Does order flow fragmentation impact market quality? The case of Nasdaq SuperMontage

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Abstract

On December 2002, The Nasdaq Stock Market completed the roll out of its new trading platform SuperMontage. It was initially conceived to centralize the order flow for Nasdaq stocks. However, Island, one of the biggest ECN, decided not to participate to the montage and stopped to be "hard-linked" to Nasdaq systems. To what extent this increase in order flow fragmentation affected market functioning? Are orders executed at the best available prices on the market? We find no evidence that market quality worsened following this exit. Effective and realized spreads remained unchanged. This suggests that information dissemination and third-parties smart routing services has been sufficient to counterbalance the lack of built-in linkages. Additionally, we observed a persistent frequency of trade-through of around 15%, testifying of a non-negligible proportion of orders executed at a price worse than the best available one. However, using simulations, we showed that even when Island quote is better than the actual transaction price, an investor trading in Nasdaq would have generally experienced losses if the order were rerouted to Island. This suggests that trade-through regulation should consider depth as a major dimension.

Keywords: fragmentation, market linkages, trade-through, best execution.

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1 Introduction

For several years now, US equity markets are experiencing major changes, marked by the proliferation of alternative trading venues for the same security. These new markets are essentially Electronic Communication Networks (ECNs) and Regional Exchanges. They compete for the order flow with primary markets, like the New York Stock Exchange (NYSE) or the Nasdaq Stock Market, leading to an increased level of fragmentation of the order flow. Indeed, during the five past years, a significant portion of Nasdaq order flow migrated to ECNs, which now gather a major part of market shares. This phenomenon raises concerns about the possible impacts of such a fragmentation.

In response to these changes, the Security and Exchange Commission (SEC) published on February 2004 the "Regulation NMS" proposal. The primary goal of this proposal was to "enhance and modernize the regulatory structure of the U.S. equity markets" in compliance with the two main objectives of the National Market System: efficient price discovery and best execution. Trade-through prohibition and market linkages constitute the core of this proposal. The most important change in the proposed regulatory framework is the enforcement of a trade-through rule for the Nasdaq Stock Market.

The trade-through rule was introduced in the late 1970's to prevent execution of an order for a listed stock at a price inferior to best bid or offer prices available in other market centers. It states that a market receiving an order cannot execute it at a price inferior to any other order found on other markets without giving a fill to the better-priced order. To implement this rule, the Intermarket Trading System (ITS) was created. Its aim was to provide a hard linkage between all market centers engaged in listed stocks trading.[1] Thus only NYSE and Amex securities where concerned by this rule. The Nasdaq Stock Market has operated without a trade-through rule for its entire history and does not have any mandatory hard linkage like the ITS.

On December 2002, the Nasdaq Stock market completed the roll out of its new trading platform, SuperMontage. Like an ECN, SuperMontage features a book, which gathers Market Makers and ECNs best quotes. ECNs can choose to accept auto-execution or to be integrated via a delivery mechanism. Market participants are able to enter orders anonymously.[2] It also allows users to choose price time, price size and price fee priority on an order-by-order basis.

[1] More details on ITS and trade-through rule functioning are available on Hasbrouck, Sofianos and Sosedee (1993).

[2] Simean, Weaver and Whitcomb (2003) argue that the ability to enter anonymous orders is a particularly attractive feature of ECNs, which allowed them to capture an important portion of order flow.

While originally conceived to centralize all liquidity available through a unique limit order book, SuperMontage resulted, on the contrary, in higher fragmentation of the order flow. Indeed, several large ECNs, including Island, refused to participate to the montage. From their point of view, this project constituted an attempt from Nasdaq market to capture their liquidity through the use of anticompetitive rules decreasing the probability of execution of orders submitted via ECNs. ECNs perceived SuperMontage as an unfair intrusion on their business because it would allow Nasdaq to act both as a regulator and a competitor.

Island, handling approximately one out of every five trades in Nasdaq securities, was the largest ECN in 2002. Island was a pure order driven market, allowing submission and automated execution of orders without intervention of market makers. It operated as a separate liquidity pool, executing orders by matching them regardless of quotes posted in the Nasdaq market. Thus, Island did not guarantee the best price in the market.

However, before the roll out of SuperMontage, tight automated linkages existed between Island and Nasdaq. First, starting June 11th 2002, Island used a registered market maker (ILND) to mirror its best quotes (ISLD) in Nasdaq, thus exposing them to marketable orders routed through SuperSoes. However, it should be noted that Island used this automatic execution system for a limited number of stocks (26 in October 2002). The activity generated through this channel remained rather low.[3] More importantly, SelectNet, the Nasdaq automated order routing system, was widely used by market makers as a way to access Island quotes.

Thus, despite being two independent market places operating with no common trade-through prohibition rule, Island and Nasdaq were quite closely connected.

At a first glance, two events seem to contradict this statement. First, on March 18th 2002, Island began reporting trades to the Cincinnati Stock Exchange (CSE).[4] Second, from August 5th to September 19th 2002, Island also progressively redirected its best quotes to the CSE. However, in both cases, Island trades and best quotes still appeared on Nasdaq screens, through the CSE.[5] Despite these two changes, the same information about Island was available to all Nasdaq participants. Furthermore, SelectNet and

[3]Using Nasdaq's "monthly market shares" reports, we have measured the total volume traded against ILND between January and October 2002 for some of these 26 stocks. We found about 3.5 millions shares for Cisco, and about 6 millions shares for DELL.

[4]Nguyen, Van Ness and Van Ness (2004) use this event to analyze differences in trading costs between Island and Nasdaq.

[5]Orders submitted to Island were displayed as CINN instead of ISLD.

SuperSoes linkages were not affected.[6]

After the roll-out of SuperMontage, the situation changed significantly. Upon complete implementation of the new system, on December 2nd 2002, Nasdaq retired SelectNet and SuperSoes. Since Island refused to participate to SuperMontage, the automated linkages between the two liquidity pools were notably weakened. Despite the fact that Island best prices were still displayed on Nasdaq screens, they were no more reachable via Nasdaq systems. To access these quotes, investors had to directly connect to Island. The new SuperMontage system does not route orders to non-participating venues. Indeed, as mentioned above, although best quotes of non-participating venues remain visible on Nasdaq screens, they were no more reachable via Nasdaq systems. Nasdaq has clearly announced that SuperMontage would trade-through quotes posted by non-participants. The new Nasdaq trading landscape exhibited at least two pools of liquidity where orders no more interacted and ignored each other's for execution.[7]

What are the possible effects of such an event in terms of market quality? Did the trade-through rate increased for Nasdaq stocks? On the one hand, the termination of built-in regulated automated linkages between the two markets may have a negative impact on execution quality. On the other hand, information about the two markets was still widely available to investors after the launch of SuperMontage. Island trades and best quotes were displayed in SuperMontage through its connection with CSE, and Island's full order book was still displayed in real time through Internet. These information linkages may have been sufficient to maintain market quality. Moreover, several automated routing services were offered by third parties, ECNs or specialized firms like Lava Trading. These peripheral routing systems, meant to consolidate market data and offer best execution across a wide range of available liquidity sources, may have compensated the lack of built-in linkages.

For regulators, this issue is highly relevant. Should the SEC intervene as suggested by regulation NMS or should it let the nature and extent of linkages be decided by market forces? One aim of this paper is to shed some light on these regulatory concerns. We believe that this particular setting provides an interesting natural experiment, to quantify trade-throughs on Nasdaq market and that it gives us the opportunity to study the role played by market links to mitigate market fragmentation.

[6]Since CSE was prohibited from receiving SelectNet preference orders from Nasdaq members, Island maintained a 'stub' ISLD quote in Nasdaq away from the inside market, in addition to the 'real' CINN quote reported through the CSE. This stub ISLD quote allowed Nasdaq members to access the best available price on Island using SelectNet preference orders.

[7]Other venues, like Instinet or Archipelago decided not to participate. However, they have developed so-called "smart routers" to redirect their order flow to other markets when best prices are not available on their own platform. Thus, they have chosen to maintain a strong linkage with other marketplaces.

Market fragmentation is defined as the trading of the same stock in multiple market centers. It arises, as stated by Stoll (2001), "when investors send their orders to one market where the orders do not interact with orders from other market". The more markets, the greater degree of fragmentation. The commonly admitted view is that, as the number of markets increases, fragmentation increases undermining the overall quality. The worst effect being when two transactions for the same stock occur simultaneously at two different prices depending on the venue to which the orders were routed for execution. However, competition between market centers also creates pressure to cut transaction costs and significantly enhance innovation in market structure. Indeed, as outlined by Stoll (2001), regulatory mechanisms designed to link trading venues may stifle competition and innovation. He precisely cites the ITS as being "a good example of linking that did not kept pace with technology".

The Nasdaq market has always been considered as a fragmented marketplace by opposition to the NYSE. Indeed, whereas the Nasdaq controls less than 50% of trades in its listed securities, the NYSE has managed, until now, to maintain 80% of its order flow on its floor. Some theoretical papers have tried to evaluate the impact of fragmentation and multimarket trading. Mendelson (1987) argues that market fragmentation is not sustainable as the dispersion of order flow between multiple markets decreases the liquidity on these markets. This leads agents to direct their orders to the venue with the highest level of liquidity. Pagano (1989) shows that several trading markets for one security may co-exist when traders are heterogeneous and markets respond to particular group needs. Several studies have examined the effect of fragmentation for Nasdaq stocks. They show that fragmentation has foster competition: Barclay et al. (1999) find that transaction costs decreased by about 30% following the introduction of ECNs. For Biais, Bisière, and Spatt (2003), decimalization on Nasdaq can be interpreted as a reaction of Nasdaq market makers to the competitive pressure from Island. Regarding the price discovery process, Huang (2002) compares the quality of quotes submitted to ECNs and traditional market makers. He finds that ECNs quote updates are more informative than market makers ones. Barclay, Hendershott and McCormick (2003) show that ECNs, as they offer the advantages of anonymity and speed of execution, attract more informed traders. Their trades have larger permanent price impacts and more information is revealed through ECNs trades than through market makers trades. The presence of ECNs has thus induced better price discovery and lower transaction costs on Nasdaq stock market. However, studies comparing the fragmented structure of the Nasdaq with the more concentrated one of the NYSE, found

significant advantages for the latter. Bennett and Wei (2003) examined several quality indicators for companies that recently switched listing from Nasdaq to NYSE. They found that these indicators were significantly better after their switching, leading to the conclusion that order flow consolidation improves market quality. Market conditions under which brokers and market makers have to manage their order flow have clearly changed following the launch of SuperMontage. The primary concern of regulators is how these changes might affect orders' quality of execution.

To conduct our analysis, we focus on Island decision not to participate to the Montage. This particular setting allows us to quantify the trade-through level for Nasdaq stocks. The second interest of this study is to assess the role played by market links. By refusing to participate to SuperMontage, Island loosened its links with Nasdaq, thus increasing the potential for market fragmentation. In this paper, we try to evaluate the impact of this change on overall market quality. By measuring execution quality, trading costs, and routing behaviors before and after Island's exit, we will be able to assess if investors actually suffered from this fragmentation.

Our results show that while trade-through is substantial, market quality did not worsen after Island's exit. Moreover, from the point of view of an isolated investor, choosing to trade on Nasdaq instead of sending a marketable order to Island did not make a substantial difference in terms of execution price, and this difference did not increase after the exit.

The remainder of the paper is organized as follows. Section 2 presents our data. Section 3 evaluates the impact of Island's exit on execution quality. Section 4 focuses on trading costs. Section 5 presents our simulation results meant to measure to what extend investors are routing their orders to the market venue offering the best execution price.

2 Data

Trades and quotes data were gathered from two databases: NASTRAQ and ITCH. The former is maintained by Nasdaq while the latter is offered by Island. Our dataset consists of five trading days before SuperMontage's launch in October 2002 (from October 7 to October 11) and five trading days after its complete roll out in December 2002 (from December 2 to December 6). They cover all trades and quotes for 72 Nasdaq-100 stocks during the normal trading hours, from 9:30 a.m. to 4:00 p.m. We selected the 72 stocks present in the Nasdaq-100 over the whole years 2002 and 2003.

The advantage of these databases is that they allow us to differentiate Island trades from the rest of the Nasdaq.[8] Moreover, using ITCH, we have access to unrounded prices for trades and quotes. The main drawback of NASTRAQ is that, contrary to the ITCH database, it does not contain trade direction. We thus applied Lee and Ready (1991) algorithm to infer it. In our case, a trade was classified as buyer initiated when its price is strictly greater than all of the quote midpoints available during the second in which it took place and as seller initiated in the reverse case.[9] When trades occur between the lowest quote midpoint and the highest quote midpoint available during the second of the trade, the so-called tick rule was used.[10] We also classified trades by size: as very small (100 to 499 shares), small (501 to 1,999 shares), medium (2,000 to 4,999 shares), large (5,000 to 9,999 shares) or very large (more than 10,000 shares).[11] Table 1 provides daily descriptive statistics for the stocks in our two samples.

Our October 2002 sample includes 4.34 millions of trades for Nasdaq and 1.14 millions of trades for Island.[12] Our December 2002 sample includes 4.10 millions for Nasdaq and 1.12 millions for Island. Average daily activity measured in number of trades and volume traded decreased between the two periods. However, this decrease is much more pronounced for Nasdaq than for Island (-22.06% versus -15.04%, in millions of shares traded).

The average trade size on Nasdaq is 707.14 shares in the pre period and 582.80 shares in the post period. On Island, it goes from 421.03 shares in the October 2002 sample to 367.22 shares in the December 2002 sample. The second part of Table 1 presents the frequency of trades by size category. As expected, trades on Nasdaq are of a larger size than on Island, in both periods. No substantial changes occurred between the pre and post period.

[8] In October 2002, Island ECN had already begun to report its trades to the Cincinnati Stock exchange. These trades appear in NASTRAQ with a 'C' symbol instead of a 'Q' symbol.

[9] NASTRAQ time points have a one second granularity. However, the best available price may have changed several times within a single second. We adopted this methodology to account for this.

[10] We did not include the trades that occurred during locked or crossed market in this study. However, including them do not change the results.

[11] Island allows trades of less than 100 shares. For purpose of clarity they are omitted as including them or not does not change the results.

[12] We make a clear distinction between marketable orders and trades. For example, an order that needed to hit two levels in the book to be fully executed will necessarily generate at least two trades.

3 Effects on execution quality

SuperMontage's execution algorithm does not take into account prices posted to non-participating venues. That is, if a non-participating venue is at the best bid or offer, an order entered in SuperMontage is executed against the next available price in the book. Island, when it cannot execute the order immediately, stores it on its order book until another order is entered to be executed against it. Is this lack of market linkages and order interaction harmful to order execution quality?

One argument could be that it should not, as markets are de facto linked by brokers' best execution obligations. Indeed, the Nasdaq market as a whole is characterized by a transparent structure: SuperMontage displays in real time the best quotes of its participants up to five levels. Even if some ECNs have decided not to participate in SuperMontage, their quotes are largely disseminated so that brokers can readily direct their orders. So, if brokers chose to send their order to a marketplace that does not necessarily post the best price, it is of their own responsibility and not due to a market linkage failure.

However, the best execution obligation is quite vague and only requires a broker "to seek the most favorable terms reasonably available under the circumstances for a customer's transaction". Moreover, contrary to the NYSE or the AMEX, there is no trade-through rule across markets for Nasdaq stocks. The trade-through rule ensures that if a better price is offered in another market, the order must be sent to this market or executed at the same price.

The worst outcome of order flow fragmentation arises when two trades occur simultaneously at two different prices. One way of measuring the level of market fragmentation is thus to look at the frequency of this phenomenon. This requires very precise databases, stamping trades on a very thin time grid. The time stamp of Island trades is expressed up to a millisecond whereas, for the rest of Nasdaq trades, a one second granularity is available. In the latter case, when several trades in the database have the same time stamp, we are unable to evaluate if they occurred simultaneously or not.

Another way to address the issue is to look at the execution quality with respect to the National Best Bid and Offer (NBBO). The NBBO represents the best bid and ask prices available for Nasdaq listed stocks taking all markets together. Indeed, market centers, to comply with their regulatory obligations, must publicly advertise their current best quotes. These best quotes are then consolidated to form the NBBO. Comparing trades prices to the NBBO will allow us to evaluate the quality of execution obtained on Island and on the rest of Nasdaq market prior and after the launch of SuperMontage. We used three

classes of execution quality. First, a trade executed at a price better than the NBBO has been classified as price improvement. Second, a trade may be executed at the NBBO. The last and worst case is when execution occurs at a price worse than the quoted one (that is, a trade-through). If markets work efficiently one would expect to observe that each trade is executed at a price better than or equal to the NBBO, even if this best price is provided by a market different from the one in which the order has been sent.[13]

To investigate this point, our methodology was the following. We used the NASTRAQ Inside Quotes file (IQ) to get the NBBO for the overall Nasdaq market. To construct our statistics, we needed to know what was the prevailing NBBO at the time of each trade. However, as previously stated, a major drawback of NASTRAQ is its coarse time grid (one second). As the market moves fast, the NBBO might change several times and several trades may occur within a single second. To bypass this problem, we compared each trade price with all of the NBBOs available during the second in which the trade took place. Over this one-second time interval, we computed the lowest and the highest best bid and best ask available. Then, a trade was classified as a NBBO trade if the NBBO quote did not move during the whole second and if the trade took place at this price. A trade executed within the highest bid price and the lowest ask price available during the second was classified as price improvement. Finally, a trade executed at a price lower than the lowest bid price or higher than the highest bid outside was classified as a trade-through. All other trades were considered as unclassified. This methodology, by giving a lower bound to each type of execution, allows us to avoid overestimation.

Table 2 reports the daily volume weighted averages for each type of execution. To account for the role played by trade size, we also present the proportion of trades executed at the NBBO, price improved or at a worse price than the NBBO conditional on trade size. The results show that Nasdaq and Island differ fundamentally in the type of execution they provide. On Nasdaq, execution at the NBBO dominates: it represents 66.77% of the volume traded in October 2002 and 63.19% on December 2002. On Island, this percentage in only 48% on October and 40% on December 2002. On island, price improvement is widely offered and increases between the two sample periods, rising from 34.24% to 40.27%. Looking at the frequency of trade-through occurrences on each trading venue, we observe that trade-through is substantial: it ranges from 14.90% to 16.02% on Nasdaq and from 13.13% to 13.99% on Island.[14]

[13] Provided that depth at the best quotes is sufficient.

[14] These figures are substantially higher than those calculated by the SEC's Office of Economic Analysis in the memorandum entitled "Analysis of Trade-Throughs in Nasdaq and NYSE Issues", dated December 15, 2004. In this study, the percentage of share volume classified as trade-through for four days between September and December 2003 on 3405 Nasdaq stocks, amounts

Given the proportion of unclassified trades we are unable to determine if price improvements are more frequent than trade-throughs on Nasdaq.

Execution quality conditioned on trade size seems to follow a similar pattern on both platforms, but with a different magnitude. When not executed at the NBBO, small trades are more likely to be price improved on both platforms. On the contrary, large orders face a higher probability of being traded through. Considering the change that occurred after the roll out of the new Nasdaq trading platform, we observe that whereas large trades (trades of more than 4,999 shares) did not experience any significant changes with respect to execution quality, this is not the case for small trades. On Nasdaq, in October 2002, very small trades had a probability of being price improved three times larger than the probability of obtaining a worse price than the NBBO. The former was equal to 15% and the latter to 5.76%. In December 2002, this difference declined as they respectively reached 16.68% and 8.33%. This illustrates the fact that the probability of being executed out of the quote increased more for small trades on Nasdaq, comparatively to other types of execution. On the contrary, on Island, the increase in frequency of price improvements benefited mostly small trades: their probability rose by 5 points for very small trades and by 4 points for small trades. Also, we observe that for larger trade size on Island, the probability of being traded through increased.[15]

By comparing a transaction price with all of the NBBOs available during the second in which the trade took place, we found a substantial proportion of orders executed at a price different from the prevailing NBBO. Is this result affected by our methodology? As argued by Hendershott and Jones (2005), price improvement and trade-through executions may result from a change in the NBBO that occurred between the time the order was executed and the time it was printed. Moreover, Biais, Bisière and Spatt (2003) document synchronicity problems when Island best quotes are included in NASTRAQ IQ files, which may induce mistakes in our best quotes comparison. To evaluate the sensitivity of our results to this potential synchronicity problem, we ran the same estimation, except that we considered a five second time interval prior each trade instead of a one second interval.[16] The results are presented in the second part of Table 2. Using a larger interval, we naturally expect to observe a larger proportion

to 9.8%. The difference may be attributed to three factors. First, our sample contains only 72 highly traded stocks, which are more subject to trade-through. Second, our time period is different. Third, to compute the trade-through rate for a market, we used as reference quote the NBBO and did not compute a BBO excluding the market's best quotes.

[15]However, this increase is statistically significant only at a 10% level.

[16]We find this level quite accurate as when lags are observed between transaction and printing, they generally average two or three seconds.

of unclassified trades. Indeed, the frequency of unclassified trades significantly increases, mainly at the expense of execution at the NBBO. The frequency of price improved and trade-throughs, though decreasing, is still significant. More importantly, they follow the same trend as the one observed with a one second interval. This provides evidence of the robustness of our results.

The results presented so far are about the relative frequency of the three types of execution. But how far are trade prices from the NBBO? Do we observe an increase of these amounts after Island's departure? Given that the two platforms have clearly announced that they would not take into account prices posted out of their respective books, we would expect some changes ex post. However, our previous results suggest that for the overall market, execution quality did not change a lot. To investigate this point, we looked at the daily average volume-weighted percentage of deviation from the NBBO. For each trading platform and each period we computed the maximum and the minimum bounds.[17] To facilitate a comparison across stocks, we expressed these amounts as percentages of the midquote price prevailing at the time of the trade. Results are presented in Table 3. We focus on the minimum bound, as we do not want to overestimate the phenomenon. First, we observe that, on both platforms, the percentage of price improvement is significantly lower than the percentage by which the NBBO is traded-through. Once again, Nasdaq and Island differ significantly: while price improvements offered on Island are on average higher than on Nasdaq, trade-throughs are lower. Indeed, on October 2002, the percentage price improvement reaches 0.054% on Nasdaq and 0.110% on Island. During the same period, the average percentage trade-through was 0.344% on Nasdaq and 0.229% on Island. This pattern is observable for all categories of trade size. Yet, differences between Island and Nasdaq are smaller for small and large trades, at least in the pre period. When we turn to the changes that occurred following SuperMontage launch, several points are worth noting. Let us first consider out of the quote executions. On Nasdaq, the general tendency is an increase in the percentage amount of trade-through. Despite the fact that all trade categories exhibit this increase, changes are not statistically significant. On Island, the overall percentage amount of trade-through does not change at all between October 2002 and December 2002. We note however a significant decrease for medium and large trades. When considering price improvements, we face a reverse pattern on Nasdaq platform. Indeed, we observe a significant decrease: it averages to

[17] As stated before, the NBBO might move during the time of the trade. If for example a sell order obtained a price improvement, the minimum amount of deviation from the NBBO was calculated as the difference between the transaction price and the highest best bid available during the second on which the trade took place. On the contrary, the maximum amount is given by the difference between the price and the lowest bid.

0.054% in the pre-period, and diminishes to 0.033% in the post period. This decrease affects all of the trade size categories. On Island, once again, no significant changes are observed between the pre and the post period.

Part of the price improvements may be due to sub-penny pricing. To investigate this point, we plot on Figure 1 the frequency of different values of maximum dollar amount of price improvement, in both periods, and for both platforms.[18] We find that the frequency of $0.001 price improved trades increased significantly between the two periods. They represent 25.21% of price-improved trades in October 2002 and reaches 31.19% on December 2002 on Nasdaq. For Island we also have an increase of less importance: 20.27% in the pre period and 24,48% in the post period. To check for the robustness of this phenomenon, we look at the same frequencies by taking all NBBOs up to five seconds prior the trade. For Island, the difference between the two periods is less important. On Nasdaq, it remains at almost the same level. One possible phenomenon behind these $0.001 price improvements is sub-penny pricing: as market makers are constrained by the Nasdaq tick size and cannot compete with ECNs quotes, they offer price improvement at the same level as ECNs (at a three digit level) to attract order flow. Another possible explanation is rounding: some ECNs allow for prices on sub penny levels but when advertised on Nasdaq screens these prices are rounded to the Nasdaq price grid, thus generating a price improved trade when executed.[19] To determine which explanation dominates, we need to have access to all unrounded quotes posted by each market maker or ECN. Due to data limitation we are unable to provide an answer. However, on both cases, the results suggest that sub-penny quoting and pricing have become a widespread practice on Nasdaq market as a whole. The Security and Exchange commission has expressed some concerns about the proliferation of such practices which allow traders to "step ahead of costumer orders for economically insignificant amounts".

4 Effects on transaction costs

A first measure of transaction costs is given by the inside quote: the difference between the best bid and the best offer in the market. We computed the daily time-weighted percentage inside spreads for each

[18] To avoid overestimating sub-penny pricing, we computed price improvements with respect to the lowest bid price or the highest ask price.

[19] Instinet accepted sub-penny quotation only for stocks with a price lower than $10. In our Study only 5 stocks are concerned. Brut ECN also accepted sub-penny prices.

trading platform. Results are reported in Table 4. We find that inside spreads are lower on the rest of the Nasdaq than on Island on both periods. In the pre period, Nasdaq percentage inside spreads was around 0.15% and decreased to 0.11% on the post period. On Island, in the pre period and the post period it averages to 0.63%.

By comparing inside quotes between the two periods we observe no significant change on Island. The impact on the overall market is a decrease in the NBBO. The decrease of spreads in Nasdaq suggests that competition strengthened following the launch of SuperMontage. By looking at the changes in undercutting behavior by Island, we find no reason to think that this decrease resulted from an increase in competition between Nasdaq and Island. Indeed, Table 5 shows that Island undercut Nasdaq bids about 12% of the time and that bids are equal on both platforms 18% of the time on October 2002 sample. We found no significant changes in December 2002. Similar results are obtained on the Ask side.

Thus, SuperMontage resulted in tighter spreads on Nasdaq, whereas Island spreads did not change. However, even if Nasdaq spreads shrunk relatively to Island spreads, this did not resulted in a better position for Nasdaq in its competition with Island. A possible explanation is that the lower spreads in Nasdaq are mainly due to competition between SuperMontage participants, and not to an increase in competition with Island. Additionally, in line with the results of Biais, Bisière and Spatt(2003), this suggests that Island traders often undercut Nasdaq quotes whereas they undercut each other much less frequently, and that this behavior did not change after the launch of SuperMontage.

We showed that a non-negligible proportion of trades are executed at a price higher or lower than the best available prices in the market. It is thus interesting to look at more accurate measures of transaction costs. The effective spread measures the real price paid by investor. It is calculated as the difference between the execution price and the contemporaneous quote midpoint signed by the direction of the trade.[20] The realized spread is also an interesting measure of transaction costs. It provides a measure of the profits realized by the supplier of liquidity. It is calculated as the difference between the transaction price and the quote midpoint in effect five minutes after the trade signed by the direction of the trade.

To get more straightforward comparison across stocks, we expressed these transaction costs as percentages of the midquote price prevailing at the time of the trade.

What results could we expect on each platform? On Island, price improvement dominates, inside

[20] A buyer-initiated trade is signed "$+1$" and a seller-initiated trade is signed "-1".

spread decreases, and we do not observe significant increase in the amounts of deviation from the NBBO. Thus, we expect either no change on the spreads or a decrease in effective spreads after SuperMontage roll out. On Nasdaq, the expected effect is more mitigated: we found no domination of price improvement or out of the quote execution. However, the significant decrease in the amount of price improvement suggests that effective spreads may increase. Table 6 reports the daily volume weighted effective and realized spreads. Results show that the percentage effective and realized spreads are significantly lower on Island for every trade size category. The spread pattern among volume categories is however different on each trading venue. On Nasdaq, trade costs increases with size. On Island, the relation is not monotonic: small and large trades exhibit smaller spreads than medium size one. We note that on October 2002, the percentage effective spread is 0.1463% on Nasdaq and 0.0803% on Island. On December 2002, these differences increase as Island spread falls to 0.0487%. As expected, on the post period, Island spreads decrease significantly. This is in line with the previous results: small trades experienced more frequent price improvement executions and larger trades benefited from the decrease in the average amount of their trade-through. On Nasdaq, the effective spreads increases for every trade size categories between October 2002 and December 2002. The overall effective spread rises from 0.1463% in the pre period to 0.1648% in the post period. However, none of these changes are statistically significant. The overall impact is also limited: the percentage effective spread increases after SuperMontage launch by 0.01 points as it ranges from 0.1396% on October 2002 to 0.153% on December 2002. Once again, this increase is not significant. If we turn to the percentage realized spreads, we see that they are significantly lower on Island than on Nasdaq. On October 2002, it averages 0.0785% on Nasdaq against 0.0025% on Island. As the realized spread is equal to the difference between the effective spread and the price impact of a trade, this reflects the ability of Nasdaq market makers to attract less informed investors and thus more profitable order flow via practices such as payment for order flow or internalization.[21] Between the post and the pre period, the percentage realized spread has not experienced any significant change on both venues.

To summarize, the effect of SuperMontage launch on quality of execution and on trading costs is limited. The effective spreads and the realized spreads remain almost unchanged. It seems that the weaker linkage between SuperMontage and Island platforms did not impact negatively the market. However, a

[21]This phenomenon is known as "cream skimming" and has previously documented by Simaan, Weaver and Whitcomb(2003).

non-negligible proportion of the trades are executed out of the quote.

5 Simulation Results

When an order obtained an execution price worse than the NBBO on one market, does it necessarily mean that this order would have obtained a better execution when placed on another venue? Due to potential insufficient depth, the fact that a market provides the best price does not guarantee that the order will be fully executed at this price. To investigate this point, we ran a simulation based on real data. In this simulation, for each trade executed out of the quote on Nasdaq, we compute the price that would have been obtained if the order were placed on Island instead of Nasdaq.

This methodology is based on a strong assumption: the overall market conditions are not affected by this change of platform. Obviously if all these orders were placed on Island instead of Nasdaq the overall market conditions would have been different. However, what we focus on is the decision process of an individual investor choosing on which platform to place an order. Additionally, focusing on the best favorable cases concerning time to execution, we assume that orders are immediately executed. Table 7 presents the characteristics of the order flow we virtually redirected to Island for the purpose of our study. Large orders represent the majority of these orders (56.78% of the order flow). Between October and December 2002, this proportion decreases in favor of small trades, which account for 30% of the order flow in the post period against 23% in the pre period. Table 7 also shows that in October 2002, the best price on Island was better that or equal to the transaction price obtained on Nasdaq in about 53% of cases (44.18% + 8.27%) . This proportion decreases to about 48% in December 2002 (39.92% + 8.93%). This means that in 50% of the cases, placing the order on Island would have not resulted in a better execution price.[22]

Let us now turn to the execution that would have been obtained on Island by these orders submitted on other market venues. Results are presented on table 8. In the computation of the final prices obtained on Island, we took into account the fees that traders have to pay when placing orders consuming liquidity in the book.[23]

In 6.36% of the cases, placing these orders on Island would have resulted in a better final execution

[22]This suggests that these trades may have been executed in another ECN participating to SuperMontage. Indeed ECNs also report on Nasdaq the trades that they executed internally.

[23]These fees were equal to $0.0019 in October 2002 and $0.0030 in December 2002

price. About 0.10% of the orders would have obtained the same price and 93.64% a worse price. Small and medium trades have a higher probability of being filled at a better price than very large orders. We find no significant changes between the pre and the post period. The most interesting case is when prices are at least as good as the prices obtained on Nasdaq platform. Indeed, in this case, under a trade-through, Island would have legitimately been able to receive the order flow. The second part of table 8 displays the results in such a case. If we consider all trades, the proportion of trades that would have obtained a better price averages 16.92% in October 2002. This proportion is stable on December 2002 as it reaches 16.51%. When the first price in the book is equal to the one obtained on Nasdaq, all transactions result in a worse final price.

The most interesting results come from the analysis conditioned on order size. On October 2002, 71.92% of the very small trades would have benefited from an execution on Island. Similarly, for the small category, this percentage averages 42.14%. The last part of Table 7 shows that, being small, this trades do not need large depth. When we turn to larger trade size categories, the probability to obtain a better execution on Island is much lower: 11.16% for large orders and 2.44% for very large trades on October 2002. The situation on December 2002 does not change.

Table 9 offers an explanation to such a situation: on average, very small and small trades hit respectively 1.26 and 2.20 book levels when submitted to Island. Large trades hit on average, 20 levels.

Table 10 reports the volume weighted average price difference between the price obtained on Nasdaq and the one that would have been obtained on Island. These values are expressed as percentages of quote midpoint prevailing at the time of trade. When Island offers a better final price, this amount averages 0.23% in the pre period. When Island proposes a worse final price, the price difference is remarkably larger: it reaches 5.16% on October 2002. The higher the size of trade, the greater the price difference whatever the final type of execution obtained. On December 2002, price differences increase modestly at 0.30% when orders are executed at a better price. However, they decrease significantly when Island price is worse: they average 2.62%. This decrease is essentially driven by large trades, which, as seen previously, experienced a decrease of the amount by which they are traded-through on Island.

These results thus suggest that orders executed at a worse price than the best quotes on Nasdaq do not automatically get a better price when routed to Island. Even in the "best scenario" case, where order flow is directed to Island when Island book exhibits better prices, a final better execution price is not

guaranteed is most cases. However, for small orders, a better final price could have been obtained in 70% of the cases.

We think that these results depicts the fact that practices such as payment for order flow or preferencing may result in worse execution prices for small sized order flow.

6 Conclusion

This paper provides an analysis of the type of execution obtained on Nasdaq Stock Market. Given the increase in order flow fragmentation and the lack of trade-through rule on this market, the Security and Exchange Commission is indeed concerned of possible harmful effects for investors.

To conduct our analysis, we focused on Island's decision not to participate to SuperMontage, the new Nasdaq trading platform launched on December 2002. This particular setting allows us, first, to quantify the trade-through level for Nasdaq stocks and to look at the role played by market links. We find that on Nasdaq, as well as on Island, the trade-through rates average 15% testifying of a non-negligible portion of the order flow executed at a worse price than the best price available on the market. To investigate further this point, we ran a simulation: we looked at what would have been the execution price of orders that experienced a trade-through execution on Nasdaq if they were placed on Island instead. The results show that in most cases prices would not have been better.

We find no significant changes on quality indicators after Island's departure. This result suggests that despite the lack of hard linkage maintained by Nasdaq or Island, execution quality did not worsen. Explanations can be found in the large dissemination of information that characterizes this market. It can also be due to the development of privately owned routers like Lava or Sunguard systems which counterbalances the lack of hard linkages between markets.

From the point of view of regulators, our simulation results suggest that best execution involves other dimension than best quoted price. In particular, depth should be taken into account.

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Table 1: Descriptive Statistics

This table reports the average daily number of trades, the total volume traded (in number of shares), the average trade size (in terms of number of shares per trade) and the average transaction price. The pre period is composed by five trading days on October 2002 and the post period by five trading days on December 2002.

	Nasdaq trades		**Island Trades**	
Daily averages	Pre	Post	Pre	Post
Number of trades (000 trades)	12.06	11.39	3.16	3.12
Volume (millions of shares)	8.52	6.64	1.33	1.13
Price (in $)	23.74	27.78	24.04	28.07
Trade size (shares)	707.14	582.80	421.03	367.22
Proportion of trades by order size	Pre	Post	Pre	Post
100 - 499 shares	30.72%	33.70%	48.79%	54.62%
500 - 1999 shares	37.68%	35.78%	38.88%	35.28%
2000 - 4999 shares	12.34%	11.48%	11.95%	9.66%
5000 - 9999 shares	6.36%	6.08%	3.95%	3.45%
more than 10,000 shares	13.72%	13.77%	2.21%	2.55%

Table 2: Type of execution obtained conditional on the prevailing NNBO

This table presents the daily weighted average percentage of trade volume executed at the National Best Bid or Offer (NBBO), price improved or incurring a loss (trade-through) with respect to the current NBBO. The second part of the table presents the same proportion computed by taking as reference all best quotes available up to five seconds prior the trade. The pre period is composed by five trading days on October 2002 and the post period by five trading days on December 2002.

Type of execution	**Current quote**						**0 to 5 seconds prior the trade**					
	Nasdaq Trades			**Island Trades**			**Nasdaq Trades**			**Island Trades**		
	Pre	Post		Pre	Post		Pre	Post		Pre	Post	
Execution at the NBBO												
all trades	66.77%	63.19%	***	48.37%	40.16%	***	43.34%	41.75%	***	30.28%	25.11%	***
100 - 499 shares	73.06%	67.37%	***	43.96%	35.85%	***	45.39%	42.71%	***	28.34%	22.89%	***
500 - 1999 shares	73.71%	68.62%	***	50.11%	42.37%	***	47.17%	44.71%	**	31.15%	26.47%	***
2000 - 4999 shares	68.26%	66.09%	**	62.14%	57.19%	***	45.27%	44.42%	-	40.16%	39.35%	-
5000 - 9999 shares	56.46%	56.72%	-	73.76%	73.37%	-	40.69%	41.10%	-	55.63%	56.08%	-
more than 10,000 shares	41.51%	42.83%	-	83.69%	84.43%	-	33.19%	33.53%	-	67.74%	72.35%	-
Price improved												
all trades	13.46%	14.56%	***	34.24%	40.27%	***	8.99%	10.21%	***	25.91%	31.66%	***
100 - 499 shares	15.00%	16.68%	**	41.36%	46.56%	***	8.44%	11.39%	***	30.53%	35.78%	***
500 - 1999 shares	13.59%	15.77%	***	32.28%	36.27%	***	9.23%	11.24%	***	24.08%	27.35%	***
2000 - 4999 shares	13.78%	14.02%	-	30.27%	30.75%	-	10.11%	10.07%	-	25.35%	25.37%	-
5000 - 9999 shares	14.18%	15.25%	-	30.17%	25.97%	-	11.06%	12.68%	-	27.23%	24.86%	-
more than 10,000 shares	14.39%	14.54%	-	41.91%	38.55%	-	11.82%	13.24%	-	37.59%	35.04%	-
Trade-through												
all trades	14.90%	16.02%	**	13.13%	13.99%	*	11.75%	13.23%	***	10.92%	11.61%	-
100 - 499 shares	5.76%	8.33%	***	10.51%	12.03%	***	3.60%	6.33%	***	8.54%	9.85%	**
500 - 1999 shares	7.36%	8.92%	***	15.08%	16.88%	***	4.67%	6.54%	***	12.74%	14.38%	***
2000 - 4999 shares	14.49%	15.68%	-	21.63%	26.37%	**	11.08%	12.49%	-	18.90%	23.61%	**
5000 - 9999 shares	32.94%	32.67%	-	27.11%	35.66%	**	27.74%	28.36%	-	25.79%	32.80%	*
more than 10,000 shares	52.65%	50.76%	-	46.61%	49.62%	-	48.04%	45.47%	-	45.07%	46.11%	-
Unclassified	4.87%	6.23%		4.37%	5.62%		35.92%	34.81%		32.89%	31.62%	

***, **, *: Indicates that a difference between pre and post period is statistically significant at respectively 1, 5 and 10 percent.

Table 3: Average amounts of deviation from the NBBO

This table presents the volume-weighted average amount of deviation with respect to the current National Best Bid or Offer conditional on the type of execution obtained. Amounts are expressed as percentages of quote midpoints prevailing at the time of the trade. The pre period is composed by five trading days on October 2002 and the post period by five trading days on December 2002.

	NASDAQ						ISLAND					
Type of execution	max amount			min amount			max amount			min amount		
	Pre	Post		Pre	Post		Pre	Post		Pre	Post	
Price improved												
all trades	0.056%	0.036%	***	0.054%	0.033%	***	0.114%	0.109%	-	0.110%	0.105%	-
100 - 499 shares	0.063%	0.032%	***	0.048%	0.028%	***	0.101%	0.094%	-	0.097%	0.091%	-
500 - 1999 shares	0.053%	0.034%	***	0.050%	0.031%	***	0.140%	0.182%	-	0.136%	0.178%	-
2000 - 4999 shares	0.062%	0.045%	***	0.059%	0.042%	***	0.120%	0.159%	-	0.117%	0.156%	-
5000 - 9999 shares	0.075%	0.054%	***	0.072%	0.052%	***	0.099%	0.079%	-	0.096%	0.070%	*
more than 10,000 shares	0.079%	0.054%	***	0.077%	0.052%	***	0.103%	0.087%	-	0.098%	0.087%	-
Trade-through												
all trades	0.347%	0.355%	-	0.344%	0.351%	-	0.233%	0.238%	-	0.229%	0.229%	-
100 - 499 shares	0.241%	0.310%	-	0.237%	0.304%	-	0.226%	0.250%	-	0.222%	0.244%	-
500 - 1999 shares	0.253%	0.309%	-	0.250%	0.303%	-	0.234%	0.208%	-	0.230%	0.202%	-
2000 - 4999 shares	0.271%	0.333%	-	0.268%	0.328%	-	0.301%	0.124%	**	0.297%	0.119%	**
5000 - 9999 shares	0.316%	0.391%	-	0.314%	0.388%	-	0.150%	0.117%	**	0.147%	0.112%	**
more than 10,000 shares	0.399%	0.416%	-	0.396%	0.414%	-	0.131%	0.168%	-	0.131%	0.164%	-

***, **, *: Indicates that a difference between pre and post period is statistically significant at respectively 1, 5 and 10 percent.

Table 4: Percentage inside spreads by venue

This table presents the daily time-weighted average inside spread prevailing on Island and on the rest of the Nasdaq. The pre period is composed by five trading days on October 2002 and the post period by five trading days on December 2002.

Market Center	**October 2002**		**December 2002**	
Overall	0.1388%	**	0.0958%	**
Nasdaq	0.1473%	***	0.1072%	***
Island	0.635%	-	0.631%	-

***, **, *: Indicates that a difference between pre and post period is statistically significant at respectively 1, 5 and 10 percent.

Table 5: Undercutting activity

We identify three types of situations on each side of the book (bid and ask): 1)When the best price is set by Island, 2)When the best price is set by the rest of the Nasdaq, 3)when prices on Island and on the rest of the Nasdaq are equal. The pre period is composed by five trading days on October 2002 and the post period by five trading days on December 2002.

Side of the market	**October 2002**	**December 2002**
Bid Side		
Island Bid $>$ Nasdaq Bid	12.11%	11.08%
Island Bid $=$ Nasdaq Bid	18.33%	18.51%
Island Bid $<$ Nasdaq Bid	69.56%	70.41%
Ask Side		
Island Ask $<$ Nasdaq Ask	10.63%	10.75%
Island Ask $=$ Nasdaq Ask	19.07%	18.84%
Island Ask $<$ Nasdaq Ask	69.7%	70.41%

Table 6: Percentage effective and realized spreads by venue

This table presents the daily volume-weighted average percentage effective and realized half-spreads prevailing on Island and on the rest of the Nasdaq. The pre period is composed by five trading days on October 2002 and the post period by five trading days on December 2002.

	Nasdaq Trades			**Island Trades**		
Transaction Costs	Pre	Post		Pre	Post	
Percentage effective half spread						
all trades	0.1463	0.1648	-	0.0803	0.0487	**
100 - 499 shares	0.1113	0.1314	-	0.0700	0.0471	**
500 - 1999 shares	0.1226	0.1441	-	0.0868	0.0414	**
2000 - 4999 shares	0.1345	0.1684	-	0.1435	0.0717	*
5000 - 9999 shares	0.1930	0.2392	-	0.0782	0.0664	*
more than 10,000 shares	0.2880	0.2828	-	0.0956	0.0762	-
Percentage realized half spread						
all trades	0.0785	0.0874	-	0.0056	-0.0025	-
100 - 499 shares	0.0436	0.0590	-	0.0068	0.0110	-
500 - 1999 shares	0.0474	0.0757	-	0.0041	-0.0178	-
2000 - 4999 shares	0.0471	0.0640	-	0.0176	0.0623	-
5000 - 9999 shares	0.1070	0.1173	-	-0.0374	-0.0722	-
more than 10,000 shares	0.2682	0.2265	-	-0.0899	0.0019	-

***, **, * Indicates that the difference between the October 2002 sample and the December 2002 one is statistically significant at respectively 1, 5 and 10 percent.

Table 7: Descriptive statistics on orders fictitiously redirected to Island book

This table presents the composition of the order flow we fictitiously redirected to Island book, in order to measure the benefit an investor would gain by submitting to Island. The second part of the table presents the conditions prevailing on Island order book when this order flow is submitted. The pre period is composed by five trading days on October 2002 and the post period by five trading days on December 2002.

	Pre	**Post**
proportion by order size		
100 - 499 shares	6.95%	10.83%
500 - 1999 shares	16.26%	19.83%
2000 - 4999 shares	9.35%	10.20%
5000 - 9999 shares	6.66%	8.42%
more than 10,000 shares	59.78%	50.71%
order book conditions		
First price is better than the transaction price		
all trades	44.18%	39.92%
100 - 499 shares	22.68%	16.84%
500 - 1999 shares	26.15%	21.21%
2000 - 4999 shares	40.67%	39.83%
5000 - 9999 shares	54.40%	57.27%
more than 10,000 shares	65.04%	66.48%
First price is the same as the transaction price		
all trades	8.27%	8.93%
100 - 499 shares	12.06%	11.84%
500 - 1999 shares	12.43%	13.41%
2000 - 4999 shares	16.66%	17.03%
5000 - 9999 shares	17.19%	16.53%
more than 10,000 shares	10.41%	10.34%
First price is worse than the transaction price		
all trades	47.62%	51.46%
100 - 499 shares	65.45%	71.75%
500 - 1999 shares	62.98%	67.60%
2000 - 4999 shares	54.54%	56.56%
5000 - 9999 shares	47.93%	44.05%
more than 10,000 shares	39.92%	37.3%

Table 8: Final price obtained conditional on the Best limit available at the time of the trade

This table presents the type of execution obtained when the order flow is submitted to Island book. The second part of the table presents the same results conditional on Island best limit position with respect to Nasdaq trade price at the time of the trade. Island trade prices are all discounted by the amount of fees applicable . (0.0019$ per share traded on October 2002 and 0.0030$ on December 2002.

	Better Final price		**Same Final price**		**Worse Final price**	
unconditional probabilities	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
all trades	6.36%	5.74%	0.10%	0.11%	93.64%	94.28%
100 - 499 shares	18.44%	13.32%	9.11%	8.47%	72.45%	78.21%
500 - 1999 shares	13.91%	10.61%	4.35%	4.29%	81.74%	85.10%
2000 - 4999 shares	10.49%	8.52%	2.35%	1.38%	87.15%	90.10%
5000 - 9999 shares	6.43%	8.36%	0.37%	0.56%	93.20%	91.08%
more than 10,000 shares	1.74%	2.24%	0.00%	0.03%	98.25%	97.73%
conditional probabilities						
First price is better than the transaction price						
all trades	16.92%	16.51%	0.00%	0.07%	83.07%	83.42%
100 - 499 shares	71.92%	66.78%	0.01%	0.29%	28.07%	32.93%
500 - 1999 shares	42.14%	38.29%	0.00%	0.22%	57.87%	61.49%
2000 - 4999 shares	22.46%	20.02%	0.00%	0.14%	77.53%	79.85%
5000 - 9999 shares	11.16%	12.33%	0.00%	0.05%	88.84%	87.62%
more than 10,000 shares	2.44%	2.85%	0.01%	0.00%	97.55%	97.15%
First price is the same as the transaction price						
all trades	0.00%	0.00%	0.00%	0.00%	100.00%	100.00%
100 - 499 shares	0.00%	0.00%	0.00%	0.00%	100.00%	100.00%
500 - 1999 shares	0.00%	0.00%	0.00%	0.00%	100.00%	100.00%
2000 - 4999 shares	0.00%	0.00%	0.00%	0.00%	100.00%	100.00%
5000 - 9999 shares	0.00%	0.00%	0.00%	0.00%	100.00%	100.00%
more than 10,000 shares	0.00%	0.00%	0.00%	0.00%	100.00%	100.00%

Table 9: Average number of Island order book levels needed for full execution

	Pre	**Post**
Number of levels needed for full execution		
100 - 499 shares	1.26	1.26
500 - 1999 shares	2.20	2.21
2000 - 4999 shares	4.96	4.96
5000 - 9999 shares	8.48	8.26
more than 10,000 shares	23.25	20.11

Table 10: Average price difference obtained on Island

This table presents the volume-weighted average difference between the price obtained on Nasdaq and the one that would have been obtained if submitted on Island. Amounts are expressed as percentages of quote midpoints prevailing at the time of the trade. The pre period is composed by five trading days on October 2002 and the post period by five trading days on December 2002.

Trade size	**Better Final price**		**Worse Final price**	
	Pre	**Post**	**Pre**	**Post**
all trades	0.23%	0.30%	5.16%	2.62%
100 - 499 shares	0.21%	0.29%	0.70%	0.52%
500 - 1999 shares	0.22%	0.34%	0.67%	0.70%
2000 - 4999 shares	0.32%	0.57%	1.43%	1.10%
5000 - 9999 shares	0.44%	0.69%	3.49%	1.94%
more than 10,000 shares	0.69%	1.13%	9.21%	4.55%

Figure 1 : Frequency of Maximum amount of price deviation from the NBBO given that the trade is price improved with respect to all NBBOs available for the second on which the trade took place

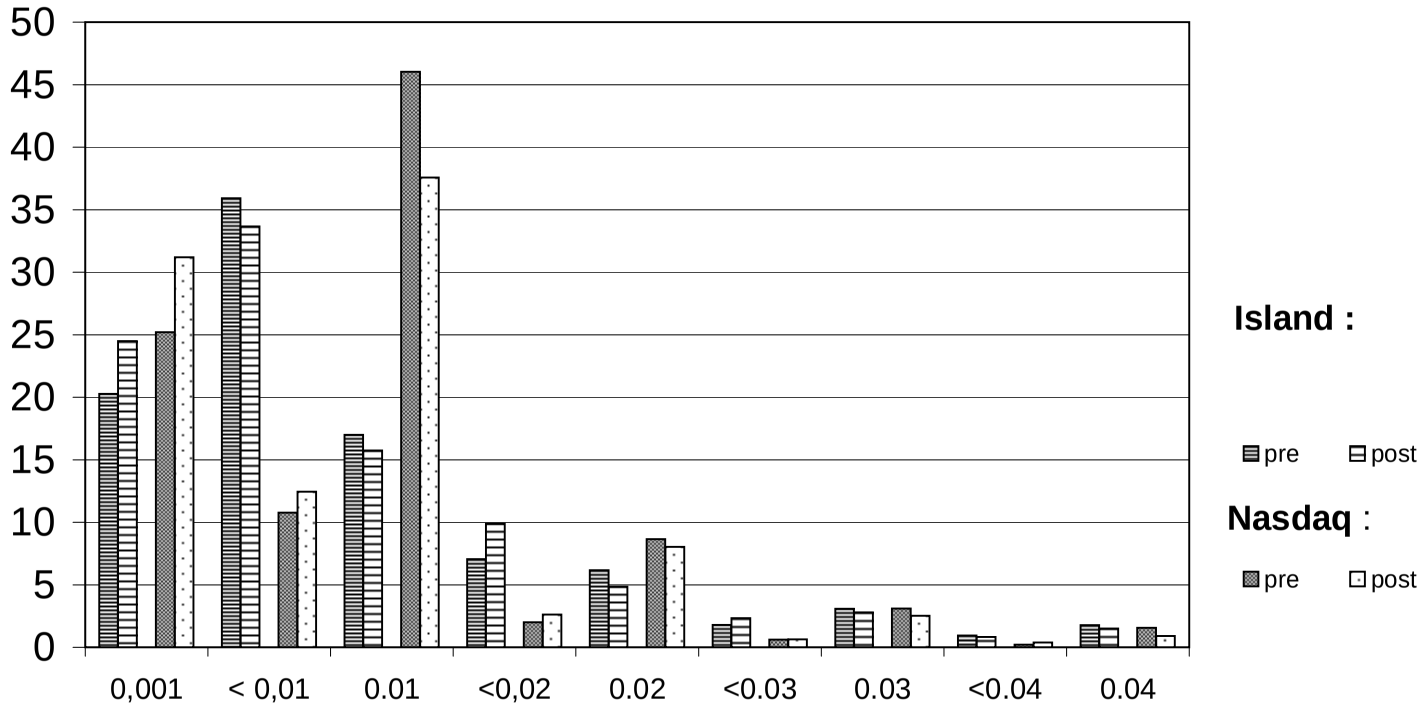

Figure 2 : Frequency of Maximum amount of price deviation from the NBBO given that the trade is price improved with respect to all NBBOs available up to five seconds prior the trade