portfolios over the decimal-trial period. This increase is small in the smallest dollar volume portfolio, becomes larger in the intermediate size portfolios and declines for the largest portfolio. In contrast, the control stocks display a universal decline in volatility over the same period. As always, the net difference variable attempts to isolate the effects of decimalization on decimal

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stocks. The results indicate that decimalization has led to a significant increase in volatility in all but the smallest portfolio.

On following the path of volatility in the two groups of stocks over the all-decimal period, we find a significant decline in volatility in both groups of stocks relative to the decimal-trial period. This might indicate a reduction in decimal-related risk in the market as participants "learn" the new trading environment.

4.3   Runs and Reversals in Price Adjustments

We continue with our theme of investigating differential risks of trading in stocks following decimalization. Specifically, there has been concern amongst practitioners in Wall Street that decimal pricing may lead to more runs in price and less price reversals, thereby exposing the limit orders of individual investors to greater stale price risks, which may, in turn, leave them at the mercy of being picked off by professional investors. Thus, for example, an investor could easily step in front (by a penny) of a standing limit order in a rising market or sell into a standing limit order in a falling market (see also footnote 8). In either situation, the liquidity supplier would be faced with losses in her position. If this situation leads some limit order traders to avoid submitting such orders, the overall liquidity and depth of the markets are in jeopardy. Brown and Holden (1999) model "mispricing" risk of limit orders and show how market adjusted (or smart) limit orders can mitigate this risk.

To examine the issue of price runs versus reversals, we define a simple metric to measure such phenomena. Specifically, we examine the prevailing BBO quote midpoint sequence and define an increase in quote midpoint by +1 and a decrease by –1. A simple run of length 1 is defined as (+1+1) or a (-1-1). Similarly, a run of length 2 is defined as (+1+1+1) or (-1-1-1), and so on. A reversal is defined very simply as triples of BBO quote changes, where the direction of the quote midpoint is reversed, as in (+1-1+1) or (-1+1-1). It provides us with a simple but intuitive framework to study the issue.[9]

Table 7 Panel A documents quote reversals, both in terms of the frequency of quote reversals and the corresponding percentage of all non-zero quote changes, among decimal and control stocks, over the three periods of study. While the frequency of quote reversals between decimal and control stocks over the pre-decimal period is statistically similar (10.8% and 10.7%,

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[9] For robustness, we replicated our work using changes in transaction prices in place of quote midpoint changes and obtained qualitatively similar results.

respectively), about 12% (10%) of all non-zero quote changes were reversals in the decimal (control) stock sample over the decimal-trial period. This difference is statistically distinct at reasonable levels of significance. Thus, quotes appear to be reversed more frequently in decimal stocks following decimalization. Interestingly, the percentage reversal in both decimal and control stocks over the all-decimal period have increased even more (about 13% for both groups of stocks). Thus, there appears to be significantly greater percentage of quote reversals following decimalization in the NYSE. The implication is that there appears to be less risk from stale prices in a post-decimal world.

Panel B provides the frequency (and the corresponding cumulative percentage) of runs in quote adjustments between decimal and control stocks over the three distinct periods. While the pre-decimal run length frequency at run lengths up to 25 are statistically similar between the decimal and control stocks, we find statistically significantly greater run lengths among decimal stocks relative to control stocks over the decimal-trial period. Further, the cumulative frequency at every run length continues to increase over the all-decimal (relative to decimal-trial) period.

In summary, our results indicate, on one hand, more frequent quote reversals (i.e., lower stale price risk), and on the other hand, significant increases in quote trends (i.e., higher stale price risk) in the decimal-trial period, continuing on through the all-decimal period. The overall effect on stale price risk, faced by the liquidity supplying limit order traders, is therefore uncertain.

5.   Concluding Discussion

Even though it is tempting to think of decimalization as just another decrease in minimum tick size, it is, in reality, much more than just that. The mantra is that the minimum tick must make it an economic cost for someone to step up in front of another liquidity supplier. While this was true even up to the conversion to sixteenths, it may not be true anymore -- where it takes just one penny to step ahead of a standing limit order. And if it is almost costless to step ahead, as one fund manager puts it, "......*mutual funds may stop using limit orders and simply pay fees to brokers to buy and sell at the prevailing market price. Most stocks already are traded that way on the nation's exchanges.*" With this backdrop -- and using tick-by-tick transaction and quote data over three distinct periods related to before, during and after decimalization in the NYSE -- we

study the impact of decimalization on some of the common metrics of market liquidity, price and order competition and the impact of regional versus the national exchanges. To isolate the effects of decimalization, by ensuring that our results are not influenced by market trends over the decimal period, we carefully construct a sample of control stocks matched 1:1 with each decimal stock in our sample.

We find mixed evidence related to market liquidity following decimalization. Specifically, while both the quoted and effective bid/ask spreads show significant decline, and continue to decline in a decimal-trial world, the corresponding bid and ask depths also display a similar significant downward trend over the same period. Thus, while better prices now exist to buy and sell, the quantities that can be purchased or sold at those improved prices are also fewer. Our finding of significantly smaller spreads following decimalization bodes well for retail traders trading smaller size trades. We find that both trades and trading volume have declined significantly in all trade size categories as well as in all stock size categories. Stock return volatilities show an increase in the short term but a decrease in the long term. This may imply a degree of comfort experienced by market participants, as they learn to navigate their way around in the new environment.

Although we find some increased activity among the regional stock exchanges in terms of bid/ask quote adjustment frequencies, BBO times, and percentage of autoquotes, the evidence is not strong and there is no evidence to suggest that the market share of transactions executed by the regionals has increased, as a result. The NYSE appears to be still leading the way in terms of 1-5 cent changes in bids and offers among all exchanges as well as in (dollar) transactional volume. Finally, using a simple metric to capture runs and reversals in bid/ask quotes, we find mixed evidence on stale price risk among stocks in a decimal-trial world. Specifically, we find more frequent quote reversals, and simultaneously a significant increase in quote trends in the market following decimalization.

One implication of our research is that retail investors are probably paying less to transact in a decimal world. These are investors whose trade sizes do not usually exceed the prevailing bid or ask sizes quoted at the improved (or tighter) prices. What it does for institutional investors' trading costs is unclear since these trades are typically large and require significant inroads into the limit order book and/or the presence of other suppliers of liquidity – typically in the upstairs market. Institutional trades are also distinct in that they require

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multiple trades, sometimes spanning days, to complete. In that regard, Chakravarty, Panchapagesan and Wood (2001) examine institutional execution costs around decimalization in the NYSE using a large sample of institutional trades. They find no increase in trade execution costs in institutional trades after decimalization. An implication of their study is that the available supply and demand of shares outside the best bid and offer prices remains undiminished. Our results, combined with those of Chakravarty, Panchapagesan and Wood, should be of some comfort to regulators who are under pressure from some professional investors and academics to roll back decimalization and, instead, move to nickel ticks.[10]

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[10] See *Decimal Move Brings Points Of Contention From Traders,*" (Wall Street Journal, February 12, 2001, p. C1) and *"Deals & Deal Makers: Grasso Says NYSE Must Stick to Penny As Trade Increment,"* ((Wall Street Journal, March 22, 2001, p. C18).

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Table 1A. Distribution of Odd and Even Tick Bid/Ask Spreads Among Regional Exchanges

The sample comprises of selected NYSE-listed common stocks included in the Decimal Pilot, and their corresponding NYSE-listed matched control stocks over the decimal-trial and all-decimal periods. The cumulative percentages presented here are computed from *all* (not just the BBOs) bid and ask quotes originating from the various exchanges. Only quoted spreads of up to a dollar are considered for this table. Well over 95% of all quoted spreads are within a dollar.

| Exchanges | ticks | Decimal-Trial Period (October 2, 2000 -- January 26, 2001) | | All-Decimal Period (January 29, 2001 - March 30, 2001) | |
		Decimal Stocks Cum %	Control Stocks Cum %	Decimal Stocks Cum %	Control Stocks Cum %
Boston	Even-ticks	52.69%	100.00%	51.45%	51.43%
	Odd-ticks	100.00%	100.00%	100.00%	100.00%
Cincinnati	Even-ticks	54.12%	100.00%	52.26%	53.45%
	Odd-ticks	100.00%	100.00%	100.00%	100.00%
Chicago	Even-ticks	52.78%	99.97%	52.31%	52.51%
	Odd-ticks	100.00%	100.00%	100.00%	100.00%
NYSE	Even-ticks	46.33%	99.99%	45.28%	44.27%
	Odd-ticks	100.00%	100.00%	100.00%	100.00%
Pacific	Even-ticks	50.52%	100.00%	52.63%	50.87%
	Odd-ticks	100.00%	100.00%	100.00%	100.00%
Nasdaq	Even-ticks	51.44%	99.97%	60.54%	59.91%
	Odd-ticks	100.00%	100.00%	100.00%	100.00%
Philadelphia	Even-ticks	52.75%	100.00%	51.07%	51.07%
	Odd-ticks	100.00%	100.00%	100.00%	100.00%

Table 1B. Distribution of BBO Quoted Spreads of NYSE-listed Decimal and Control Stocks

The sample comprises of selected NYSE-listed common stocks included in the Decimal Pilot, and their corresponding NYSE-listed control stocks over the decimal-trial and all-decimal periods. The quoted bid/ask spreads are denominated in cents and the cumulative percentages are computed from the best bid and ask (BBO) prices in the various exchanges. Only quoted spreads of up to a dollar are considered for this table. About 99.9% of all quoted BBO spreads are within a dollar.

Quoted Spread Cents	Decimal-Trial Period (October 2, 2000 -- January 26, 2001)		All-Decimal Period (January 29, 2001 -- March 30, 2001)	
	Decimal Stocks Cum%	Control Stocks Cum%	Decimal Stocks Cum%	Control Stocks Cum%
1	11.86%	0.00%	10.50%	10.97%
2	21.81%	0.00%	19.72%	21.37%
3	29.46%	0.00%	27.29%	29.63%
4	36.58%	0.00%	34.59%	37.38%
5	44.89%	0.00%	42.73%	45.48%
6	51.26%	42.35%	49.15%	52.18%
7	56.47%	42.35%	54.23%	57.44%
8	60.46%	42.35%	58.77%	62.08%
9	64.43%	42.35%	63.37%	66.72%
10	70.02%	42.36%	69.13%	72.29%
11	73.03%	42.36%	72.62%	75.80%
12	75.33%	72.59%	75.14%	78.33%
13	77.45%	72.59%	77.49%	80.66%
14	79.63%	72.59%	80.00%	83.06%
15	82.59%	72.60%	82.96%	85.89%
16	84.09%	72.60%	84.62%	87.38%
17	85.22%	72.60%	85.93%	88.54%
18	86.35%	86.49%	87.23%	89.67%
19	87.71%	86.49%	88.75%	90.93%
20	89.84%	86.49%	90.80%	92.64%
21	90.81%	86.49%	91.84%	93.39%
22	91.47%	86.49%	92.56%	93.97%
23	92.12%	86.50%	93.27%	94.53%
24	92.93%	86.50%	94.11%	95.19%
25	94.25%	94.04%	95.15%	96.02%
26	94.83%	94.04%	95.66%	96.41%
27	95.17%	94.04%	96.02%	96.68%
28	95.52%	94.04%	96.38%	96.96%
29	95.91%	94.04%	96.80%	97.28%
30	96.54%	94.05%	97.35%	97.71%
31	96.83%	96.82%	97.58%	97.91%
32	97.02%	96.82%	97.76%	98.06%
33	97.21%	96.82%	97.93%	98.21%
34	97.42%	96.82%	98.14%	98.39%
35	97.74%	96.82%	98.39%	98.59%
36	97.89%	96.82%	98.51%	98.71%
37	98.02%	98.43%	98.62%	98.80%
38	98.14%	98.43%	98.73%	98.89%
39	100.00%	100.00%	100.00%	100.00%

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