One tick fits all? A study of the Island and Instinet ECN merger

Bidisha Chakrabarty[a] and Rahul Tripathi

First Draft: September, 2004

Bidisha Chakrabarty
367 Davis-Shaughnessy Hall
John Cook School of Business, Saint Louis Univ.
St Louis, MO 63108
(314) 977 3607
Email: chakrab@slu.edu

Rahul Tripathi
Elsevier Science
11830 Westline Industrial Dr
St. Louis, MO 63146
(314) 995-3258
Email: r.tripathi@elsevier.com

JEL classification: G10; G14; G29

Keywords: Limit Order Market; Tick Size; Electronic Communications Networks; ITCH data; Liquidity; Quote Clustering; Cost of round trip trade

We would like to thank Josh Levine and Alex Goor from INET ATS. Thanks are also due to Mike Alderson, Brian Betker, Kee Chung, Oliver Hansch, Pankaj Jain, Neil Seitz, Bob Wood and seminar participants at the 2004 FMA for helpful comments and suggestions. All remaining errors are our own responsibility. The comments and opinions expressed herein are the authors', and do not necessarily reflect those of Elsevier Science, Island or INET. Chakrabarty gratefully acknowledges a research grant from the CSB for this project.

a: Corresponding author
Bidisha Chakrabarty, *Assistant Professor (Finance), John Cook School of Business*
Email: chakrab@slu.edu, web site http://www.slu.edu/users/users/chakrab/

Abstract

On October 27th, 2003, INET, the largest Electronic Communications Network, began eliminating sub penny quotation for securities. In this paper we examine the impact of this tick size increase for the pilot stocks. We find that while depth increases for all stocks, spreads widen significantly for the low-priced stocks. Overall, the cost of a round trip trade increases (decreases) for low (high) priced securities. We document that while the low priced securities use the (sub penny) price points to establish optimal spread, the high priced stocks show a quote clustering at price points ending in the digit one (nine) for bid (ask) quotes, consistent with front-stepping explanations. Our findings suggest that a stock's reaction to tick size change is a function of its price and the penny tick size is not optimal for low priced stocks.

1. Introduction

In September 2002, the two largest Electronic Communications Networks (ECNs) Instinet and Island announced a merger worth over a half billion US dollars. The deal married the largest ECN, Instinet, with the fastest growing upstart ECN, Island, and created the biggest global ECN, with a quarter of the market in over-the-counter US securities and over 14% of US equity share volume.[1] This placed it ahead of its biggest competitor, Archipelago LLC, which had merged with REDI Book the previous year.

Amidst the fluid changes in market share that this mammoth merger resulted in, concerns were raised regarding the systems compatibility of the two alternative trading platforms. Specifically with respect to the pricing grid, while Island allowed sub-decimal quotes and trades for all securities, Instinet followed a tiered tick size schedule. For all stocks priced at $10 or higher, Instinet (INCA) allowed only two decimal place quotes. For stocks priced lower, it allowed sub penny trading, with the rule being subject to revision bi-annually. At the time the merger was announced, it was determined that the two systems would operate independently until the best way to meld the two systems was decided.

The melding of the two separate order books began on October 27th, 2003 and the market participant identifier for the merged firm was officially changed to INET. Integration of the order books began with the migration of six securities (Pilot I) from sub-decimal to decimal trading, to be followed by another four stocks (Pilot II) on November 17th, 2003. Pilot I included Amgen Inc. (AMGN), Flextronics International Ltd. (FLEX), Cisco Systems Inc. (CSCO), JDS Uniphase Corp. (JDSU), SPDRs (SPY; S&P Depository Reciept) and Starbucks Corp. (SBUX). Pilot II included four stocks from the computer software industry - Intel Corp. (INTC), Microsoft Corp. (MSFT), Oracle Corp. (ORCL) and Sun Microsystems Inc. (SUNW).

How did this exogenous increase in the minimum price variation impact the market quality in these stocks? This is a question of importance not just to investors, but also to regulatory authorities. In fact, the Securities and Exchange Commission (SEC) has periodically addressed the issue of sub penny

pricing for some years now. In July 2001, under concept release No. 43-44568, the SEC sought comments from market participants regarding the efficiency of sub penny quotes display. Subsequently it allowed the NASDAQ market makers and the CHX the flexibility of sub decimal pricing.[2] On March 3rd, 2004, in concept release No. 34-49325, the SEC solicited public comment on the proposal to amend certain rules in Section 11A of the Securities Exchange Act of 1934. One of these rules was a proposal pertaining to sub penny pricing. Specifically, this proposal would prohibit market participants from accepting, ranking, or displaying orders, quotes, or indications of interest in pricing increments finer than a penny, except for securities with a share price of below $1.

The response of the investment community was unanimous opposition. It was pointed out that for many securities (usually low priced and widely held ones like Sun Microsystems, Lucent Technologies, Nortel Networks, etc.), efficient quotation may be in sub pennies. Recognizing this fact, the ECN BRUT permits sub penny quoting for stocks trading under $5. On the INET platform, QQQ trades in sub pennies even though it trades at over $35.[3] The academic evidence on this issue is very limited, primarily because of (sub-decimal quotations) data availability problems.

In this paper, we examine the optimality of a uniform (one penny) tick size by characterizing the changes in market quality for the pilot stocks following the migration to the decimal pricing grid.[4] We use real time data for an event window of 64 trading days, partitioned at the event (migration) date for each of the pilot securities, to examine the impact of tick size increase on the liquidity, order submission strategies and quotation patterns for these securities. The proprietary data used in this study allows us to

---

[1] *See* SNL Financial Report special edition "Securities and Investments, Mergers and Acquitions". The market participant identifier (MPID) for Instinet is INCA and for Island it is ISLD. The latest available figures for INET ETS, at the time of writing, are for the second quarter ending June, 2004.

[2] See Chakrabarty and Chung (2004) for a detailed discussion of the rule and the impact of sub decimal pricing in NASDAQ stocks.

[3] In February of 2004, INET switched Sirius Satellite Radio (SIRI), a stock valued then at $4, from sub penny to penny quotes. Immediately INET lost market share to BRUT, the only market still trading Sirius in sub penny increments. Finally, on June 28th, it switched SIRI back to sub penny increments. In fact, in his response to the SEC's proposal, Edward Nicoll, the CEO of Instinet Group pointed out that for a security like QQQ, whose existing spread in a sub penny pricing grid is around $0.003, if all investors traded QQQ in sub penny increments, the savings would approximately be $150 million a year. (*See* "Response to Hearing on Proposed Regulation NMS, April, 2004)

[4] We do not include SPY in the sample since it is a depository receipt.

reconstruct the entire limit order book (LOB) for these stocks and examine how a change in the minimum price variation impacts liquidity beyond the best bid and ask.

More importantly, while there have been instances of tick size reduction in several exchanges and equities markets around the world, tick size increases are not nearly as frequent. For the US equities markets, this is the first instance of an exogenous tick size increase for all stocks on a trading platform. Hence, this event presents a unique opportunity to examine whether some of the empirical regularities associated with a reduction in the tick size get reversed, or if the causality flows in just one direction.

We find that inside spreads widen significantly for low-priced stocks following the abolition of sub-decimal quotes, indicating that a penny tick is a binding constraint for these stocks. For higher priced securities, there is no change in inside spread for some while others actually experience a slight reduction in spread. Depth at the inside bid and ask prices increases significantly and for all the stocks in both the pilots. One striking finding is the uniform and significant drop in the proportion of hidden orders across all stocks following the increase in MPV. We show that the reduced possibility of front-stepping due to an increase in the tick size encourages traders to reveal their orders instead of using the "hidden orders" clause that INET allows its subscribers.

We provide evidence that the cost of a round trip trade (CRT), which combines information on both spreads and depths, actually increases for the low priced stocks following the migration to a coarser pricing grid. Thus, for low priced stocks, the impact of increased spread more than outweighs the gains in the form of higher depth. This finding is further bolstered by the patterns of quote clustering that we observe for the pilot stocks on each price point of the grid before and after the migration. We find that in the sub penny regime, while the higher priced stocks show a clustering of quotes at the third decimal place ending in '1' ('9') for bid (ask) quotes, the low priced stocks have a fairly uniform distribution of quotes across all sub penny price points. This is consistent with the explanation that while for the high priced securities a sub-decimal tick size encourages greater front-stepping, low priced stocks use the sub penny grid to establish optimal (equilibrium) spreads. We conclude that the move to a wider tick size has

adversely affected low priced stocks while improving some measures of trading costs (e.g., increased depth) for the higher priced securities.

By the very design of the pricing pilots, our samples are small – five stocks in pilot I and four in pilot II. To verify that our results are robust, we use pilot I stocks as the estimation sample and pilot II stocks are used as the (independent) robustness sample.[5] All our estimation results hold in the out-of-sample robustness tests.

The rest of this paper is organized as follows. Section 2 is a brief literature review on tick size changes and various measures of market quality. Section 3 describes the INET trading protocol and the structure of ITCH data that we used in this study, as well as select sample characteristics. Section 4 presents initial evidence on spread and depth changes following the pricing grid change. We also provide empirical evidence on changes in order submission strategies as a result of tick size change. Sections 5 and 6 discuss the results on changes in the cost of round trip trade induced by the increase in tick size, and evidence on quote clustering before and after tick size change, respectively. Section 7 concludes.

2. Tick size changes and market quality

Price changes of financial securities have a lower bound known as the 'tick size'. Since the markets moved from $1/8^{th}$ to $1/16^{th}$ pricing and subsequently to decimals, the magnitude of tick size mandated by various exchanges and trading platforms has received considerable attention, both from regulatory authorities as well as in the academic literature. While a number of SEC discussion papers have highlighted the need to scientifically document the effect of tick size changes on investor protection issues in US securities markets,[6] there have been other studies that examine the role of the pricing grid in establishing the quoted and effective spreads as well as its impact on posted depth.

[5] An alternative could be to use all nine stocks as one (bigger) sample, but since that would still be a statistically small sample, the power of the tests based on cross-sectional analysis of such a sample would be very low.

2.1. Tick size changes and spread

The theoretical argument is that a reduction in the tick size can only lower spread, since the tick size is a floor on the bid ask spread. The large majority of empirical evidence till date seems to confirm this argument. Chakravarty et. al. (2001) show that decimalization leads to lower effective spreads in a sample of NYSE listed stocks. Bacidore (1997) finds similar evidence for stocks listed on the Toronto Stock Exchange and Ahn, Cao and Choe (1996) show that for stocks on the American Stock Exchange priced under $5, decimalization is accompanied by a 10% decline in effective spreads.

However, tick size reduction has not been unanimously hailed as a positive move. Grossman and Miller (1988) defend a larger tick size, arguing that it serves to maintain a minimum level of profit to market makers, thus guaranteeing the provision of liquidity by these agents. Bourghelle and Declerck (2002) find mixed evidence for the Paris Bourse, which adopted a tiered tick size schedule since January 1999. In fact, they show that following this change to a graduated minimum price variation (MPV) scale, certain stocks that experienced a tick size reduction actually show a higher spread to tick ratio.

2.2. Tick size changes, depth and volume

The evidence on the relation between changes in the MPV and depth is, at best, mixed. Goldstein and Kavajecz (2000) document that for a sample of NYSE stocks, depth at best quotes, as well as depth throughout the entire limit order book declined following a tick size reduction. Chan and Hwang (2000) find contradicting results for the Hong Kong Stock Exchange; for stocks that experience a tick size reduction, while the depth at best prices falls, the depth through the limit order book is not adversely impacted. They conclude that overall, market liquidity improves with a tick size reduction. Following the American Stock Exchange's adoption of the $1/16^{th}$ tick size in May 1997, Ronen and Weaver (2001) show that depths at best prices remain virtually unchanged.

Nemiroff and Mackinnon (2004) measure liquidity by the price impact of unanticipated volume for a sample of Toronto Stock Exchange stocks around a tick size decrease from $0.125 to $0.05, and find

[6] *See* Chakrabarty and Chung (2004) for a discussion.

that price impact is virtually unchanged. However, effective spreads decline significantly, leading them to conclude that a lowering of the MPV has an overall positive effect. Cao and Choe (1996) find no evidence of a change in volume for AMEX stocks that moved from $1/8^{th}$ to $1/16^{th}$ pricing. Hau (2002) also finds that for the French stock market, higher tick size regimes are characterized by higher returns volatility and generally higher transactions costs. Chung and Chuwonganant (2004) study a sample of NYSE stocks prior to decimalization and find the number of quote revisions that involve changes in the spread increased dramatically after tick-size reduction. The number of spread-quote revisions is smaller for stocks with lower prices and larger volumes, during both the pre and post tick-size change periods. They interpret this result as evidence that the minimum price increment is a binding constraint on absolute spreads, and MPV reduction is likely to reduce price rigidity and increase price competition.

In aggregate, there is no consensus on the effect of tick size on overall market liquidity. While some aspects of liquidity, viz., quoted and effective spreads, are improved, others like volume, volatility and depth show mixed evidence.

In addition, much of the evidence that has been presented on the impact of tick size changes is in the context of specialist or dealer markets. Only recently has there been an interest in examining how the pricing grid impacts trading on automated platforms with no dealer or specialist intervention. In fact, Bourghelle and Declerck (2002) is the only study that examines the event of (a tiered) tick size increase in the context of a fully electronic market.

We add to the literature by examining a unique event in the US equities markets – the merger of two crossing networks that led to an exogenous tick size increase, for the first time, for US equities. We present evidence of the impact of tick size increase, from sub penny to penny increment, on various measures of market liquidity, order submission strategy and trading pattern for the pilot stocks. We begin by presenting a brief discussion of the trading protocol on Island/INET and the structure of the proprietary (ITCH) data used in this study. This is followed by a description of the sample securities for the estimation sample (Pilot I) and robustness sample (Pilot II).

3. Trading protocol, ITCH data and sample selection

INET provides its more than 800 U.S. broker-dealer subscribers access to the one of the largest electronic marketplaces for U.S. over-the-counter securities. Representing the consolidated order flow of the former Instinet ECN and former Island ECN, INET collects, prioritizes, displays and matches orders within its subscriber network as well as offers routing services for its U.S.-registered broker-dealer subscribers.

3.1. Trading on INET

Currently INET executes over one out of every four trades in NASDAQ securities. It is a pure electronic limit order book that matches incoming orders with existing orders in the book based on the following priorities:

a) Price – the limit order price of the order

b) Display – non-display orders lose price-time priority over display orders, and

c) Time – the exact time the order was placed (in milliseconds)

INET does not accept market orders. All incoming orders are limit orders. If a trader wants immediate execution, (s)he must place an order that meets or crosses the best opposing price.

The Life Cycle of a Limit Order sent to INET:

- Subscribing broker-dealer/investor sends a display limit order to INET.
- Upon receiving the order, INET first performs a series of checks (i.e., verifying the stock symbol, checking that the security is not halted, etc.)
- After clearing those checks, INET's system is instantaneously scanned to determine if there is a matching order.
- If a matching order exists, the order is executed immediately.
- If a matching order does not exist, a display order is placed on INET's limit order book until a matching order is received, or until the order is cancelled. All unmatched orders are cleared from INET's system at the end of each trading day.

INET accepts orders from 7:00 a.m to 8:00 p.m., EST. The best-priced order on INET for a NASDAQ security is also represented on the NASDAQ Level II quotes, where all market participants post their best bids and offers.

For NASDAQ securities and AMEX listed Exchange Traded Funds (ETFs), INET execution fee schedule is as below:

- Rebate per executed share of $.0020 for trades that add liquidity to the INET book[7]
- Charge per executed share of $.0030 for trades that remove liquidity from the INET book
- No charge or rebate for unexecuted order(s)
- $0.00025 per share charge for each side of internalized trade(s).[8] This price is a 50% discount to the net charge on non-internalized shares.

For NYSE and AMEX listed securities (excluding AMEX ETFs), INET allows free addition and removal of liquidity to the order book.

3.2. ITCH data structure

ITCH is the vendor level data feed of the INET ECN. It disseminates information about orders and executions on the ECN in real time. ITCH does not allow order entry, subscribers may enter orders using a separate system known as OUCH. The ITCH feed is made up of a series of sequenced messages that describe orders added to, removed from, and executed on the INET ECN. There are six types of

[7] At the time of writing, rebate per executed share is $.0025 for trades that add liquidity to the INET book for subscribers, who, for a calendar month, have an average daily share volume for executed orders: (1) exceeding 30 million shares of added liquidity; (2) exceeding 30 million shares of removed liquidity and routed volume; or (3) exceeding 50 million shares combined of added, removed and routed. The calculation for added and removed includes shares executed on either the INET or Instinet books. For example, a subscriber that averages 13 million executed shares of added liquidity per day on INET and 18 million per day on Instinet would receive a rebate per executed share of $.0025 for the shares contributing to its average of 13 million shares of added liquidity executed on INET. Routed shares are routable shares sent through SmartRouter but executed outside the INET and Instinet ECNs. Upon subscriber's request, added liquidity among subscribers that are wholly owned by a common parent may be aggregated.

[8] An internalized trade is an execution on INET where a single subscriber is both the buyer and seller in the transaction.

messages – add order, modify order, order executed, order cancelled, trade message and broken trade message.

Add Order – an add order message indicates that a new order has been accepted by the INET system and added on to the display book. It includes a day-unique order reference number, a time stamp, buy or sell reference, price and the display condition (hidden or displayed).

Modify Order – references an order previously submitted, using the order reference number. A modify order always reduces the number of shares currently pending in the referenced open order by the number of shares indicated. An increase would be a new add order.

Order Executed – is a message sent whenever an order on the book is executed in whole or in part. The execution price is always equal to the limit price of the order as indicated in the add-order message.

Order Cancel – is a message sent whenever an order on the book is modified as a result of being cancelled in part or whole.

Trade Message – provides information about execution events that involve orders not visible on the INET book. Since no add-order message is sent for non-displayed orders, it is not possible to send a modify order message when a hidden order is executed. Instead a trade message is transmitted when a hidden order is executed in whole or in part.

Broken Trade – is a message sent when a trade falls under the "clearly erroneous" category, pursuant to INET's clearly erroneous procedure. A trade break is final; once a trade is broken, it can not be reinstated.

3.3. Sample securities

Our estimation sample comprises of the five stocks that formed pilot I[9] and the sample period is from September 11th to December 11th, 2003 with 64 trading days, centered on the migration date of

[9] As mentioned earlier, SPY is dropped from the sample.

October 27th. For robustness check, we repeat our analysis with the four stocks in pilot II. Again, we adopt the 64 trading days' window for the second batch of stocks, now beginning on October 2nd, 2003 and ending on January 2nd, 2004, centered on November 17th.

Table 1 presents the summary statistics for sample stocks; Panel A comprises of the estimation sample and Panel B is the robustness sample. Share price shows a wide range for both pilots. In Panel A the range is from $3.60 for JDSU to $62.46 for AMGN. In Panel B, price ranges from $3.97 for SUNW to $31.20 for INTC. Our measure for trading volume is dollar volume on INET. We find that, unlike share price, volume does not show a high dispersion. In fact, all nine stocks rank within the top 50 highest volume stocks for the entire 64 days trading history that we investigate. Interestingly, the five 'tech' stocks (CSCO, INTC, ORCL, MSFT and SUNW) each rank within the top 10 highest volume stocks for their respective sample periods. Market capitalization is captured by the market value of equity, and here the sample firms again differ widely. While the largest firm in the sample, Microsoft Corp., has close to $300 billion in market capitalization, the smallest firm, JDS Uniphase, has around $7 billion.

4. Spread, depth and order submission patterns

Market liquidity is an elusive concept to define since it encompasses multiple facets of a market's transactional properties. These include the costs borne by investors (spread and depth), trading conditions and various measures relating to informational efficiency of prices and market transparency.

4.1. Spread

In Section 2, we discussed the robust evidence on the positive relation that has been documented in the literature between tick size *decrease* and spread reduction. We now address the flip side of this issue: is a tick size *increase* followed by an increase in spread?

Ex ante, we expect that the answer to this question depends, among other things, on a stock's price. Stocks have an equilibrium spread that is positively related to price; the higher a stock's price the

higher is its equilibrium spread. If the MPV is non-binding on spread, i.e., if the equilibrium spread is greater than the tick size, then an increase in tick size should not impact a stock's spread until it becomes greater than the equilibrium spread.

Our results on the relation between spread and tick size change are presented in the first two rows each of tables 2(a), 2(b), 3(a), and 3(b). Table 2(a) shows the simple average spread for the estimation sample before and after the tick size increase and Table 3(a) presents similar statistics for time weighted spreads. The evidence point to some interesting dynamics amongst spread, price and tick size in a regime of MPV change. In Table 2(a), we find that for SBUX, FLEX and AMGN, there is actually a decline in average (dollar) spread after the change to a higher tick size. Similar conclusions apply when we consider relative spread, which is measured as the ratio of dollar spread to share price. In table 3(a) we find that the same result holds for time-weighted dollar spread for SBUX and AMGN. FLEX shows no change and while CSCO shows an increase in spread following the move to a wider pricing grid. Time weighted relative spread also reinforces the same results, although now FLEX shows no difference in spread pre- and post tick size increase.

Perhaps the most striking finding here is the contrast between these stocks and JDSU. JDSU is a low priced stock with an average price of $3.60 in the sample period. In both Tables 2(a) and 3(a), we find a very significant increase in spread for JDSU following the move to a coarser pricing grid. In dollar as well as percentage terms, JDSU experienced a big jump in spread after October 27th, 2003. In the period prior to tick size increase, the average spread for JDSU was close to half of one cent. This increased to around one cent after the pricing grid change. Relative to its price, this amounts to a 30% increase.

Tables 2(b) and 3(b) present the spread change results for the four stocks in our robustness sample. The results we find here reinforce the findings in Tables 2(a) and 3(a). While the higher priced stocks (INTC, MSFT) show either no change in relative spread or a modest drop in absolute (dollar) spread, the lowest priced stock, SUNW (average price $3.97) shows dollar spread increase from about 3/10^{ths} of a cent to just over a cent, which amounts to about 25% of its price. Figure 1 presents evidence

to the same effect. It shows that while the higher priced stocks have virtually no change in relative spread before and after the tick size increase, the two low-priced securities, JDSU and SUNW, experience a drastic jump in relative spread following the move to a penny MPV. These results are similar to the findings of Chakrabarty and Chung (2004) who show that for stocks priced under $10, even a one-penny tick size is a binding constraint and a sub penny pricing grid may be optimal for them.[10] Here we find that a move from sub penny to penny tick size artificially increases the spreads for these low priced stocks.

4.2. Depth

The next few rows in Tables 2(a) (3(a)) present evidence on simple average (time weighted) bid and ask depths for the estimation sample. The findings on changes in (share) depth is uniform: there is an increase in depth for all the stocks in our sample following the change in tick size. Tables 2(b) and 3(b) indicate that this is true also of the robustness sample. Both bid and ask depth increase significantly following the move to a higher tick size. Figures 2 and 3 corroborate the same. There is uniform increase in depth that accompanies the migration to a penny pricing grid for all the securities, for both pilots.

Increase in depth as a result of tick size increase is consistent with two alternative explanations. First, a rise in the MPV makes it more costly (one cent instead of one-tenth of a cent) for a quote matcher to step ahead of an existing order, and this knowledge should encourage investors to expose their true trading interests to a greater degree in the post tick size change regime. Alternatively, since it is not possible to place sub penny quotes after the pricing grid change, all the orders that would have been dispersed across the sub penny price points earlier are now aggregated at the penny increments, and this pooling should mechanically lead to greater depth. In Section 6 we examine quote clustering patterns at various price points to illustrate which of these alternative explanations fit the data.

[10] This finding clearly reinforces the statement made by the CEO of Instinet to the SEC in response to its NMS rule ammendment proposal (*See* concept release No. 34-49325 mentioned earlier).

4.3. Order submission patterns

Tables 4(a) and 4(b) present some summary statistics on other features of the limit order book before and after the tick size change. Specifically, we look at the absolute and proportional changes in cancelled orders, executed orders, hidden orders and the average time taken to obtain order execution. For the estimation sample (Table 4(a)), we find that in absolute numbers, there is an increase in both cancelled orders and executed orders following the MPV change, indicating that overall order submission actually increased in the post-change period. This provides empirical support for Large (2004) who theoretically showed that in periods of high uncertainty, *fleeting* limit orders are submitted and quickly cancelled, which enhances the liquidity supply. Since the migration dates were known to INET's subscribers in advance, there possibly was a higher degree of uncertainty in the period immediately following the pricing grid change.

What is most striking here is the evidence on hidden orders. Our results show that there is a significant drop in the actual number of hidden orders following the move to a higher tick size, both in absolute terms as well as a percentage of the total numbers of orders placed. Undisclosed orders fell from an average of 9% of all placed orders to 2.5% for the estimation stocks and from 15.5% to 2.6% for the robustness sample.[11] Visually, Figure 4 verifies this drastic drop in the proportion of hidden orders. In this figure, we calculate the proportion of hidden orders to total orders executed and find that for all nine stocks, there is a uniform drop in this fraction following the tick size increase. This corroborates Harris (1996) who examined data for 300 stocks on the Paris Bourse and found that order disclosure is affected by the tick size.[12]

[11] We note here that our pre-migration estimates for the proportion of hidden orders are similar to what Hasbrouck and Saar (2002) find. They report that executed hidden orders constituted almost 12% of all order execution. The numbers we report here are obtained by summing across the hidden orders (%) row in Tables 4(a) and 4(b).

[12] There could be an alternative explanation for the drop in the proportion of hidden orders. As shown in the previous section, post merger, there is uniform increase in depth for all the stocks in both samples. Since hidden orders lose time priority to visible orders, an investor submitting a hidden order in the post merger market (with higher depths) will face a lower likelihood of order execution. Since investors know this, we expect to see a reduction in the use, and hence proportion, of hidden orders following the move to the penny pricing grid.
To test this alternative hypothesis, we run the following regression for each stock in both samples. If depth is an explanatory factor, then its coefficient should be negative and significant. If not, then the time dummy should be negative and significant.

In examining volatility on the Island ECN, Hasbrouck and Saar (2002) found that higher volatility is associated with shorter expected time to execution. They utilize a duration model to estimate the time to execution. In contrast, by reconstructing the entire limit order book and tracking each submitted order until it is executed, cancelled or partially executed, we provide evidence here on the actual (average) time taken for order execution for each of our sample stocks before and after tick size change.[13] We find that, in general, there is a reduction in the time taken to execute an order after the move to a higher MPV. Except for the low priced stock, JDSU, which shows virtually no change, all other sample stocks show this same pattern. This result could be due to the increase in volume that results from the merger, since the clients of both Island and Instinet now trade on the INET platform. To determine whether the improvement in execution time is fully explained by the bigger post-merger book, we regress the trade volume for each stock against the average time to execution and include a time

---

Proportion of hidden orders = $\alpha + \beta$ Average Depth + γ Time Dummy + ε

The time dummy equals 0 before merger and 1 after. The regression results are reported below.

	α	β	γ	Adj. R^2	F
Pilot I					
AMGN	0.0429**	-0.0001	-0.0125**	0.37	21.58**
CSCO	0.1610**	0.0001	-0.1546**	0.94	601.77**
FLEX	0.0926**	-0.0009	-0.0549**	0.70	83.17**
JDSU	0.1589**	-0.0002	-0.1314**	0.86	215.02**
SBUX	0.0344**	0.0003	-0.0243**	0.65	65.07**
Pilot II					
INTC	0.1605**	-0.0001	-0.1011**	0.80	124.75**
ORCL	0.1993**	-0.0029*	-0.1377**	0.90	299.72**
SUNW	0.1195**	-0.0000	-0.0680**	0.86	191.16**
MSFT	0.1606**	-0.0000	-0.1204**	0.86	199.20**

** Significant at the 1% level
* Significant at the 5% level
Clearly, the increase in depth following the merger has little power in explaining the decrease in the proportion of hidden orders.

[13] We point out here that our measure of average execution time involves tracking every order for each stock from the moment it enters island's LOB until it is executed (we consider only completely executed orders for this measure). Tracking each order as it enters the ITCH system, compiling the time taken for each order until execution each day, aggregating over a stock, and then over the 64 trading days is a computation intensive process; it could be done here because our sample size, by the nature of the pricing pilots, is only nine stocks. Hasbrouck and Saar (2002) use a sample of 300 stocks.

dummy to capture changes introduced by the tick size change.[14] Our results show that the coefficient for volume is negative and significant and the time dummy coefficient is insignificant for all the securities. Thus, after controlling for volume, tick size change does not have additional power to explain the drop in the average time to execution of limit orders.

Table 4(b) examines the same measures for the robustness sample. The results are remarkably similar. Both cancelled and executed orders increase in absolute numbers, but as a proportion of total number of orders submitted, there is no significant change. Hidden orders, on the other hand, show a consistent and significant decrease following the move to penny pricing. As in the estimation sample, this result is true also when we consider hidden orders as a proportion of all executed orders.

As in Table 4(a), average time to execution falls significantly for three of the four stocks, the exception being SUNW, which is the only low-priced stock in the robustness sample. Our evidence from this section, as well as on spread changes, indicate that the dynamics for low priced stocks and their responses to changes in market design differ substantially from the higher priced stocks.

5. Cost of Round Trip Trade (CRT)

In the previous sections we have presented evidence on changes in spread, depth, order execution time, the proportion of hidden and exposed orders, all of which measure aspects of market liquidity. However, the question still remains whether this move from a sub penny to penny pricing grid helps or hinders overall liquidity of these stocks on the INET platform? Liquidity is a multi-dimensional concept to quantify. As Bessembinder (1997) points out, an accurate measure of trade execution cost has to include a broad measure of liquidity, which extends beyond the inside bid-ask spread and associated posted depths, i.e., includes information on the order book.

The reason why the accuracy of trading costs is enhanced by the inclusion of limit order book data is that for orders whose size exceed the inside depth, the inside spread is not the upper bound on per

[14] The regression equations estimated are of the form $TimeToExecution = \alpha + \beta MergerDummy + \gamma TradeVolume + \varepsilon$, one for each security.

unit variable cost. While this fact has been recognized in the literature, limitation regarding the availability of limit order book information, especially for US equities markets, has been a major reason why methodologically not much advance has been made in capturing the information in the entire limit order book to compute measures of trading cost.

In the following section, we adopt a measure of liquidity that represents the information contained in the entire limit order book – bid and ask prices and associated quantities – in one summary statistic - the Cost of Round Trip Trade (CRT). This is similar to the measure that Irvine, Benston and Kandel (2004) used to assess trading costs in the Toronto Stock Exchange. Below we outline the calculation of the CRT for one snapshot of the entire limit order book for one stock.

We begin with a perfectly competitive securities market as the benchmark, with unlimited number of buyers and sellers, each of whom is a price-taker. In terms of the limit order book, this implies infinite quoted depths at both the best bid and ask prices. In this market-clearing situation with no intermediary, an investor who wants to buy and sell a quantity Q of shares instantaneously would pay zero (variable) transaction cost. Thus, CRT = 0 is the benchmark market against which an actual securities market is compared. In real securities, there is always a wedge between the buy and sell price, the bid-ask spread. The percentage cost of a round-trip trade (CRT) therefore, will be positive. It is equal to the inside spread for trades that are smaller than the inside depth. For larger trades, CRT will capture additional price-quantity information from the limit order book.

Let the table below represent the limit order book at any given point in time:

Bid Depth	*Bid Price*	*Ask Price*	*Ask Depth*
Q_{-0}	P_{-0}	P_0	Q_0
Q_{-1}	P_{-1}	P_1	Q_1
Q_{-2}	P_{-2}	P_2	Q_2
Q_{-3}	P_{-3}	P_3	Q_3

Q_{-4}	P_{-4}	P_4	Q_4
…	…	…	…

Here $P_{-0} > P_{-1} > P_{-2} > P_{-3} > P_{-4}$ and $P_0 < P_1 < P_2 < P_3 < P_4$, where P_{-0} and P_0 are the inside bid and ask prices respectively. For a total dollar amount D, the number of shares that can be bought/sold at the midpoint price of P_{-0} and P_0 is:

$T(D) = 2D / (P_{-0} + P_0)$

Next, we define two indicator variables, I_{-k} and I_k, which respectively refer to sell and buy orders of D dollars:

$$I_{-k} = \begin{cases} 1 \text{ if } T(D) > \Sigma\, i=_{-0,-k} Q_i \\ (T(D) - \Sigma_{i=-0,-k+1} Q_i) / Q_{-k} \quad \text{if } T(D) > \Sigma_{i=-0,-k+1} Q_i \text{ and } T(D) < \Sigma_{i=-0,-k} Q_i \\ 0 \text{ otherwise.} \end{cases}$$

And,

$$I_k = \begin{cases} 1 \text{ if } T(D) > \Sigma_{i=0,k} Q_i \\ (T(D) - \Sigma_{i=0,k-1} Q_i) / Q_k \text{ if } T(D) > \Sigma_{i=0,k-1} Q_i \text{ and } T(D) < \Sigma_{i=0,k} Q_i \\ 0 \text{ otherwise.} \end{cases}$$

The per dollar cost of a roundtrip trade of D dollars, $CRT(D)$, is then defined as:

$$CRT(D) = (\Sigma_{k=0,\infty} I_k P_k Q_k \; - \; \Sigma_{k=0,\infty} I_{-k} P_{-k} Q_{-k}) / D$$

The above formulation of the cost of a round trip trade takes into account the information in the entire limit order book, instead of just the price and quantities at the inside market. Based on this formula, it is easy to see that market i offers higher liquidity for transactions of size D than market j if

$CRT_i(D) < CRT_j(D)$. We point out here that in this formulation, we are not calculating actual cost of executed trade, but the per dollar cost of trade for different trade sizes.

While the CRT measure used here is a new means to capture information of the entire LOB in one summary measure, there have been other studies that look at the impact of tick size changes on spread for different trade sizes. Huson, Kim and Mehrotra (1997) find that for Toronto Stock Exchange stocks, effective spread declines for 500-1000 share trades but increase for smaller trade sizes. Ronen and Weaver (1999) find that similar conclusions apply to AMEX stocks.

Before we present our evidence on the CRT changes for our sample stocks due to tick size increase, we briefly discuss our methodology for reconstructing the Island LOB. Following Kavajecz (1999), we implement an algorithm that ensures that the LOB, at any instant in time, reflects those orders remaining after the orders placed prior to that time are netted with all prior executions, partial cancellations and cancellations. Starting from the commencement of Island's trading day (07:00 AM), we follow the orders as they are entered into the system, and as they are cleared from the system (by means of full/partial execution or cancellation). Thus, for every instant in time, we have a complete snapshot of all standing orders in the LOB. However, since overnight order submissions create unusually high volatility in the early trading hours, and our focus here is on the impact of tick size change on average cost of round trip trade, the first snapshot we use each day begins at 10:30 AM. From this point on, we save hourly snapshots until 3:30 PM. We disregard snapshots after this time, since the NYSE closing at 4:00 PM again creates changes in intra-day volatility patterns. Thus we have 6 snapshots per day for each stock.

To examine how liquidity provision is affected by tick size changes for various trade sizes, we choose five dollar trade size ranges: \$0-\$10,000, \$10,001-\$25,000, \$25,001-\$50,000, \$50,001-\$100,000 and \$100,000-\$200,000. Assuming the midpoints of these ranges (\$5,000, \$17,500….) are representative of the entire range, we compute *CRT(D)* for these dollar amounts for each LOB snapshot. In Tables 5(a) and 5(b) we report the CRT results for the estimation and robustness samples respectively. In table 5(a), we find that four of the five stocks experienced a decline in CRT, the exception being JDSU. Recall that

these four stocks had either a spread decrease or no change in spread while depth significantly increased following the tick size increase. Thus, the mixed reaction of spread to a tick size increase was more than outweighed by the uniform increase in depth for these stocks. This result is generally true across the five (dollar) trade sizes.

JDSU, the low priced stock in the estimation sample, shows a different pattern. For the smallest trade size bin, it has a significant increase in the CRT measure. For this stock, the depth increase due to tick size increase did not wipe out the adverse impact on liquidity via increased spread for trade size between $0-$10,000. The near doubling of its spread caused by the bigger MPV outweighs the increase in depth, and this shows up as an increase in CRT for JDSU. Table 5(b) verifies that the same is true for SUNW, the lowest priced stock in the robustness sample. For the lowest trade size bin, it shows a significant increase in cost of round trip trade (per dollar), and this continues up to the $25,001-$50,000 range. ORCL, which trades around $10, also shows an increase in CRT for the lowest trade size bin.[15] As we move across trade sizes, from low to high, we find that the difference between pre- and post tick size change CRT uniformly increases, implying that overall cost of round trip trade for the larger trade sizes decreases as a result of the move from sub penny to penny tick size.

6. Quote Clustering

Beginning with Christie and Schultz's seminal paper (1994) on NASDAQ market makers' avoidance of odd-eight quotes, researchers have identified that quote clustering is one mechanism by which spreads, and therefore liquidity, can be affected. Comparing a sample of NYSE to NASDAQ stocks, Chung, Van Ness and Van Ness (2003) document that part of the difference in spreads between these matched samples of stocks can be attributed to differential quote clustering amongst these two groups. They also find a high degree of clustering on dimes and nickel in a post-decimalization environment. Bessembinder (2000) shows that for a set of securities trading near $10, trading costs fall

[15]Note that ORCL, like JDSU and SUNW, also experienced a significant increase in spread following the move to a higher tick size (Table 2(b)).

significantly as a result of tick size change for those firms whose market makers avoid odd-eighth quotations. The implication here is that for stocks with a greater proportion of even clustering, tick size reduction leads to bigger reduction in spread than for comparable stocks that do not show such clustering.

However, most of the evidence and rationale offered for stock quote clustering comes from specialist and dealer markets, where clustering can be interpreted as a mechanism for tacit collusion. In this section of the paper, we present evidence on changes in stock price clustering pattern as a result of tick size change on INET's LOB. Since the collusion hypothesis is untenable in a limit order market with anonymous traders, our focus here is on documenting whether quote clustering patterns can systematically arise from the granularity of the pricing grid.

Tables 6(a) and 6(b) present the evidence on clustering for the estimation and robustness samples respectively. For the pre- (post) tick size change period, we present the number of quotes that end in zero through nine at the third (second) decimal place. For example, *x.xx3* (*x.x3*) denotes a sub-decimal (decimal) quote that ends in 3. We compute this for both the bid and ask side. If there is no front-running in a sub-decimal pricing grid, we should find a fairly even distribution of quotes across the ten digits; however, if there is an incentive for investors to step ahead of the line under a finer pricing grid, then we should see a higher concentration of quotes ending in one (nine) for the bid (ask) side. To illustrate why that should be the case, take the following example. Assume that the best bid (ask) prevailing for stock *X* at time *t* is \$12.40 (\$12.43). Under a decimal environment, to step ahead of the order, an investor would have to place a bid (ask) price of \$12.41(\$12.42), which costs the investor one cent. In the sub penny regime, to step ahead of the existing best bid (ask), and investor needs only offer \$12.401 (\$12.429). Thus, we would see a higher clustering of quotes ending in one (nine) on the bid (ask) side under a sub penny regime.[16]

Table 6(a) shows a very clear and predictable clustering pattern in the pre- tick size increase regime for the estimation sample. For every stock, we find that the highest number of quotes are numbers

[16] Hansch (forthcoming) finds a similar pattern for hidden orders on Island. He shows that the most frequent third decimal digit for buy (sell) orders is '1' ('9') which accounts for 57% (53%) of all sub penny priced orders.

ending in 0, indicating that there may be some psychological bias towards placing a two-decimal place quote. However, sub decimal quotes are also widely used. Interestingly, strategic use of the sub-decimal pricing grid seems to be price-dependent. While the low priced stocks use sub-pennies to establish optimal (sub-decimal) spread, the higher priced stocks use the finer grid to step ahead of existing orders. This is evident from the distribution pattern of sub-decimal quotes for the sample stocks.

On the bid (ask) side, there is a significant concentration of quotes ending in one (nine) at the third decimal place and this is more evident for the higher priced stocks. For JDSU, although the highest number of quotes at the sub-decimal level on the bid (ask) side is at one (nine), the distribution of quotes across other decimal points is more uniform than for the higher priced securities. The higher the stock price, the greater is the difference between the number of quotes at the quote at *x.xx1* and those at the other (sub)decimal places. For the high priced securities, there is a tapering pattern in the number of quotes placed at each distinct decimal place. On the bid side, the highest number of sub penny quotes is at the number ending in one and then it uniformly tapers off for the next seven decimal places. While the lower priced stock actually uses the sub penny grid to more uniformly place bid and ask quotes, the higher priced stocks use the finer grid to place high number of quotes ending in one (nine) on the bid (ask) side to step ahead of existing orders.

Table 6(b) verifies that the same pattern repeats for our robustness sample. For the low priced stock SUNW, there is clearly a more uniform distribution of quotes across all sub-decimal price points on the grid although on the bid (ask) side there is a significantly higher number of quotes ending in one (nine). For the other three stocks, the distribution of quotes is markedly more skewed, with the tapering pattern from *x.xx1* through *x.xx9* for the bid quotes and the reverse for ask quotes.

In the regime post the tick size change, we find that there is a fairly even distribution of quotes across all the price points. This uniformity also shows across bid and ask quotes, there is no unusual clustering of quotes at any one price point. The difference between the bid and ask quote at almost every price point is statistically insignificant. This is true of both the estimation and robustness samples. Figures 6(a) and 6(b) graphically illustrate the same findings.

7. Conclusion

In the first ever case of a general tick size increase in a US equities trading platform, the ECN INET, formed by the merger of Island and Instinet ECNs, began migrating their stocks from a platform of sub penny quotes to penny quotes. In this study we look at the effect of this pricing grid change on the pilot securities. We use the five stocks in the first pilot as our estimation sample and the four stocks in the second pilot as our robustness sample. Using proprietary data from INET, we rebuild the entire limit order book in these nine securities for a period of 64 trading days, centered on the day the stocks migrated from the finer to the coarser pricing grid, and examine the impact of this move on the trading and quotation patterns in these stocks.

Our findings point to some interesting dynamics. First, we find that for the two low priced stocks in our samples, JDSU and SUNW, there is a significant increase in spread following the move to a penny tick size. For the higher priced stocks, while some show no significant change in spread, others actually show marginally reduced spread. The evidence on depth changes is uniform across all stocks, there is a marked increase in depth after the increase in the minimum price variation. This is consistent with the front-running hypothesis.

There are some significant changes in order submission strategies that we document following the tick size increase. For stocks in both the estimation and robustness sample, we find that the proportion of hidden orders drops remarkably. This corroborates the front-running hypothesis. Since the cost to stepping-ahead of an order rises from one-tenth of a cent to one cent, the likelihood of 'pennying' falls and this encourages investors to reveal their true trading interests to a greater extent.

While spread and depth changes capture a significant part of the impact to market liquidity, a tick size change creates a basic change in market conditions by changing the number of price points available to place quotes on. Thus, to offer a more accurate picture of liquidity changes following tick size change, we adopt a measure that calculates the cost of round trip trade by combining information from the entire limit order book, and not just the best bid and offer prices and depth. We find that the low priced stocks

experience an overall increased cost of round trip trade for trade sizes ranging from $0-$10,000. The significant increase in spread they face as a result of the one-cent tick size is not fully compensated for by the increased depth. For the higher priced stocks, the opposite conclusion holds. The higher depth, combined with little or no change in spread leads to an overall decrease in the cost of a round trip trade.

We also document that while the sub penny pricing points are widely used by all stocks irrespective of their average price, there appears to be a difference in the way this capacity is used. While the lower priced stocks actually use the various price points in the grid fairly uniformly to quote stocks, the higher priced stocks use the grid to step ahead of existing orders. This is evident in the unusually high number of bid (ask) quotes that end in 1 (9) in the pre-change regime. Post tick size change, there is a fairly even distribution of quotes across the various price points on both the bid and ask side.

The collective body of evidence we present leads us to conclude that a 'one size fits all' scenario, as exists today in US equities markets, is clearly not optimal. Lower priced stocks have an equilibrium spread that is artificially kept high by imposing a minimum price variation of one cent. For these stocks, the one-cent grid establishes an artificially high floor on spread, and leads to increased overall cost of trade, especially for trade sizes that are less than $10,000. Comprehensive measures of trading cost show that these stocks fare better in a sub penny pricing grid. For high priced stocks, a finer than one-cent grid provides the opportunity for front-stepping and thereby reduces depth, which together lead to a high cost of round trip trade. Finally, our results lead us to believe that a promising direction for future research would be to examine the efficiency of a tiered pricing grid that determines tick size based on security price, a scheme such as the one Instinet used before merging with Island.

References

Ahn, H., Cao, C. Choe, H., 1996, Tick size, spread and volume, Journal of Financial Intermediation, 5, 2-22

Bacidore, J. 1997. The impact of decimalization on market quality: an empirical investigation of the Toronto stock exchange, Journal of Financial Intermediation Vol. 6, No. 2

Bacidore, J., Battalio, R., Farkas, S., 2001. Changes in order characteristics, displayed liquidity, and execution quality on the New York Stock Exchange around the switch to decimal pricing, Working Paper. The New York Stock Exchange

Bias, B., Hillion, P., Spatt, S., 1995, An empirical analysis of the Limit Order Book and the order flow in the Paris Bourse, Journal of Finance, Vol. 50, No. 5, 1655-1689

Bourghelle, D., and DeClerck, F., 2002, Why markets should not necessarily reduce tick size, EFMA Conference Paper, Lugano

Chakrabarty, B., Chung, K., 2004, Can sub penny pricing reduce trading costs? Working Paper, SUNY, Buffalo.

Chakravarty, S., Harris, S., and Wood, R., 2001. Decimal trading and market impact. Working Paper, University of Memphis

Chan, K. C., and C. Y. Hwang, 2000, The impact of tick size on the quality of a pure order driven market: Evidence from the Stock Exchange of Hong Kong, Working Paper, Hong Kong University of Science and Technology.

Chen, M., Chou, R. K., Shyy, G., 2002, An empirical investigation of ECNs and the dealer market: order imbalances and spread patterns, EFMA Conference Paper, Lugano

Cho, D., and Frees, E., 1988, Estimating the volatility of discrete stock prices, Journal of Finance, Vol. 43, Issue 2, 451-467

Chordia, T., and Subrahmanyam, A., 1995, Market making, the tick size and payment for order flow: theory and evidence, The Journal of Business, Vol.68, No. 4, 543-576

Chung, K. H., Charoenwong, C., and Ding. D., 2002. Penny pricing and the components of spread and depth changes, Working Paper, University at Buffalo, The State University of New York

Chung, K., Chuwonganant, C.,2003, Tick size, order handling rules and trading costs, Working Paper, University at Buffalo, The State University of New York

Chung, K., Chuwonganant, C., McCormick, T., 2003, Order preferencing and market quality on NASDAQ before and after decimalization, *Forthcoming* Journal of Financial Economics

Chung, K.H., Van Ness, B., Van Ness, R., 2003. Trading costs and quote clustering on the NYSE and NASDAQ after decimalization. Working paper, SUNY-Buffalo.

Goldstein, M., and K. Kavajecz, 2000, Eights, Sixteenths and Market Depth: Changes in tick size and liquidity provision on the NYSE, Journal of Financial Economics 56, 125-149.

Harris, L., 1994. Minimum price variations, discrete bid-ask spreads, and quotations sizes, Review of Financial Studies 7, 149-178

Harris, L., 1996. Does a large minimum price variation encourage order exposure? Working Paper, University of Southern California

Harris, L., 1997. Decimalization: A review of the arguments and evidence. Working Paper, University of Southern California

Hasbrouck, J., 1999, The dynamics of discrete bid and ask quotes, Journal of Finance, Vol. 54, Issue 6, 2109-2143

Huang, R., and Stoll, H., 2001, Tick size, bid ask spreads and market structure, Journal of Financial and Quantitative Analysis, Vol. 36, Issue 4, 503-522

Irvine, P., Benston , G., Kandel, E., 2004, Liquidity beyond the Inside Spread: Measuring and Using Information in the Limit Order Book, Working Paper, University of Georgia.

Nemiroff, G., and H. Mackinnon, Tick Size and the returns to providing liquidity, International Review of Finance and Economics (forthcoming).

Parlour, C., 1998, Price Dynamics in Limit Order Markets, The Review of Financial Studies, Vol.11, No. 4, 789-816

Ricker, J., Decimal quotes: the price is right, Working Paper, Social Sciences Research Network

Ronen, T. and Weaver, D., 2001, Teenies anyone? The effect of tick size on volatility, trader behavior and market quality, Journal of Financial Markets, 4, 231-260

Wallman, S., Technology and our markets: time to decimalize, speech before the center for the study of equities markets, Pace University, 09/25/96

Table 1: INET Descriptive Statistics

This table reports some summary statistics that describe the sample securities. There are 5 (4) securities in pilot I (pilot II). The sample period is 09/11/03 to 12/11/03 for pilot I, and 10/02/03 to 01/02/04 for pilot II. Share price is measured by the mean quote mid-point. Trading volume is the average daily number of shares traded on INET over the sample period. Market value of equity (MVE) measures the firm size. Pilot I (II) comprises of the stocks AMGN, FLEX, CSCO, JDSU and SBUX (INTC, MSFT, SUNW, and ORCL) that migrated to penny trading on 10/27/03 (11/11/03).

		Mean	Std. Dev.	Minimum	5th Percentile	25th Percentile	Median	75th Percentile	Maximum
Pilot 1									
AMGN	Price ($)	62.46	3.51	57.62	58.19	59.74	61.2	65.34	70.00
	Trade Vol (‘000)	9816	3608	1647	5459	7628	9419	11797	24758
	MVE($ bn.)	85.02							
FLEX	Price ($)	14.68	0.53	13.62	13.93	14.27	14.67	15.03	16.00
	Trade Vol (‘000)	8641	5970	3546	4189	5645	6931	9875	48730
	MVE($ bn.)	9.53							
CSCO	Price ($)	21.90	1.38	19.59	19.98	20.79	21.64	23.12	24.40
	Trade Vol (‘000)	46255	16542	7099	26600	37487	43236	52430	116611
	MVE($ bn.)	167.2							
JDSU	Price ($)	3.60	0.26	3.13	3.27	3.38	3.51	3.81	4.16
	Trade Vol (‘000)	28829	21898	4728	12136	19709	24241	32403	184927
	MVE ($ bn.)	7.27							
SBUX	Price ($)	30.93	1.14	28.80	29.10	30.03	31.05	32.00	33.00
	Trade Vol (‘000)	2754	1167	601	1239	2029	2543	3258	8134
	MVE ($ bn.)	14.57							
Full Sample	Price Range ($)	3.60-62.46							
Pilot 2									
INTC	Price ($)	31.20	1.93	27.27	27.93	29.74	31.29	32.82	34.12
	Trade Vol (‘000)	51292	14530	11868	32660	43013	50062	57651	110833
	MVE ($ bn.)	196.09							
ORCL	Price ($)	12.30	0.49	11.25	11.59	11.97	12.28	12.70	13.33
	Trade Vol (‘000)	45300	18097	8155	26840	35463	41756	50368	125847
	MVE ($ bn.)	69.37							
MSFT	Price ($)	27.30	1.41	25.10	25.30	26.09	27.10	28.79	29.96
	Trade Vol (‘000)	66353	27253	12076	34650	48443	64162	80195	210558
	MVE ($ bn.)	291.41							
SUNW	Price ($)	3.97	0.35	3.20	3.37	3.62	4.08	4.24	4.54
	Trade Vol (‘000)	50951	26037	10469	23210	33749	45669	59586	163605
	MVE ($ bn.)	16.73							
Full Sample	Price Range ($)	3.97-31.20							

Table 2(a): Spread and Depth changes in the Pilot 1sample (Simple average)

This table reports the changes in inside spread and depth for the stocks in Pilot I. Average spread is simple dollar spread and Rel.Spread is measured as dollar spread divided by share price. Before (after) refers to the 32 trading days beginning 09/11 (10/27) and ending 10/24(12/11), 2003. The t-statistics test for equality of means for the before and after samples.

	AMGN	CSCO	FLEX	JDSU	SBUX
Average Spread					
Before	0.0815	0.0118	0.0365	0.0061	0.0659
After	0.0532	0.0129	0.0270	0.0103	0.0412
Before – After	0.0283	-0.0010	0.0095	-0.0043	0.0247
t-stat	13.78**	-3.34**	7.36**	-15.95**	12.05**
Average Rel. Spread (%)					
Before	0.1245	0.0575	0.2495	0.1575	0.2215
After	0.0892	0.0578	0.1838	0.3032	0.1300
Before – After	0.0352	-0.0003	0.0657	-0.1456	0.0915
t-stat	9.98**	-0.17	6.72**	-18.87**	13.87**
Average Bid Depth					
Before	588.19	1587.86	1110.15	3205.20	762.22
After	846.27	7642.69	1670.47	37604.13	944.08
Before – After	-258.08	-6054.83	-560.31	-34398.90	-181.86
t-stat	-8.28**	-34.82**	-7.35**	-19.51**	-4.93**
Average Ask Depth					
Before	554.21	1509.90	1053.97	3353.00	722.93
After	831.38	7785.01	1748.18	36555.25	971.55
Before – After	-277.16	-6275.11	-694.21	-33202.20	-248.62
t-stat	-8.61**	-35.38**	-8.23**	-12.59**	-7.06**

** Significant at the 1% level

Table 2(b): Spread and Depth changes in the Pilot II sample (Simple average)

This table reports the changes in inside spread and depth for the stocks in Pilot II. Average spread is simple dollar spread and Rel.Spread is measured as dollar spread divided by share price. Before (after) refers to the 32 trading days beginning 10/02 (11/17) and ending 11/14 (01/02), 2003/4. The t-statistics test for equality of means for the before and after samples.

	INTC	MSFT	ORCL	SUNW
Average Spread				
Before	0.0154	0.0142	0.0101	0.0033
After	0.0142	0.0122	0.0110	0.0104
Before – After	0.0011	0.0019	-0.0009	-0.0071
t-stat	2.88**	3.74**	-4.19**	-54.23**
Average Rel. Spread (%)				
Before	0.0482	0.0511	0.0830	0.0903
After	0.0446	0.0464	0.0877	0.2434
Before – After	0.0036	0.0046	-0.0047	-0.1531
t-stat	3.48**	3.24**	-2.46*	-46.12**
Average Bid Depth				
Before	1102.68	1649.93	2112.61	5216.26
After	4763.33	7857.57	13653.27	33351.92
Before – After	-3660.65	-6207.64	-11540.60	-28135.70
t-stat	-17.09**	-21.92**	-16.62**	-22.75**
Average Ask Depth				
Before	1151.31	1399.64	1975.00	5178.42
After	4702.93	8360.90	13798.93	35537.04
Before – After	-3551.62	-6961.26	-11823.90	-30358.60
t-stat	-17.83**	-25.95**	-11.96**	-21.69**

**Significant at the 1% level
* Significant at the 5% level

Table 3(a): Spread and Depth changes in the Pilot 1sample (Time weighted average)

This table reports the changes in inside spread and depth for the stocks in Pilot I. Average spread is time-weighted dollar spread and Rel.Spread is dollar spread divided by share price. Before (after) refers to the 32 trading days beginning 09/11 (10/27) and ending 10/24(12/11), 2003. The t-statistics test for equality of means for the before and after samples.

	AMGN	CSCO	FLEX	JDSU	SBUX
Average Spread					
Before	0.0721	0.0110	0.0338	0.0050	0.0557
After	0.0514	0.0129	0.0277	0.0098	0.0413
Before – After	0.0206	-0.0019	0.0060	-0.0048	0.0144
t-stat	4.10**	-2.50**	1.62	-8.50**	2.17*
Average Rel. Spread (%)					
Before	0.1099	0.0529	0.2300	0.1302	0.1873
After	0.0864	0.0588	0.1877	0.2876	0.1300
Before – After	0.0234	-0.0059	0.0422	-0.1573	0.0572
t-stat	2.63**	-1.67	1.76	-9.64**	2.76**
Average Bid Depth					
Before	562.39	2032.49	1166.64	5967.39	688.92
After	796.80	7535.01	1738.50	43190.85	932.45
Before – After	-234.41	-5502.52	-571.85	-37223.40	-243.53
t-stat	-7.95**	-9.15**	-4.97**	-6.77**	-5.23**
Average Ask Depth					
Before	534.02	2026.18	1218.49	5709.49	620.28
After	794.20	7597.30	1681.53	42234.75	953.07
Before – After	-260.18	-5571.12	-463.04	-36525.30	-332.78
t-stat	-8.73**	-8.43**	-2.38*	-7.28**	-6.78**

**Significant at the 1% level
* Significant at the 5% level

Table 3(b): Spread and Depth changes in the Pilot 2 sample (Time weighted average)

This table reports the changes in inside spread and depth for the stocks in Pilot II. Average spread is time-weighted dollar spread and Rel.Spread is dollar spread divided by share price. Before (after) refers to the 32 trading days beginning 10/02 (11/17) and ending 11/14 (01/02), 2003/4. The t-statistics test for equality of means for the before and after samples.

	INTC	MSFT	ORCL	SUNW
Average Spread				
Before	0.0145	0.0129	0.0086	0.0023
After	0.0165	0.0122	0.0114	0.0116
Before – After	-0.0020	0.0007	-0.0028	-0.0093
t-stat	-1.06	0.96	-4.33**	-10.21**
Average Rel. Spread (%)				
Before	0.0455	0.0466	0.0708	0.0624
After	0.0518	0.0462	0.0908	0.2702
Before – After	-0.0063	0.0003	-0.0200	-0.2077
t-stat	-1.05	0.14	-3.63**	-9.86**
Average Bid Depth				
Before	1149.06	1484.39	2015.62	4806.74
After	4809.40	8521.86	14068.24	35750.74
Before – After	-3660.34	-7037.47	-12052.60	-30944.00
t-stat	-14.37**	-19.48**	-15.16**	-19.51**
Average Ask Depth				
Before	1154.79	1384.88	1862.82	4934.72
After	4797.55	8633.18	14081.29	37900.69
Before – After	-3642.76	-7248.30	-12218.50	-32966.00
t-stat	-16.75**	-21.21**	-12.60**	-19.21**

**Significant at the 1% level

Table 4(a): Statistics on Order submission (Estimation Sample)

This table reports changes in order submission patterns for the Pilot I stocks. Order types (cancelled, executed, etc.) are in the ITCH data description. % is measured as a proportion of total number of orders. Time to execution is measured in milliseconds. Before (after) refers to the 32 trading days beginning 09/11 (10/27) and ending 10/24(12/11), 2003. The t-statistics test for equality of means for the before and after samples.

			AMGN	CSCO	FLEX	JDSU	SBUX
Cancelled	Raw	Before	31111	27988	11618	12016	9226
		After	38481	51363	14181	13275	15383
		Before–After	-7369	-23375	-2563	-1259	-6156
		t-stat	-4.38**	-6.19**	-2.36**	-1.59	-7.58**
	%	Before	0.9505	0.8890	0.9214	0.9031	0.9544
		After	0.9226	0.9049	0.9082	0.8757	0.9309
		Before–After	0.0279	-0.0159	0.0131	0.0274	0.0235
		t-stat	7.93**	-3.45**	2.05*	4.75**	5.50**
Partially Cancelled	Raw	Before	24.56	80	29.93	72.96	31.00
		After	27.21	67.90	47.71	123.71	41.75
		Before–After	-2.65	12.09	-17.78	-50.75	-10.75
		t-stat	-0.65	1.04	-2.50*	-2.95**	-1.69
	%	Before	0.0007	0.0026	0.0024	0.0053	0.0034
		After	0.0006	0.0012	0.0031	0.0090	0.0026
		Before–After	0.0001	0.0013	-0.0006	-0.0036	0.0007
		t-stat	1.07	4.58**	-1.39	-2.76**	1.37
Executed	Raw	Before	1251.25	2791.18	803.03	975.40	313.78
		After	2714.15	4341.84	1177.53	1514.43	888.96
		Before–After	-1462.90	-1550.65	-374.50	-539.03	-575.18
		t-stat	-10.41**	-4.14**	-2.70**	-3.84**	-10.02**
	%	Before	0.0390	0.0884	0.0647	0.0734	0.0331
		After	0.0651	0.0768	0.0742	0.0961	0.0552
		Before–After	-0.0261	0.0116	-0.0094	-0.0226	-0.0221
		t-stat	-8.39**	2.82**	-1.63	-4.35**	-6.38**
Partially Executed	Raw	Before	308.15	619.09	138.00	234.87	83.87
		After	473.34	953.96	218.96	288.40	180.81
		Before–After	-165.18	-334.87	-80.96	-53.53	-96.93
		t-stat	-7.83**	-4.60**	-4.47**	-2.75**	-9.13**
	%	Before	0.0096	0.0199	0.0113	0.0179	0.0090
		After	0.0115	0.0169	0.0143	0.0190	0.0111
		Before–After	-0.0019	0.0029	-0.0029	-0.0010	-0.0021
		t-stat	-3.20**	4.94**	-3.16**	-1.20	-2.99**
Hidden	Raw	Before	1134.12	4502.78	995.71	1906.78	341.90
		After	843.18	1994.75	381.43	437.25	208.96
		Before–After	290.93	2508.03	614.28	1469.53	132.93
		t-stat	3.99**	6.31**	5.30**	6.47**	4.39**
	%	Before	0.0355	0.1543	0.0811	0.1488	0.0368
		After	0.0211	0.0402	0.0234	0.0266	0.0129
		Before–After	0.0143	0.1140	0.0576	0.1222	0.0238
		t-stat	5.57**	8.11**	9.12**	8.28**	9.56**
Avg Time to Execution		Before	124803.83	300115.43	152816.92	582117.54	173462.58
		After	63101.61	238769.07	135294.17	631283.55	105921.81
		Before–After	61702.21	61346.36	17522.75	-49166.01	67540.76
		t-stat	5.87**	1.34	0.76	-0.66	2.83**

**Significant at the 1% level; *Significant at the 5% level

Table 4(b): Statistics on Order submission (Robustness Sample)

This table reports changes in order submission patterns for the Pilot II stocks. Order types (cancelled, executed, etc.) are in the ITCH data description. % is measured as a proportion of total number of orders. Time to execution is measured in milliseconds. Before (after) refers to the 32 trading days beginning 10/02 (11/17) and ending 11/14 (01/02), 2003/4. The t-statistics test for equality of means for the before and after samples.

			INTC	MSFT	ORCL	SUNW
Cancelled	Raw	Before	38147.75	29477.59	19855.78	16818.34
		After	70696.22	56408.16	38711.72	13453.16
		Before–After	-32548.50	-26930.60	-18856.05	3365.00
		t-stat	-5.51**	-7.87**	-6.95**	2.75**
	%	Before	0.9012	0.8988	0.8762	0.8597
		After	0.8810	0.8961	0.8994	0.8822
		Before–After	0.0202	0.0027	-0.0231	-0.0224
		t-stat	3.48**	0.47	-5.02**	-2.65*
Partially Cancelled	Raw	Before	51.93	60.34	70.62	74.81
		After	65.81	97.93	108.25	102.59
		Before–After	-13.87	-37.59	-37.62	-27.80
		t-stat	-1.80	-4.30**	-2.90**	-2.41*
	%	Before	0.0012	0.0018	0.0031	0.0039
		After	0.0009	0.0016	0.0030	0.0072
		Before–After	0.0003	0.0001	0.0001	-0.0034
		t-stat	-1.80*	0.74	0.15	-3.97**
Executed	Raw	Before	3308.50	2708.46	2196.84	2187.03
		After	7797.15	5381.46	3592.21	1401.40
		Before–After	-4488.66	-2673.00	-1395.4	785.60
		t-stat	-7.43**	-7.74**	-4.98**	4.68**
	%	Before	0.0805	0.0824	0.0990	0.1128
		After	0.0978	0.0855	0.0812	0.0917
		Before–After	-0.0173	-0.0030	0.0178	0.0211
		t-stat	-3.43**	-0.62	4.70**	2.99**
Partially Executed	Raw	Before	687.06	547.18	471.25	446.06
		After	1558.71	1055.00	707.46	281.56
		Before–After	-871.65	-507.813	-236.22	164.50
		t-stat	-8.62**	-7.48**	-4.39**	6.13**
	%	Before	0.0169	0.0168	0.0215	0.0235
		After	0.0202	0.0167	0.0163	0.0187
		Before–After	-0.0032	0.0001	0.0052	0.0047
		t-stat	-3.17**	0.13	4.89**	3.23**
Hidden	Raw	Before	6334.06	4996.59	4242.68	2244.28
		After	2862.75	1674.71	993.15	279.09
		Before–After	3471.31	3321.87	3249.50	1965.01
		t-stat	8.65**	10.75**	15.36**	12.47**
	%	Before	0.1555	0.1580	0.1934	0.1145
		After	0.0383	0.0267	0.0223	0.0185
		Before–After	0.1171	0.1313	0.1710	0.0959
		t-stat	19.45**	19.06**	24.31**	17.81**
Avg Time to Execution		Before	181118.90	265442.30	245120.70	319914.60
		After	66360.92	108071.50	148407.50	318990.90
		Before–After	114758.01	157370.70	96713.20	923.70
		t-stat	3.06**	3.43**	2.97**	0.01

**Significant at the 1% level; *Significant at the 5% level

Table 5(a): Cost of round trip trade (Estimation Sample)

This table reports changes in the CRT measure for the Pilot I stocks. Trade sizes are selected for five dollar-ranges and the reported sizes are the range mid-points. For example, trade size 5,000 represents the range $0-$10,000. Before (after) refers to the 32 trading days beginning 09/11 (10/27) and ending 10/24(12/11), 2003. The t-statistics test for equality of means for the before and after samples.

Panel A						
		Trade Size ($)				
		5,000	17,500	37,500	75,000	150,000
AMGN	Before	0.0023	0.0027	0.0034	0.0051	0.0107
	After	0.0020	0.0026	0.0034	0.0051	0.0100
	Before - After	0.0004	0.0002	0.0001	0.0000	0.0008
	t-stat.	2.11*	0.93	0.23	-0.03	1.0114
FLEX	Before	0.0061	0.0094	0.0150	0.0307	0.0623
	After	0.0048	0.0071	0.0118	0.0263	0.0456
	Before - After	0.0013	0.0024	0.0032	0.0044	0.0167
	t-stat.	2.10*	2.66**	2.50*	1.99*	1.64
CSCO	Before	0.0013	0.0019	0.0026	0.0036	0.0055
	After	0.0013	0.0014	0.0015	0.0018	0.0026
	Before - After	0.0000	0.0005	0.0010	0.0018	0.0030
	t-stat.	0.45	4.87**	8.76**	12.95**	15.14**
JDSU	Before	0.0036	0.0067	0.0127	0.0243	0.0456
	After	0.0061	0.0063	0.0070	0.0092	0.0159
	Before - After	-0.0025	0.0004	0.0057	0.0151	0.0297
	t-stat.	-14.44**	1.27	11.19**	16.41**	16.02**
SBUX	Before	0.0040	0.0050	0.0068	0.0144	0.0362
	After	0.0033	0.0048	0.0077	0.0076	0.0376
	Before - After	0.0007	0.0002	-0.0009	0.0068	-0.0014
	t-stat.	1.4552	0.24	-0.80	1.21	-0.91

**Significant at the 1% level; *Significant at the 5% level

Table 5(b): Cost of round trip trade (Robustness Sample)

This table reports changes in the CRT measure for the Pilot I stocks. Trade sizes are selected for five dollar-ranges and the reported sizes are the range mid-points. For example, trade size 5,000 represents the range $0-$10,000. Before (after) refers to the 32 trading days beginning 10/02 (11/17) and ending 11/14 (01/02), 2003/4. The t-statistics test for equality of means for the before and after samples.

Panel B						
		Trade Size ($)				
		5,000	17,500	37,500	75,000	150,000
INTC	Before	0.0010	0.0014	0.0019	0.0026	0.0039
	After	0.0011	0.0012	0.0014	0.0018	0.0028
	Before - After	-0.0001	0.0002	0.0004	0.0007	0.0010
	t-stat.	-0.78	1.23	2.93**	3.33**	2.83**
MSFT	Before	0.0010	0.0015	0.0020	0.0028	0.0042
	After	0.0010	0.0011	0.0012	0.0014	0.0019
	Before - After	0.0000	0.0004	0.0008	0.0014	0.0022
	t-stat.	0.16	5.28**	8.85**	11.46**	11.70**
ORCL	Before	0.0016	0.0026	0.0038	0.0056	0.0088
	After	0.0019	0.0021	0.0024	0.0030	0.0047
	Before - After	-0.0003	0.0005	0.0014	0.0026	0.0041
	t-stat.	-2.60**	3.09**	7.24**	9.95**	10.21**
SUNW	Before	0.0020	0.0033	0.0055	0.0107	0.0204
	After	0.0056	0.0060	0.0068	0.0088	0.0146
	Before - After	-0.0036	-0.0027	-0.0012	0.0018	0.0058
	t-stat.	-10.14**	-6.03**	-1.96*	1.8076	3.77**

**Significant at the 1% level; *Significant at the 5% level

Table 6(a): Quote Clustering (Estimation Sample)

This table reports the quote clustering patterns before and after the tick size change for the Pilot I stocks. For example, x.xx3 (x.x3) denotes a sub-decimal (decimal) quote that ends in 3. The numbers represent the average daily distinct quotes at each denoted sub penny or penny increment. Before (after) refers to the 32 trading days beginning 09/11 (10/27) and ending 10/24(12/11), 2003. The t-statistics test for equality of means for the before and after samples.

Ticker	Decimal Places										
	Pre	x.xx0	x.xx1	x.xx2	x.xx3	x.xx4	x.xx5	x.xx6	x.xx7	x.xx8	x.xx9
	Post	x.x0	x.x1	x.x2	x.x3	x.x4	x.x5	x.x6	x.x7	x.x8	x.x9
AMGN											
Pre	Bid	6819	7573	1181	571	245	142	59	45	29	397
	Ask	6456	424	45	64	118	208	315	655	1213	6912
	Bid-Ask	363	7149	1135	507	127	-66	-256	-610	-1184	-6515
	t-stat.	2.38*	24.86**	9.92**	7.22**	5.48**	-3.78**	-7.51**	-8.38**	-10.98**	-30.97**
Post	Bid	1220	1045	1036	1006	975	1193	1119	1053	1061	1004
	Ask	1262	1001	1024	1024	990	1102	984	1013	1036	1091
	Bid-Ask	-42	44	12	-18	-15	91	135	40	24	-87
	t-stat.	-0.96	1.39	0.37	-0.57	-0.7	2.84**	3.78**	1.33	0.73	-2.46*
FLEX											
Pre	Bid	2017	1290	82	11	3	6	0	1	1	2
	Ask	2113	5	4	3	3	6	5	12	101	1324
	Bid-Ask	-96	1285	78	7	0	0	-5	-11	-100	-1322
	t-stat.	-1.31	12.12**	6.34**	2.69**	-0.02	0.03	-1.96*	-2.97**	-6.30**	-11.44**
Post	Bid	293	253	256	255	249	273	261	270	276	275
	Ask	322	292	283	272	280	291	254	262	268	279
	Bid-Ask	-29	-40	-27	-17	-31	-18	6	8	8	-4
	t-stat.	-2.51*	-3.17**	-2.14*	-1.22	-1.82	-1.57	0.41	0.61	0.75	-0.28
CSCO											
Pre	Bid	2473	1997	412	258	255	293	253	199	162	294
	Ask	2604	291	176	198	238	312	286	294	415	2113
	Bid-Ask	-131	1706	236	60	17	-19	-33	-94	-253	-1818
	t-stat.	-2.55*	19.07**	12.44**	3.71**	1.23	-1.04	-2.25*	-5.02**	-11.62**	-22.86**
Post	Bid	276	266	271	279	274	271	280	287	284	282
	Ask	297	270	261	264	279	290	277	279	283	295
	Bid-Ask	-21	-4	11	15	-5	-19	3	8	1	-12
	t-stat.	-2.33*	-0.32	1.03	1.57	-0.56	-1.3	0.27	0.91	0.1	-1.13
JDSU											
Pre	Bid	343	272	148	124	107	131	109	98	79	80
	Ask	341	87	80	97	108	129	101	107	131	270
	Bid-Ask	3	185	67	27	-1	1	8	-10	-51	-190
	t-stat.	0.35	13.46**	10.60**	6.13**	-0.21	0.27	1.73	-2.25*	-9.32**	-12.29**
Post	Bid	24	21	20	22	21	23	26	27	30	29
	Ask	30	25	21	21	22	22	25	28	28	30
	Bid-Ask	-6	-4	0	0	-1	2	1	-1	2	-2
	t-stat.	-1.53	-1.25	-0.18	0.13	-0.42	0.62	0.32	-0.37	0.79	-0.65
SBUX											
Pre	Bid	1588	542	226	109	52	26	14	9	7	6
	Ask	1742	7	10	13	21	33	64	143	263	610
	Bid-Ask	-154	535	217	96	32	-7	-50	-134	-256	-604
	t-stat.	-3.08**	9.15**	5.77**	4.12**	2.76**	-1.12578	-4.38**	-4.88**	-6.45**	-9.52**
Post	Bid	365	332	339	344	334	358	340	323	319	316
	Ask	354	320	320	328	328	356	331	329	336	344
	Bid-Ask	11	11	19	16	6	2	9	-6	-18	-28
	t-stat.	0.81	0.71	1.07	0.96	0.43	0.14	0.72	-0.45	-1.47	-1.79

**Significant at the 1% level

*Significant at the 5% level

Table 6(a): Quote Clustering (Robustness Sample)

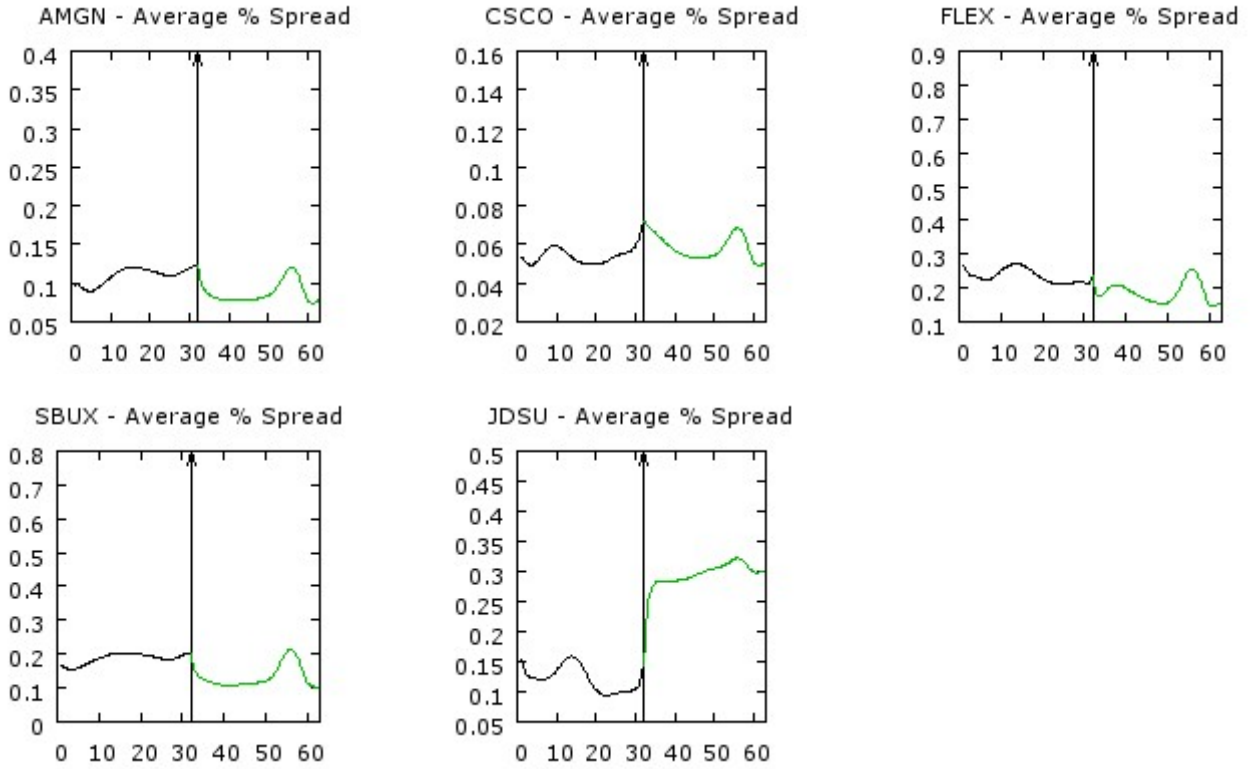
This table reports the quote clustering patterns before and after the tick size change for the Pilot I stocks. For example, x.xx3 (x.x3) denotes a sub-decimal (decimal) quote that ends in 3. The numbers represent the average daily distinct quotes at each denoted sub penny or penny increment. Before (after) refers to the 32 trading days beginning 10/02 (11/17) and ending 11/14 (01/02), 2003/4. The t-statistics test for equality of means for the before and after samples.

Ticker		Decimal	Places								
	Pre	x.xx0	x.xx1	x.xx2	x.xx3	x.xx4	x.xx5	x.xx6	x.xx7	x.xx8	x.xx9
	Post	x.x0	x.x1	x.x2	x.x3	x.x4	x.x5	x.x6	x.x7	x.x8	x.x9
INTC											
Pre	Bid	3718	3363	722	550	534	501	444	402	342	773
	Ask	4229	790	375	394	425	496	547	571	711	3705
	Bid-Ask	-511	2573	347	156	109	5	-103	-169	-369	-2931
	t-stat.	-6.11**	28.79**	14.15**	9.58**	3.52**	0.30	-3.39**	-7.67**	-16.77**	-29.93**
Post	Bid	508	445	448	450	458	468	454	452	461	504
	Ask	506	492	447	437	436	457	445	435	462	477
	Bid-Ask	2	-47	1	14	23	12	9	16	-1	27
	t-stat.	0.08	-2.54*	0.05	1.13	1.4	0.67	0.53	1.42	-0.03	0.79
MSFT											
Pre	Bid	2779	2324	618	525	379	332	289	244	212	447
	Ask	3026	453	222	269	308	361	380	524	583	2435
	Bid-Ask	-247	1871	396	256	71	-29	-92	-280	-370	-1987
	t-stat.	-3.53**	12.03**	16.19**	9.09**	5.41**	-1.92	-5.42**	-9.58**	-13.33**	-14.92**
Post	Bid	206	206	209	212	234	231	212	210	212	209
	Ask	208	206	207	203	213	223	217	215	209	206
	Bid-Ask	-2	0	2	9	20	8	-6	-5	3	2
	t-stat.	-0.18	-0.01	0.15	0.89	1.18	0.32	-0.41	-0.53	0.33	0.29
ORCL											
Pre	Bid	1469	1162	521	358	273	254	189	142	112	95
	Ask	1646	97	115	145	188	243	269	357	496	1247
	Bid-Ask	-177	1065	406	213	85	11	-80	-216	-383	-1152
	t-stat.	-4.74**	24.27**	18.72**	15.34**	12.28**	1.13	-6.22**	-15.01**	-18.23**	-23.26**
Post	Bid	109	102	103	108	105	106	111	103	96	106
	Ask	120	121	112	110	114	113	113	113	102	103
	Bid-Ask	-11	-19	-8	-3	-10	-7	-2	-10	-6	3
	t-stat.	-1.79	-3.90**	-1.23	-0.46	-1.75	-1.17	-0.27	-1.33	-1.1	0.51
SUNW											
Pre	Bid	370	306	234	217	203	215	194	184	171	158
	Ask	381	173	174	179	194	208	197	207	223	310
	Bid-Ask	-11	132	60	38	9	7	-3	-23	-53	-151
	t-stat.	-0.9	9.45**	9.67**	4.70**	1.43	0.92	-0.59	-3.92**	-7.36**	-10.66**
Post	Bid	22	20	21	26	31	35	36	29	26	24
	Ask	27	21	19	19	24	30	30	31	28	28
	Bid-Ask	-5	0	2	7	7	6	6	-2	-2	-4
	t-stat.	-1.84	-0.16	0.93	2.27*	2.19*	1.35	1.56	-0.67	-0.84	-1.31

**Significant at the 1% level
*Significant at the 5% level

Figure 1: Relative Spread
This figure shows changes in relative spread following the move to a penny tick size for the pilot securities. Relative spread is calculated as dollar spread divided by the share price. Pilot I (Pilot II) comprises of the five (four) stocks that moved to the higher grid on October 27th (November 11th). The data-points have been piece-wise bezier-smoothed for graphical presentation.

Pilot I



Pilot II

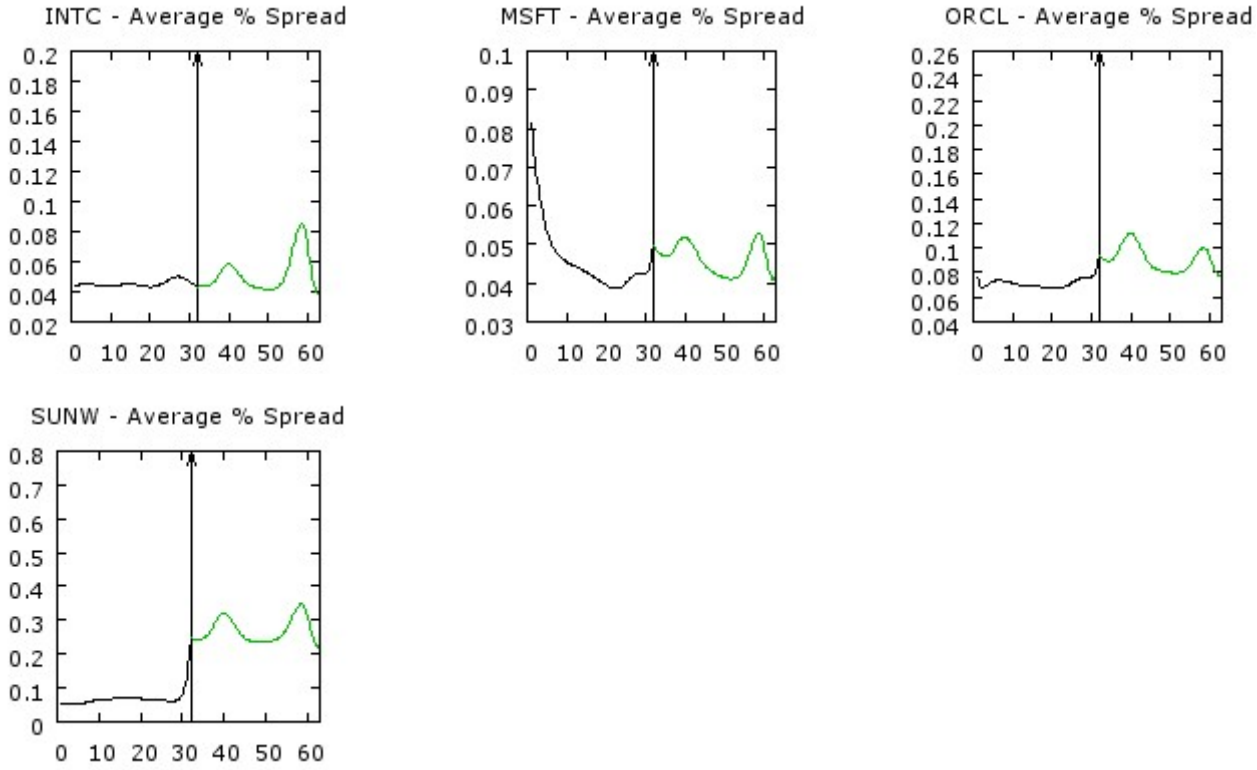
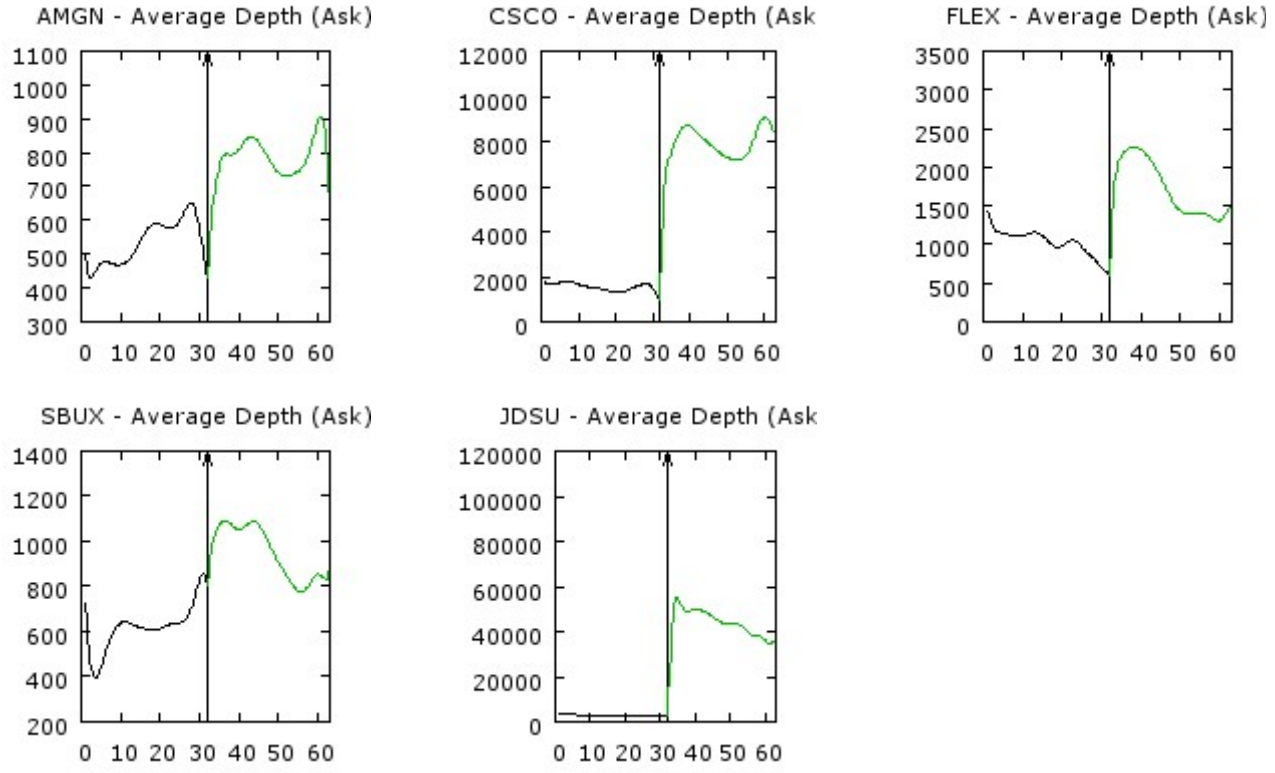


Figure 2: Average Depth (Ask)
This figure shows changes in ask depth following the move to a penny tick size for the pilot securities. Average depth is reported as actual number of shares (not round lots). Pilot I (Pilot II) comprises of the five (four) stocks that moved to the higher grid on October 27th (November 11th). The data-points have been piece-wise bezier-smoothed for graphical presentation.

Pilot I



Pilot II

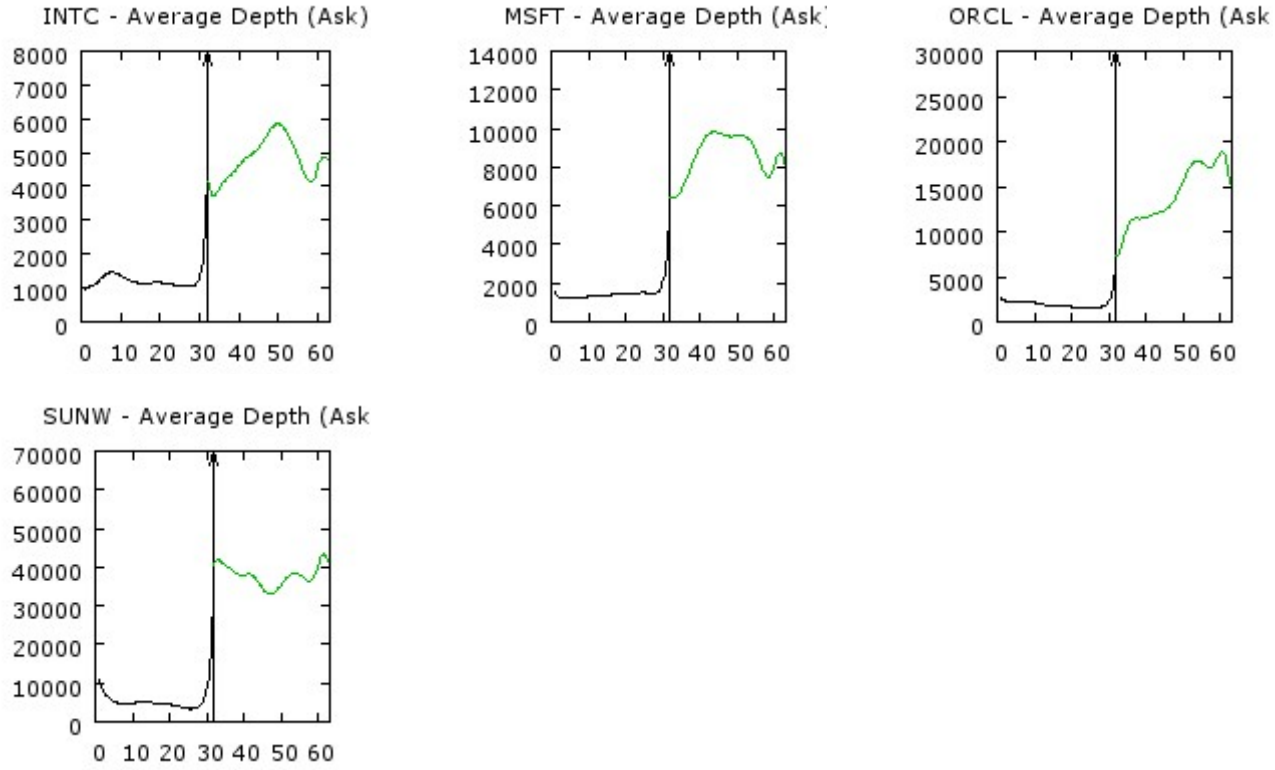
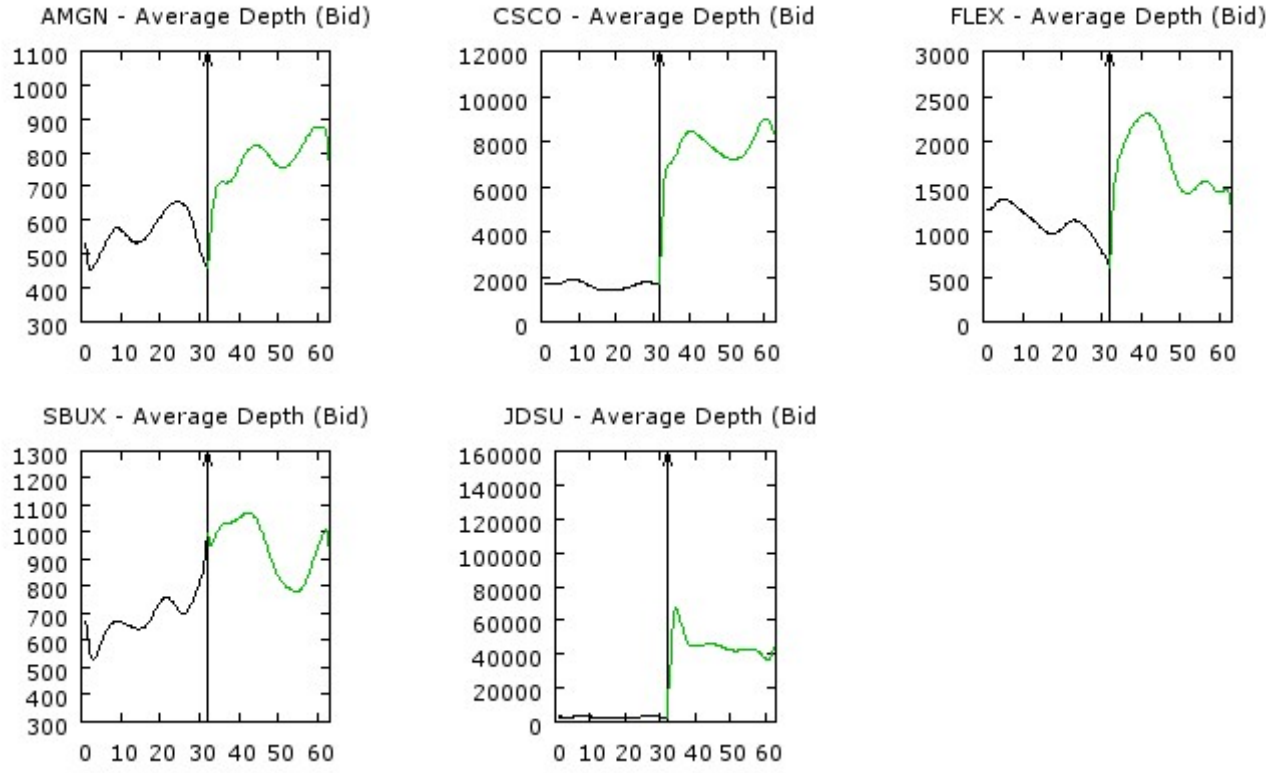


Figure 3: Average Depth (Bid)
This figure shows changes in bid depth following the move to a penny tick size for the pilot securities. Average depth is reported as actual number of shares (not round lots). Pilot I (Pilot II) comprises of the five (four) stocks that moved to the higher grid on October 27th (November 11th). The data-points have been piece-wise bezier-smoothed for graphical presentation.

Pilot I



Pilot II

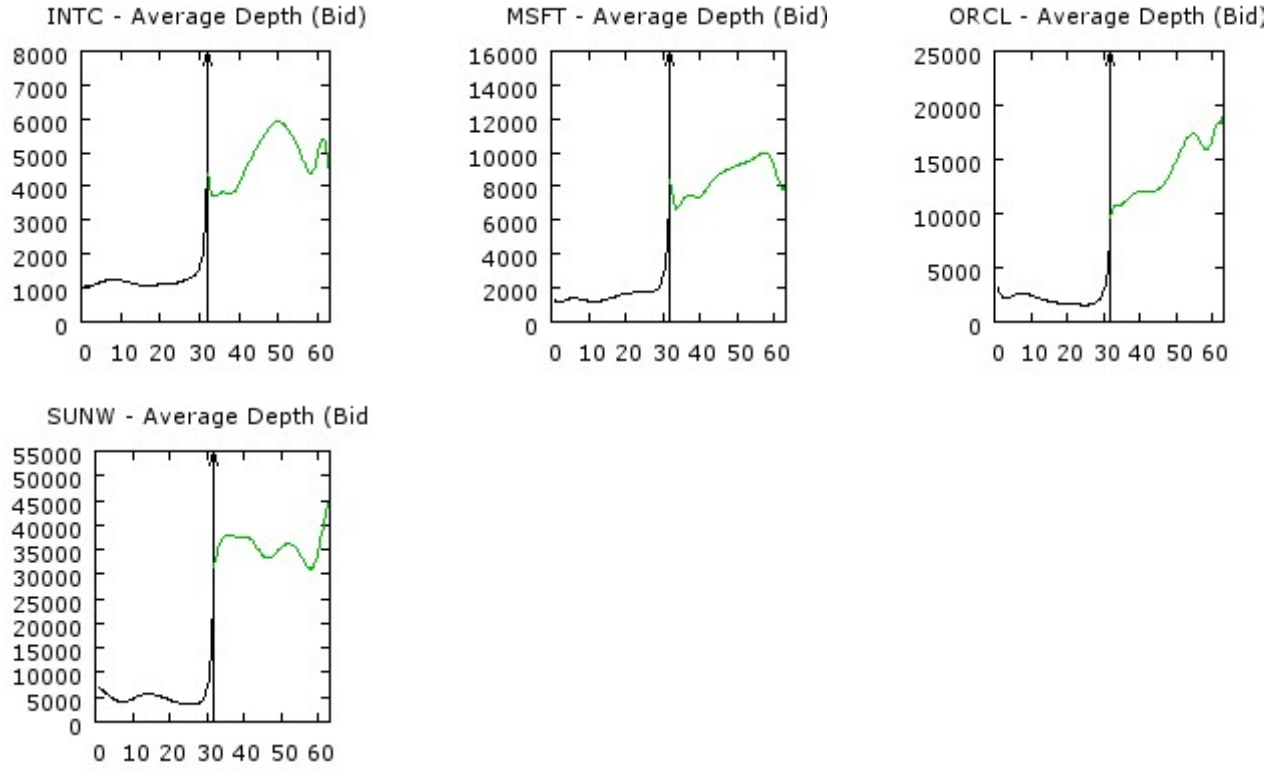
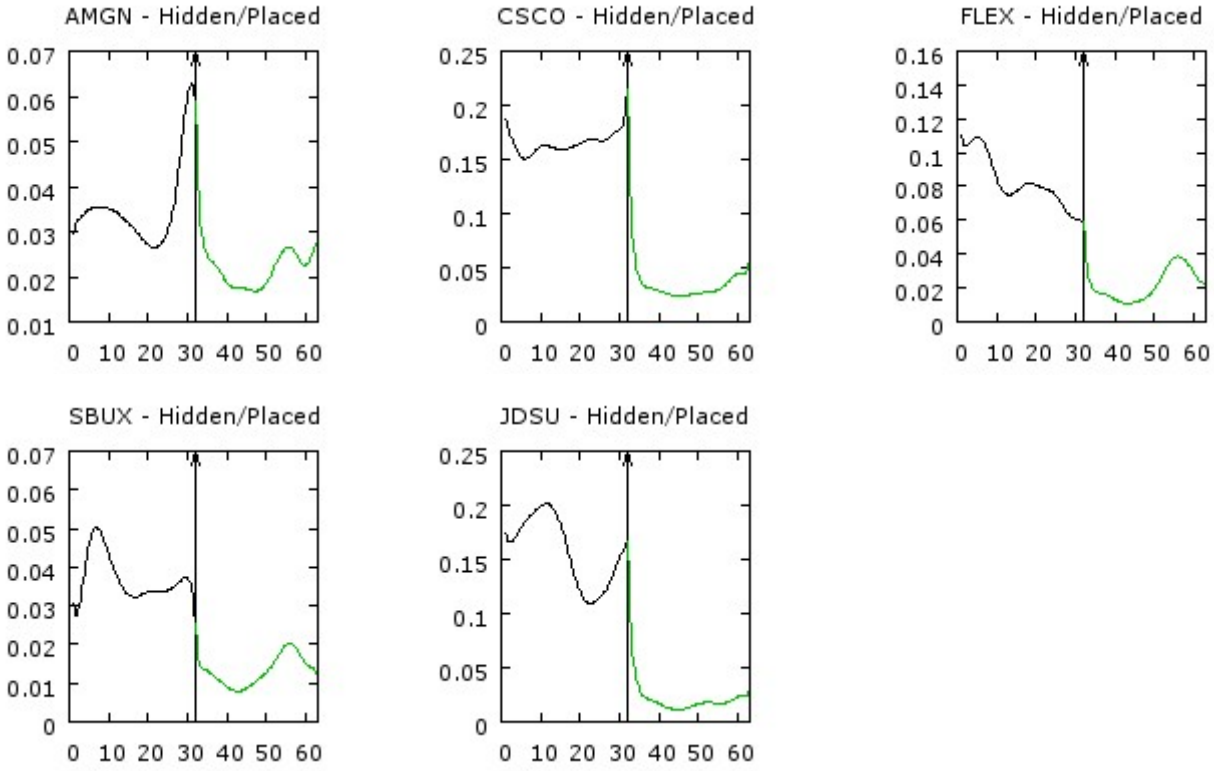


Figure 4: Proportion of Hidden Orders

This figure shows changes in the proportion of hidden orders following the move to a penny tick size. Proportion of hidden orders is the ratio of hidden orders to total orders placed. Pilot I (Pilot II) comprises of the five (four) stocks that moved to the higher grid on October 27th (November 11th). The data-points have been piece-wise bezier-smoothed for graphical presentation.

Pilot I



Pilot II

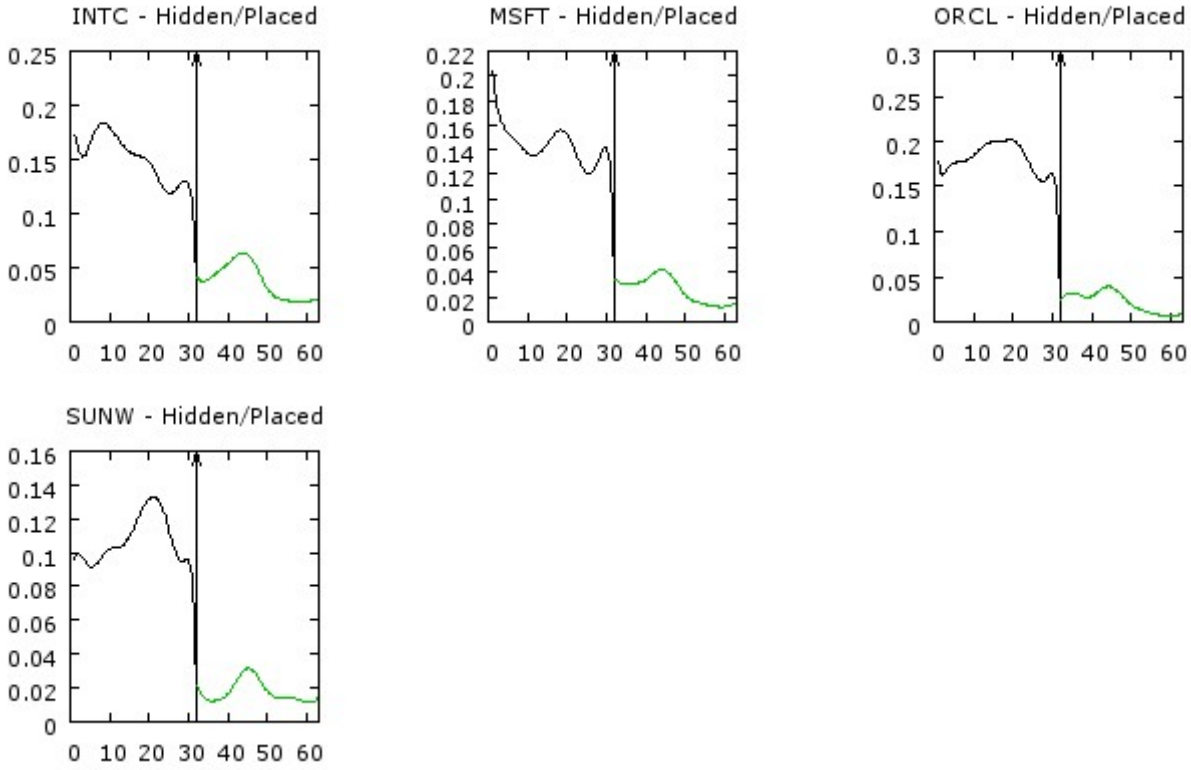
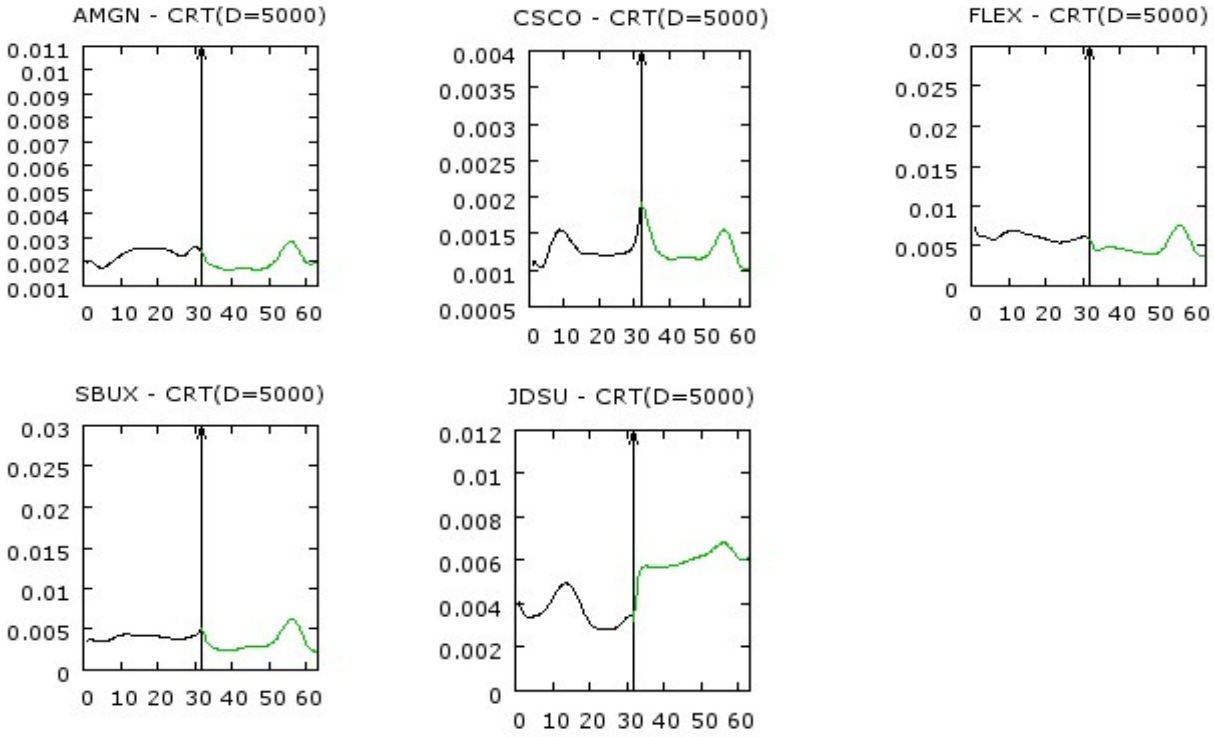


Figure 5: Cost of Round Trip Trade

This figure shows changes in the cost of round trip trade (CRT) for the lowest dollar trade size (range $0-$10,000) following the move to a penny tick size. D (=$5,000) is the mean of the trade size range. The CRT measure summarizes information on both spread and depth to present a more comprehensive picture of market liquidity. Pilot I (Pilot II) comprises of the five (four) stocks that moved to the higher grid on October 27th (November 11th). The data-points have been piece-wise bezier-smoothed for graphical presentation.

Pilot I



Pilot II

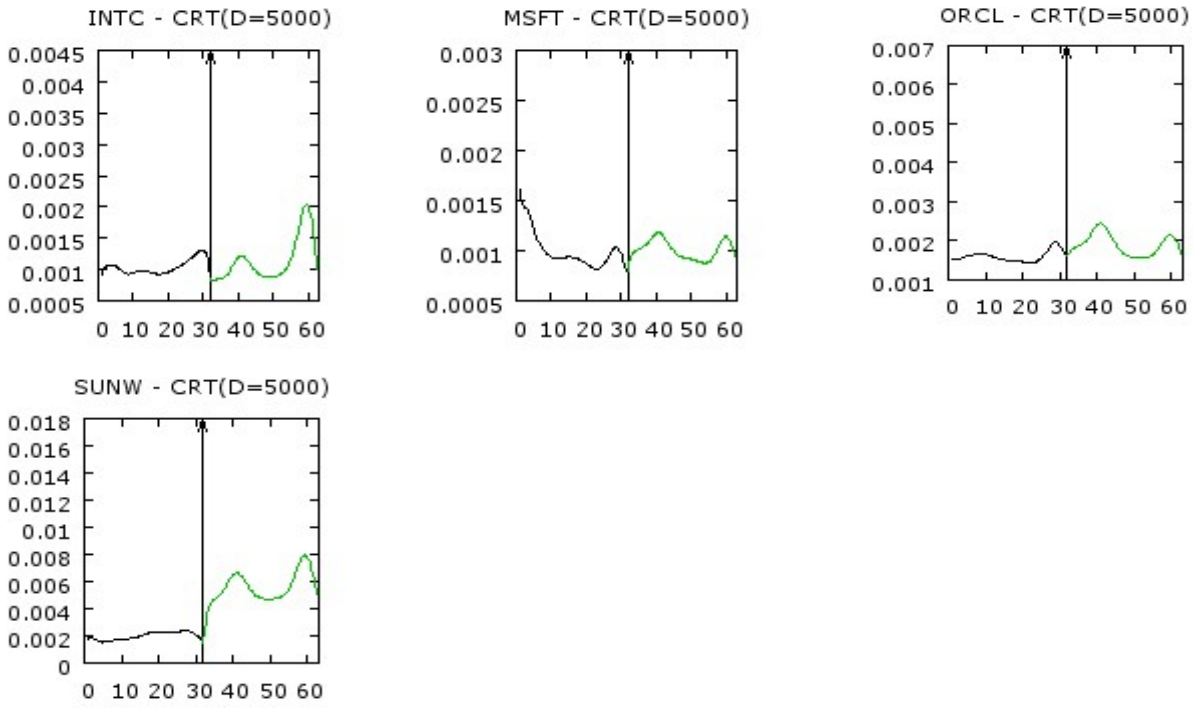


Figure 6(a): Quote-Clustering
This figure shows the patterns in quote clustering at various price points for the sample stocks before and after the move to a penny tick size. For example, x.xx6 (x.x3) denotes a sub penny (penny) price point ending in the number six (three). Pilot I (Pilot II) comprises of the five (four) stocks that moved to the higher grid on October 27th (November 11th).

Pilot I

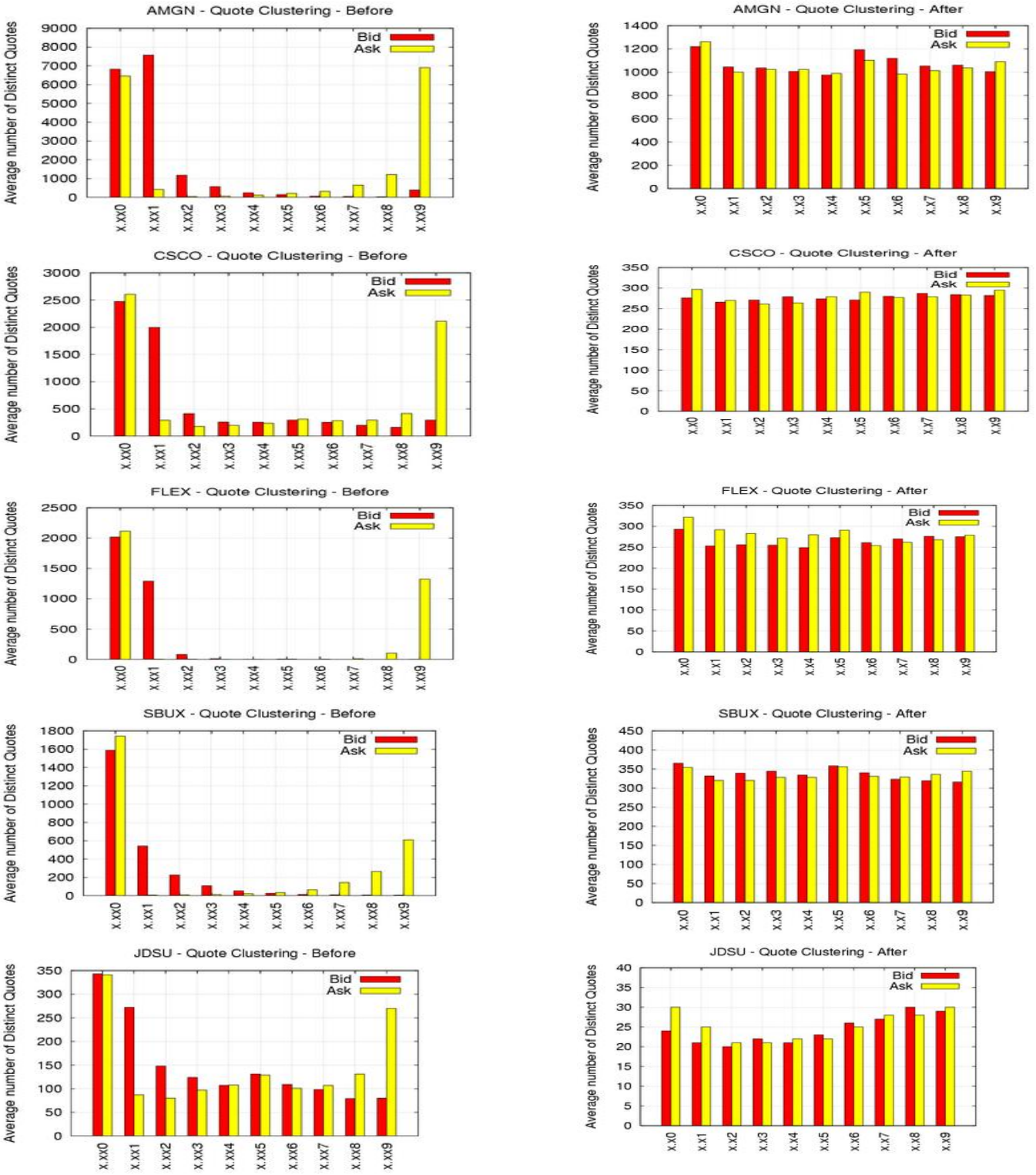


Figure 6(b): Quote Clustering (continued)

Pilot II