Inter-Market Competition and Fragmentation on NASDAQ

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ABSTRACT

We investigate competition in the market for actively traded NASDAQ-listed securities. Six market centers that report NASDAQ trades and quotes differ significantly in quoting behavior, execution costs, and trader clienteles. ECNs are more different than alike, due to dissimilar features of their limit order books. Price discovery has partially shifted from the ECNs to the market maker venues due to the inability of certain ECNs to provide timely executions. Fragmentation has also caused 14.67% of NBBOs to be locked or crossed. Overall, decimalization and increased competition have caused significant changes in competitive landscape.

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ABSTRACT

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In the past several years, the advent of decimal trading and the proliferation of electronic exchange mechanisms have resulted in intensification of competition in the market for the NASDAQ-listed securities. In addition to a dealer-operated NASDAQ system, investors have obtained an opportunity to trade securities on electronic communications networks (ECNs) such as Archipelago or Island, on institution-based matching systems such as Instinet, or on specialist systems at the American Stock Exchange (AMEX) and the Chicago Stock Exchange.[1] Currently the dealers on the NASDAQ Stock Market have to compete for order flow not only with each other, but also with the three major ECNs and with market makers from two regional exchanges. This study argues that this interaction provides more competitive quoting behavior, but does so at the cost of significantly fragmenting order flow and reducing certain venues execution abilities.

We examine the competitive landscape of the NASDAQ inter-market and investigate how competition affects trading venues of different types. This goal seems to be of interest for practitioners and academics, because the competitive structure of NASDAQ is still relatively unexplored, whereas that of the NYSE is well documented (see e.g., Lee (1993), Blume and Goldstein (1997), Bessembinder (2004), and Lipson (2004)). Until recently, it has been difficult to examine competition for NASDAQ stocks across trading venues and market types due to the absence of relevant data. Nonetheless, organizational consolidations and relocations of quote and trade reporting by the major ECNs that occurred in the past several years allow for the examination of the effects of competition and fragmentation within the NASDAQ market system. One of the features of our study that differentiates it from the previous analyses of the

[1] Island has recently changed its name to INET ATS, Inc. As this change came after our sample period, we retain the use of the former name.

NASDAQ market is that we are able to distinguish among the three major ECNs – Island, Instinet, and Archipelago – as well as introduce two specialist-operated market centers – the AMEX and Chicago Stock Exchanges.[2]

Overall, the study confirms existence of substantial fragmentation of trade flow in NASDAQ-listed stocks. In our sample, almost half (48.41%) of all trades occur away from NASDAQ, and nearly all of these non-NASDAQ trades take place on one of the three electronic limit order book systems. Individual ECNs are capable of sustaining a high level of competition in the NASDAQ inter-market by posting the best quotes. The results of a multivariate logistic regression analysis reveal that, for instance, when Island and Archipelago post the best quotes they are, respectively, 8.38% and 10.17% more likely to execute a trade than NASDAQ. We also find evidence that venues are more likely to trade when they participate in quoting of both sides of the NBBO.

Our results imply that NASDAQ is not as competitive in terms of quotes for NASDAQ-listed securities as the NYSE is for the NYSE-listed stocks.[3] NASDAQ participates in the best quote, on at least one side of the market, about 90% of the time, which is more than any other market, but still is less than the 99% as in the NYSE stocks as shown in Blume and Goldstein (1997) and Bessembinder (2004). Furthermore, NASDAQ matches *both* sides of the NBBO about half the time, and is alone at quoting the best bid or the best ask 11% of the time, while the results in Bessembinder (2004) indicate that the NYSE matches both sides of the quote almost

[2] A study by Barclay, Hendershott, and McCormick (2003) examines trading in the sixteenth environment and distinguishes between two major forces that drive competition on the NASDAQ inter-market, ECNs and market makers, but treats each as a homogeneous group. In particular, the study does not distinguish between different ECNs and does not include the specialist-operated trading venues (the AMEX and the Chicago Stock Exchange) in the analysis.

[3] The previous NYSE studies are not directly comparable to ours, as different time periods are used. Qualitatively, however, the results that have been confirmed for the NYSE by a number of earlier studies are dissimilar to those found here for NASDAQ using similar methodology. This difference suggests that it is the structure of competition and not the fact of being the primary market that drives these results.

90% of the time, and is three to four times as likely to be alone at the best quote than NASDAQ. In addition, the NYSE has lower effective spreads than its competitors, while NASDAQ's are the second largest. Collectively, our results indicate that the primary market is a much less effective competitor for NASDAQ-listed stocks than it is for the NYSE-listed stocks, and trading venues other than the primary one often present substantial competition for NASDAQ-listed order flow.

We confirm the results of several earlier studies that show that ECNs are cheaper to trade on than NASDAQ, but we additionally show that trading on Island is considerably cheaper than on the other two ECNs: Archipelago and Instinet. Moreover, the data reveals that the difference between the trading costs of Island and Archipelago is larger than the difference between those of Archipelago and NASDAQ. We thus argue that, in terms of trading costs, the primary difference among markets does not lie in the classification into ECNs and market maker-operated venues, but instead is determined by the factors related to each market individually. In addition, our investigation of price discovery conducted using the vector error correction model (VECM), shows that the distinction between the ECNs and market makers earlier documented in the literature (e.g., Huang (2002), Barclay, Hendershott, and McCormick (2003)) has become less lucid in the environment of intense competition and order flow fragmentation. In particular, we find that, at least for certain stocks in our sample, the majority of price discovery happens on the specialist- and dealer-operated venues. This result contradicts several earlier studies that argue that informed traders prefer transacting through the ECNs due to the anonymity offered by the networks. An argument that we offer to challenge this viewpoint has to do with the depth of the limit order books of certain ECNs in a fragmented market. In particular, we show that Island and Instinet may not always be able to satisfy the traders' demands for liquidity, which causes order cancellations of outstanding orders and, consequently, execution delays. If an informed trader's information is time sensitive, such a trader might not be willing to risk executing via a limit order book that is not deep enough and might go with the market maker instead, making the price discovery shift to the non-ECN venues.

Our investigation of the electronic communication networks reveals substantial variation in terms of intensity of transacting, ability to provide sufficient inside depth, level of trading costs, and informed trading. For instance, we show that Island's role in price discovery is smaller than those of Instinet and Archipelago, with the most informative trades happening on the latter. This result is consistent with the conjecture that certain features of Island's and Instinet's limit order books, such as lower depth, result in informed market participants' avoidance of these ECNs. On the other hand, relatively deeper and less volatile limit order book on Archipelago attracts more informed order flow by increasing investors' confidence as to the execution times and prices.

We partition our sample into four trade size categories, which not only allows us to investigate the ECNs' abilities to accommodate different incoming order sizes, but also to theorize that the NASDAQ dealers' expectations as to the trades' information content are not as monotonic as previous research suggests. According to Huang and Stoll (1996), dealers know their order flow and are frequently able to learn the information embedded in a trade before its execution. We argue that for large trades, the benefits of discovering the underlying information should exceed the costs, but for medium-size trades (500-4,999 shares) this cost-benefit relation may be zero or negative. Thus, it may not economically plausible to spend resources investigating medium size trades, yet dealers cannot be sure of their information content. As the evidence shows, for the dealers, one way out of this lose-lose situation is to charge medium-size trades with unusually high trading costs.

As the NASDAQ inter-market structure becomes more competitive and fragmented, non-positive spreads are frequent for NASDAQ-listed securities during continuous trading hours.[4] We find that 14.67% of inter-market spreads are either locked or crossed. Although not directly harmful to the market makers' revenues, these episodes are able to disrupt trading, presenting significant impediments to market functionality. Specifically, when the NBBO spread becomes non-positive, trading software systems on some venues halt executions until the issue is manually resolved. Non-positive spreads are often blamed on the access fee rebate practices used by the ECNs in order to attract limit orders. We, however, find that the only ECN that is able to attract additional trades during the periods of locked and crossed markets is Island, on which locking the market is the only way to submit a marketable limit order.

The rest of the paper is organized as follows. In section I, we provide a brief history of the trading venues, while section II describes the sample and provides information on market shares. Section III describes and analyzes the results on trading costs, section IV examines quote competition, and section V investigates trading activity. Section VI introduces the results on fragmentation through the examination of locked and crossed markets. Section VII analyzes the determinants of order routing and section VIII concludes.

I. History and Identification of Trading Venues

Trades and quotes for NASDAQ stocks are reported via six different venues: NASDAQ, the American Stock Exchange (AMEX), the Cincinnati Stock Exchange (CSE), the NASD Alternative Display Facility (ADF), the Chicago Stock Exchange (CHX), and the Pacific Stock

[4] Previous studies have only examined locked and crossed markets during non-trading hours or at the open itself, but not during hours of continuous trading. For example, Angel and Wu (2001) examine locked and crossed markets at the NASDAQ open, while Cao, Ghysels, and Hatheway (2000) examine the NASDAQ pre-opening period. Davies (2003) examines locked and crossed markets on the Toronto Stock Exchange pre-opening session.

Exchange (PSE).[5] In the past several years, as a result of increased competitive pressures in the market, these six reporting venues underwent certain transformations that significantly affected their trading and quoting practices and allowed for identification of some of the leading competitors for market making. In particular, by the second quarter of 2003, these changes allowed the identification of quoting and trading activities of the largest electronic limit order books competing for NASDAQ order flow: Island, Instinet, and Archipelago. As a result, disseminated data became more informative about the competitive landscape. This study uses these changes to identify the ECNs in the Trades and Quotes (TAQ) database distributed by the NYSE.

For instance, in March 2002, Island (at the time the largest ECN on NASDAQ) switched reporting of its trades to the Cincinnati Stock Exchange. Routing of the quotes through the CSE followed in October 2002. Island motivated the move, arguing that reporting fees charged by the CSE were more appealing than the ones assessed by NASDAQ. During our sample period, almost all trades and quotes reported through Cincinnati were coming from the Island ECN.[6]

In October 2002, NASDAQ introduced the Alternative Display Facility (ADF) – a quotation collection, trade comparison, and trade reporting resource operated by the National Association of Securities Dealers Inc. (NASD). During the time period of this study, Instinet mainly reported its trades and quotes through the ADF and overwhelmingly dominated the venue. On February 9, 2004, Instinet stopped reporting via the ADF, causing the activity on the

[5] The Cincinnati Stock Exchange changed its name to National Stock Exchange on November 7, 2003. As this change came after our sample period, we retain the use of the former name.
[6] According to Bonnie Greenberg, Director of Corporate Communications, at the Cincinnati Stock Exchange; about 99% of quotes and trades in NASDAQ-listed stocks routed through the CSE are coming from the Island ECN.

venue to drop by 99%.[7] We therefore speculate that virtually all trades and quotes reported on the ADF during this study's time period can be ascribed to Instinet.[8, 9]

In the past several years, Archipelago Exchange (ArcaEx) has developed an extensive alliance with the Pacific Stock Exchange. Archipelago was launched in January 1997 as one of the four original ECNs approved by the SEC. In 2000, the ECN partnered with the Pacific Exchange, Inc.; and in early 2003 the latter began disseminating Archipelago's trades and quotes in NASDAQ-listed stocks. The migration of NASDAQ-listed stocks to the Pacific Exchange started in February 2003 and was completed in early April 2003, making ArcaEx the first totally open, electronic exchange to trade all NYSE, AMEX, PCX and OTC listed securities.[10]

In addition to Island, Instinet, and Archipelago, two other markets, the Chicago Stock Exchange and the American Stock Exchange, participate in quoting and trading of NASDAQ-listed securities. The Chicago Stock Exchange employs a competing specialist system, somewhat similar to the competing dealer system of NASDAQ. The exchange is currently integrated as a part of the SuperMontage. Chicago specialists handle a number of NASDAQ stocks and have traded some of them since as early as 1987. Specialists on the American Stock Exchange also post quotes and execute trades in NASDAQ-listed stocks. AMEX was integrated into the NASD system after its acquisition in 1998; however it remains a largely self-regulated organization with the NASD Office of the Chairman responsible for strategic development and policy initiatives. Although technically a part of NASD, AMEX still does not make its quotes

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[7] We thank Tim McCormick of NASDAQ for this information.

[8] Despite Island Holding Company and Instinet Group Inc. completed their merger on September 20, 2002; during our sample period, Island reported its quotes and trades through the CSE while Instinet's trades and quotes were routed to the ADF.

[9] Despite virtually all ADF activity during the sample period can be attributed to Instinet; not all Instinet trades and quotes were routed to the ADF, as a certain portion of them was disseminated through the SuperMontage and therefore is merged with the trades and quotes of NASDAQ dealers in TAQ. We, therefore, use caution while interpreting the results obtained for NASDAQ further in the paper.

[10] The Pacific Exchange is also the regulator of the Archipelago Exchange. It provides all market surveillance, member firm financial and operating compliance monitoring, and enforcement services.

electronically available to the SuperMontage participants, causing stale quote and connectivity problems.[11]

II. Sample

The study considers a sample of 100 NASDAQ-listed common stocks comprising NASDAQ-100 market index (QQQ) in the second quarter of 2003 (April, May and June 2003).[12] The data for the study is extracted from Trade and Quote (TAQ) database provided by the NYSE and Dash-5 database reported in accordance with SEC Rule 11Ac1-5 and obtained from Transaction Auditing Group, Inc. and Instinet Group, Inc. In order to remove the issues related to after hours trading examined, among others, by Barclay and Hendershott (2003), the sample obtained from TAQ is restricted to include only quotes and trades that occur during regular trading hours (9:30 a.m. to 4:00 p.m., EST). Additionally, certain filters are applied to TAQ data to remove observations that could be subject to errors. In particular, trades and quotes are omitted, if the TAQ database indicates that they are out of time sequence or involve either an error or a correction. Quotes are also omitted if either ask or bid price is recorded in the database as equal to or less than zero. Finally, certain trades are omitted, if the price or volume is equal to or less than zero.

An analysis of trading activity in the NASDAQ inter-market is provided in Table I. Panel A contains venues' market shares as a percentage of trades; panel B – as a percentage of trading volume; and panel C – as a percentage of dollar volume. NASDAQ only executes

[11] This and other issued are investigated in detail in a study of locked and crossed markets by Shkilko, Van Ness, and Van Ness (2005).
[12] USA Networks (ticker: USAI) formed a joint venture with Vivendi Universal on May 7, 2003. A joint venture was further spun off to create USA Interactive (ticker: IACI). This stock is excluded from the sample after May 7, to account for possible instability related to the aforementioned activity. We perform our tests using two samples: A – with USAI until May 7 and B – without USAI. The results appear qualitatively identical. The findings reported in this study include USAI.

51.59% of trades in the sample; hence, its dominance is quite marginal. The three electronic limit order book systems – Instinet, Island, and Archipelago – complete 11.30%, 17.12%, and 19.31% of the trades, respectively; while the two specialist systems, AMEX and the Chicago Stock Exchange, execute a mere total of 0.68%.[13] We suggest that AMEX and Chicago do not have substantial influence on the market in NASDAQ-listed securities, since their share of trade executions is so small. This conjecture is further explored in later tables.[14]

We divide the sample into four trade size groups: group 1, small trades (less than 500 shares); group 2, trades from 500 to 4,999 shares; group 3, trades from 5,000 to 9,999 shares; and group 4, large trades – those exceeding 10,000 shares. NASDAQ's share of trading volume in large trades is 91.47%, while its share in small trades is only 48.34% (Table 1, Panel B). The same pattern is also observed for AMEX and Chicago – the two specialist systems. Conversely, the three electronic limit order book systems – Island, Instinet, and Archipelago – exhibit decreasing patterns of volume shares from small to large trade sizes. Similar results are found for shares of sample trades (Panel A) and dollar volume (Panel C). Paired *t*-tests generally confirm statistical significance of the aforementioned differences in the market shares. These results are consistent with those of Barclay, Hendershott, and McCormick (2003) who show that ECNs tend to execute smaller trades than NASDAQ market makers. Our finding that these results hold true not only for NASDAQ, but also for the competing dealer/specialist systems of

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[13] Archipelago finished the migration of NASDAQ-listed stocks to the PSE on April 11th, 2003. To avoid a possible anomalies caused by this transition, we ran our tests for a May-June sample period as well as April-May-June sample period. Analyses of the former and the latter delivered quantitatively similar results. We further present the results for the three-month period.

[14] Some of the markets we consider specialize in certain NASDAQ-100 securities and ignore others. For instance, during our sample period, AMEX participates in quoting of all stocks in the sample, but executes trades only in 98 stocks. The Chicago Exchange only makes a market in 80 of the sample stocks. We conduct an additional analysis of a sample comprising only those 80 securities that had all six venues making a market in them. The results showed no conceptual differences from those obtained for the full 100-stock sample.

AMEX and Chicago, indicates that execution of larger trades is not just a specific feature of NASDAQ dealers, but of any dealer or specialist system.

Table I also shows that, while Island's and Instinet's shares of trading volume drop by about the same amount between the 100-499 and 500-4,999 categories (4.47% and 4.43%, respectively), Archipelago's share falls only by 2.12%. We suggest that for these trade sizes the limit order book on Archipelago may be deeper and thus may give the ECN the needed capacity to handle trades in the second size category.[15] To validate this conjecture, we perform an investigation of order executions and cancellations on the three ECNs. For an order to be executed within an ECN, a market or a limit order (or several orders) with a matching price has to be pending on the other side of the book. If the number and/or depth of such orders are/is volatile, two possible scenarios may evolve. Firstly, since the traders are likely to be aware of this peculiarity of the ECN, fewer orders will be routed to it. Secondly, the orders that are submitted to the network will be cancelled more often, as the waiting time for execution (especially for the limit orders) is likely to exceed traders' initial expectations. Empirical investigation of the first scenario requires more sophisticated datasets than those that we have in possession. In particular, we would need data on traders' decision making prior to submitting an order to investigate its validity.[16] Although we are unable to empirically evaluate the first suggestion, we use Dash-5 data on orders to examine the second one. Table II contains results on the number of market and marketable limit orders executed on the networks as a percentage

[15] This suggestion is confirmed by the regression results in Table VII, in which it is shown that although trade size negatively affects ECNs' chances of executing an order, this relationship is not as economically strong for Archipelago as it is for Island and Instinet.
[16] INET makes public a database called ITCH that allows researchers to reconstruct order histories for orders submitted to the ECN. For our purposes we, however, would need a similar database for Archipelago, which to our knowledge, is not publicly available.

of all covered orders of the same type.[17] The results show that, in all but one size category, on Archipelago, more orders are executed before cancellation as compared to Island and Instinet. This corresponds to the second scenario outlined above and we, therefore, conjecture that Archipelago's limit order book is, on average, deeper and more stable than those of the two rival ECNs.

III. Trading Costs, Profits, and Price Discovery

With NASDAQ garnering around 50% of the total order flow in the sample stocks, and the remaining 50% of trading occurring on other venues, the question remains as to how much these other venues compete on the basis of price and execution quality. To answer this question, we use two measures of trade-based execution costs: the effective half-spread, and realized half-spread.[18] In the analysis of trade-based execution cost measures, we only use the NBBO quotes in which the NBBO spread is greater than zero.[19]

The effective half-spread measures how close the trade price comes to the quotation midpoint, a conventional proxy for the real value of the stock. To compute the effective half-spread measure at time *t*, we reconstruct the National Best Bid and Offer (NBBO) at time *t* across all venues, and subtract it from a trading price of a trade executed on one of our six

[17] Island did not accept market orders during the sample period; therefore we only investigate marketable limit orders for this ECN.

[18] As noted by Blume and Goldstein (1992), Lee (1993) and Petersen and Fialkowski (1994), quoted spreads are a poor proxy for the actual transaction costs faced by investors, because many large trades occur outside the spread, while many small trades occur within the spread. The situation is exacerbated by the sub-penny pricing actively applied by some exchanges (the practice is especially widespread on Island, Instinet, and NASDAQ). Sub-penny pricing is discussed later in this section.

[19] By restricting the NBBO spreads to be positive, we avoid the many instances in which the inter-market is crossed (bid price is greater than the ask price) or locked (bid and ask are identical). We find that instances of locked and crossed markets cannot be attributed fully to the presence of stale quotes coming from one of the sample venues. Section VI presents more evidence on locked and crossed markets.

sample trading venues at time *t*. Thus, the effective half-spread for security *i* at time *t* can be defined as:

$$\textit{Effective Half-Spread}_{i,t} = I_{i,t}\left(P_{i,t} - M_{i,t}\right), \text{ where}$$

I_{it} is an indicator variable that equals one for the customer-initiated buys and negative one for the customer-initiated sells, P_{it} is a trade price, and M_{it} is an NBBO midpoint for stock *i* at time *t*. Similar to Bessembinder (2004), we designate trades as customer buys and sells using the algorithm described by Ellis, Michaely, and O'Hara (2000). We use realized half-spread as a measure of trade execution cost that accounts for the possible effect of a trade's price impact:

$$\textit{Realized Half-Spread}_{i,t} = I_{i,t}\left(P_{i,t} - M_{i,t+10}\right)$$

As pointed out by, among others, Huang and Stoll (1996), realized half-spread measures revenue to the liquidity supplier, net of the trade's price impact.

Microstructure studies (e.g., Huang (2002); and Barclay, Hendershott, and McCormick (2003)) have argued that due to anonymity of trading through ECNs, the networks execute more informed trades and contribute more to price discovery than the venues that employ market makers. We contribute to this area by suggesting that under conditions of increased market fragmentation that characterize our sample, not only anonymity, but also order execution quality and speed could become issues of foremost importance to informed traders. In particular, with Island's and Instinet's limit order books being less deep than that of Archipelago's, an informed trader with a temporary informational advantage, might be willing to submit his order to a venue that provides less anonymity and faster executions (e.g., Archipelago or NASDAQ).

Table II reports the effective and realized half-spread results for each trading venue in Panels A and B. Panel C, in turn, contains results on information shares calculated via the Vector Error Correction Model (VECM) of transaction prices described in detail by Hasbrouck

(1995), Huang (2002), Harris, McInish, and Wood (2002), Hendershott and Jones (2005), Cao, Hansch, and Wang (2005), and others. VECM approach is unable to provide single-figure determinants of information shares by construction, therefore Panel C contains the upper and lower bounds of information share estimates for each exchange in the sample. Finally, for all exchanges, we also compute the percentage of orders that are price improved and percentage of orders executed outside the NBBO (Panel D). An order is considered to be completed with price improvement, if price of execution is lower than the NBBO ask for customer buys and is higher than the NBBO bid for customer sells. An order is executed outside the NBBO when the price of execution is higher (lower) than the NBBO ask (bid) price for customer buys (sells).

We find that, while overall the effective half-spread is lower on the electronic limit order book markets and higher on the dealer/specialist markets; there is substantial variation of trading costs not only *between* but also *within* these two market types. In particular, the effective half-spread for Island averages 0.71 cents per share, followed by Instinet with 0.84, and Archipelago with 0.93 cents. As for the dealer/specialist group, the effective half-spread averages 1.04 cents on the Chicago Stock Exchange, 1.10 cents on NASDAQ, and appears to be relatively high for trades executed on AMEX – 1.90 cents. Note that the difference within the two groups is at times as large as or even larger than that across groups: for instance, the difference in execution costs of a round lot (one hundred shares) between Island and Archipelago is, on average, twenty-two cents, which is larger than the seventeen cents difference between Archipelago and NASDAQ. Thus, although ECNs indeed provide the benefit of cheaper trading, the differences in costs within the ECN group appear to be as economically significant for the trading public as those across market types.

Quantitatively, our results appear quite striking when compared to those of the earlier studies. For instance, Bessembinder (2003) examines a sample of the NYSE- and NASDAQ-listed stocks and finds effective half-spreads of, respectively, 4.93 and 9.36 cents. Similarly, Bessembinder (2004), in an investigation of execution costs for one hundred large-capitalization NYSE-listed securities, finds that effective half-spreads range from 3.67 to 4.63 cents.[20] Although our results are not directly comparable to those previously mentioned, it is certainly apparent that trading costs have significantly decreased over a seemingly short time period. We attribute this discovery to the consequences of decimalization and to the increased competition from alternative trading venues, namely ECNs. Although beneficial to those who submit small market orders, this drastic reduction in execution costs has diminished dealers' and specialists' rents.

Trading costs dynamics aside, we also find substantial variation in trading costs across order sizes. NASDAQ, Archipelago, Island, and Instinet generally show a drop in effective half-spreads as order size increases from the smallest category (100 to 499 shares) to the largest (over 10,000 shares), although these transitions are not uniform. Island and NASDAQ experience a substantial increase in effective half-spreads (58% and 44%, respectively) between the first and second (501 to 5,000 shares) size categories and then about a 50% drop to the third category (5,001 to 9,999 shares). Instinet and Archipelago differ from Island in that they do not show such a sizeable increase between the first two size categories (in fact, the effective spread on Instinet drops by 2.4%) and show a smaller drop from second to the third categories. Thus, opposite to the results of Barclay, Hendershott, and McCormick (2003), we find that spreads get

[20] Bessembinder (2003) and Bessembinder (2004) consider, respectively, 1998 and 2000 sample periods prior to decimalization.

smaller, not larger, as trade size increases, though the increase is not uniform.[21] We also find substantial variation across ECNs in terms of their effective half-spreads in different trade size categories.

Our findings in Panel A necessitate further discussion. Huang and Stoll (1996) suggest that NASDAQ dealers, generally, know their order flow. We argue that, taken literally, this notion is true for trades of large sizes, while for medium-sized trades it is more difficult to establish the identity of the counterparty, therefore market makers' confidence on whether a medium-size order is informed is questionable. Lee and Radhakrishna (2000) note that, for orders greater than $100,000, there is only a one percent chance that a trade has retail participants.[22] Using this argument and taking into account that the average NASDAQ-100 security is priced at $27.45 during the sample period, we conjecture that market makers are more or less certain that trades larger than 3,600 (≈ $100,000 / 27.45) shares are informed. There is, therefore, a grey area; in which not too small (more than 499), but not too large (less than 3,600 shares) orders fall. For these trades, it is not always clear from merely observing their size whether the opposite party is informed or not. The situation is exacerbated by the fact that these trades are still relatively small, and the dealers' opportunity cost of finding out trade origination may be prohibitive. Given that such trades end up in the 500 to 4,999-share group, higher trading costs in this size category are consistent with the dealers' trying to account for the uncertainty regarding the trades' information content.

[21] Barclay, Hendershott, and McCormick (2003) use only three size categories: less than or equal to 1,000 shares, 1,001 to 9,999 shares; and 10,000 shares and over. Our four-category division reveals substantial non-linear variation in the smaller and medium categories that is masked by using coarser categories.

[22] Lee and Radhakrishna (2000) conduct their study using the TORQ database distributed by the NYSE for several months in 1991. Allowing for inflation, we expect their results to suffer from a downward bias, if applied to current data. Nonetheless, in order to add a degree of conservatism to our results, we use the $100,000 figure.

The story is considerably different for ECNs, although it leads to the similar results. These computerized trade-matching networks derive profits from membership and trading fees; therefore they neither deliberately originate spreads, nor purposefully affect their magnitudes. In addition, private information possessed by certain traders should not affect ECNs' earnings directly. For the most part, the cost of executing a customer buy (sell) order on an ECN depends on the amount of liquidity the network currently carries on the opposite side of the market. This liquidity is represented by the number and depth of market and limit orders submitted for execution. While small market orders do not require substantial liquidity and are usually not difficult to execute, large orders may encounter certain problems. In addition, if inside depth is not substantial, a large order may have to be split into smaller trades to be completed. For a large order A to be executed via an ECN and to be recorded as a large trade, another order B, at least as large as A, needs to be waiting for execution on the other side of the market. The odds of two such large orders being submitted to an ECN at the same time are rather small; however, they are likely to increase proportionally to the trading volume.[23] As shown by Barclay, Hendershott, and McCormick (2003), volume in the past 15 minutes negatively affects the effective half-spread; hence, the lower spreads for large trade size categories. One caveat to the above argument is presented by the fact that effective half-spreads increase in the second size category on Island and Archipelago. We postulate that this category captures parts of those market orders that are large enough to consume a lot of depth and are therefore split in the course of execution. The remnants of these orders end up being executed against limit orders that do

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[23] We run a simple logistic regression of occurrences of a large (> 3,600 shares) trades on cumulative trading volume in the previous fifteen minutes. Our results (not shown) indicate that a 100,000-share increase in the cumulative volume, which represents approximately a 50% increase from the average fifteen-minute cumulative volume in an average stock, increases the probability of a large trade by 12.04%.

not appear on the inside, at prices that are further away from the existent best quotes.[24] Intriguingly, an increase in trading costs from the first size category to the second does not appear on Instinet. This phenomenon may be due to Instinet's lower trading volume, which implies lower trading frequency and less frequent changes in depth. On Island and Archipelago, trades above certain sizes may be too large to be executed in one transaction: due to high trading frequency, depth might have changed substantially from the time of trade decision to the time of execution. On Instinet, however, large trades have a better chance of being executed against the inside depth.

The results in Panel B indicate that the average realized half-spread is the lowest on Instinet (0.42 cents per share), followed by Island at 0.46 cents and Archipelago at 0.47 cents. The revenues are higher for the specialist/dealer markets, with the results for NASDAQ (0.79 cents) being similar to those of the Chicago Stock Exchange (0.75 cents). The revenues to the liquidity suppliers on AMEX are markedly larger than those for all other venues and amount to 2.47 cents per share. Our findings are, again, nonmonotonic across trade sizes and across markets. Conventionally recognized as the compensation to the liquidity providers, realized spreads are usually argued to represent the market makers' revenue after accounting for the price impact of a trade. While the liquidity providers at the dealer/specialist exchanges derive their profits from realized spreads, the beneficiaries of the latter on the electronic order book systems are not as evident. On ECNs, the liquidity providers are the traders that submit limit orders to the system. In cases where a limit order is executed against another limit order there is no

[24] A large order A has a better chance of being executed against a large limit order B that is not on the inside than against a large order, C, on the inside. As soon as the order C appears on the inside, it starts being consumed by incoming smaller orders, so that the chances of such inside order being large at the time of execution against another large order are smaller than for the limit orders that are not on the inside and, therefore, preserve their integrity.

spread, and the trading costs as well as revenues to the liquidity providers are zero.[25] When a limit order is executed against a market order, and the quoted NBBO spread is positive, trading costs are positive. However, the provider of liquidity, namely the person submitting the limit order, only receives the requested price without the addition of the spread.[26] Thus, we conjecture that, in case of ECNs, the realized spreads are the deadweight cost to the liquidity demanders that is not directly transferred to the liquidity providers. Interestingly, in the largest trade size category, the deadweight losses to the liquidity demanders on Island and Instinet become the deadweight losses to the liquidity providers.

Before proceeding, we would like to point out several problems with the realized spread measure that are potentially able to introduce bias into our results. First of all, the 10-minute interval between prices and midpoints is quite arbitrary. Because of high trading frequency in contemporary stock markets, more than one informational event may happen within an interval of this length. In addition, due to the market participants' ability to see trades as they occur, information about a trade may take less than 10 minutes to disseminate. Thus, our realized spread measure is likely to be contaminated, as it will be picking up informational effects from multiple trades. Another criticism of the realized spread becomes apparent if one thinks of the measure as a difference between the effective spread and the 10-minute price impact of a trade (e.g., Bessembinder, 2004). As was mentioned before, some trading venues, especially ECNs, break up larger orders into several trades during the execution process. This practice is able to introduce bias into the price impact means as orders broken up into several trades will be counted several times. If we assume that large orders that get broken up come mostly from the informed

[25] Potentially, an effective spread might exist when two limit orders on an ECN are executed against each other, if at least one of those orders was not included into the NBBO.

[26] In the constant struggle for liquidity, ECNs often reward limit order submitters (liquidity suppliers) with rebates of trading fees. The rebate is usually equal to 2 mils (millicents) of a 3-mil trading fee. Liquidity demanders (market order submitters) are charged the full fee with no rebates.

market participants, we can expect the average to overestimate the real price impact. On the opposite, if we assume that the majority of large orders are submitted by institutions that trade for portfolio rebalancing purposes and do not base their decisions on proprietary information, the average will underestimate the real price impact.

Due to the problems mentioned above, we refrain from the further discussion of the realized spreads. Instead, we switch our attention to the results on information shares (Panel C), obtained from the vector error correction model. As opposed to what the realized spread and price impact figures indicate, VECM reveals that NASDAQ, Chicago, and AMEX possess the highest, in terms of upper bounds, information shares, respectively, 0.13 - 0.56, 0.09 - 0.63, and 0.04 - 0.55. The ECNs' shares are lower and generally less dispersed, with that of Archipelago ranging from 0.13 to 0.38, followed by Instinet and Island with, respectively, 0.18 - 0.31 and 0.08 - 0.27. The lower bounds for NASDAQ, Chicago, and AMEX are not statistically different from zero, which, together with the narrower information share distribution on the ECNs, indicates that for some stocks in our sample the majority of price discovery happens via the market maker venues, while for some – information revelation still occurs through the ECNs. The fact that Archipelago's information share is higher than those of the other two ECNs confirms our earlier conjecture that informed traders avoid trading through Instinet and Island due to the specifics of the limit order books of the two ECNs. Overall, evidence presented in Panel C contradicts earlier findings on price discovery on dealer and electronic markets and confirms our hypothesis about the partial shift of price discovery from the ECNs to the market makers due to potential execution delays on the former and different depth of the limit order books.

Panel D of Table II reports the percentage of trades executed at prices within the best quotes. All exchanges provide their customers with substantial price improvement: the percentage share of trades executed at prices better than the contemporary quotes ranges from 54.27% on Island to about 10% on Chicago. Although results seem quite impressive, a closer look at the execution prices reveals that high degrees of price improvement are deceptive and attributable, primarily, to the sub-penny pricing and rounded-to-a-penny reporting. TAQ reports bid and ask quotes rounded to the nearest penny, i.e. a XX.XXY quote is reported as XX.XX if $Y < 5$ and as XX.XX + 0.01 if $Y \geq 5$. Meanwhile, trades are reported at the actual prices, so, at times, what appears to be a substantial degree of price improvement is, in reality, caused by the fact that we simply see a crude measure of what is allegedly getting improved.

Overall, our findings indicate that there is substantial variation across different ECNs and different dealer/specialist systems. Similar to previous studies, we find that ECNs tend to have lower costs than dealers/specialists. Nonetheless, unlike the earlier inferences, we find substantial variation across ECNs and a lack of consistency across trade sizes in terms of execution costs. Insufficient inside depth on the ECNs makes informed traders willing to shift information-motivated trades away from the networks in certain cases.

IV. Quote Competition and Trade Execution

In order to measure quote-based competition between the trading venues, we examine the extent of the exchanges' participation in NBBO formation. We differentiate between the following states of competition on quotes: *at the inside bid and/or ask*, when an exchange participates in formation of one or both sides of the NBBO; *at both inside bid and ask*, when a venue participates in forming of both sides of the NBBO along with the other market centers;

alone at inside ask (bid), when an exchange forms an ask (bid) side of the NBBO by itself; and *alone at both bid and ask*, when a market center forms the entire NBBO by itself.[27] Table IV shows the percentage of time (Panel A) markets spend in each of the abovementioned states and percentage of trades (Panel B) executed in each of those states. The most active quoting venue, NASDAQ, is participating in the NBBO formation in one way or another 89.92% of the time, with 86.52% of trades executed during these periods. The electronic limit order book systems, especially Instinet and Archipelago, contribute a great deal of competition to the NBBO formation: they are on either or both sides 85.25% and 81.86% of the time, respectively. Island's participation is lower – it is competitive only slightly over half the time. Recall that our results in Section III imply that Island has lower inside depth than the other two ECNs. This characteristic of Island's limit order book together with the high trading frequency results in the venue's less active participation in the NBBO formation, as the smaller depth of the inside limit orders is quickly consumed by incoming trades.

Quoting activity of the market centers falls quite dramatically when it comes to forming the entire NBBO. NASDAQ is still the leader, determining the inside quotes 50.24% of the time, while participation of the rest of the market centers ranges from less than 1% to 24.18%. These results expose an important methodological issue: when computing the inside quotes for NASDAQ-listed securities, it is erroneous to use only the quotations coming from NASDAQ itself (in TAQ, quotes with an exchange denoted by "T"). This approach will deliver the correct inside quotes in only 50.24% of the cases and is thus prone to overestimate the quoted spread.[28]

The rest of the results in Table IV show that not only a high level of quote-based competition exists in the inter-market for NASDAQ-listed stocks, but also that this competition

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[27] *At both inside bid and ask* $\subseteq$ *at the inside bid and/or ask.*

[28] The average difference between the NBBO and NASDAQ-originated spreads equals -0.04 dollars and is statistically significant at 0.01 level.

is very acute: none of the exchanges forms the NBBO alone for more than 1% of the time. Although detrimental for the dealer/specialist markets, as tight competition restricts earnings from spreads, the overall goal of creating strong competition on quotations, referred to earlier in this work, has been achieved.

As a rule, orders are directed to a market maker based on the best offered price. If several market makers post identical quotes, a trade is supposed to be routed according to time priority. Our results in Table IV show that NASDAQ quotes had time priority 52.56% and 50.38% of the time, respectively, for the ask and bid in the NBBOs where NASDAQ participated. Price priority is not as pronounced for ECNs, mostly due to the fact that their quotes are more frequently consumed by incoming orders. Despite a new quote that matches the inter-market inside may be posted on an ECN in the next instance following the old one that has been consumed by an order execution, this quote will not have price priority unless no other exchanges have identical quotes outstanding. Panel D of Table IV studies quote submission interaction among market centers relative to quote-posting activities of each venue. For instance, some ECNs, e.g., Island and Instinet match the existing NBBO with, respectively, 9.91% and 11.61% of their quotations. Interestingly, the results show that none of the venues exhibits any noticeable quote improvement features: all market centers participate in quote improvement with 2-4% of their quotes. Although similar in quote improvement, the exchanges show a quite vivid pattern in being late with quote downgrades: AMEX and Chicago are very often slow with lowering their quoted prices with, respectively, 10.49% and 21.88% of quotes left alone at the NBBO.

Panel E reports statistics similar those in Panel D, however not as a percentage of quotes posted by each venue, but as a percentage of similar cases across the inter-market. The results reveal that Archipelago posts the most matching quotes (42.53%), followed by Instinet (35.24%) and NASDAQ (29.97%). Archipelago is also responsible for 51.83% of quote improvements, with NASDAQ improving a smaller share of 42.71%. NASDAQ is most often the last one to abandon a comparatively high quote – it is left alone at the NBBO 40.70% of the time. Thus the results of Panels D and E show that, although certain market centers have highly visible individual behavior (e.g., AMEX and Chicago are the slowest to abandon outstanding NBBO quotes), it is the exchanges with not so vivid patterns that determine the overall picture.

Next, we examine percentage of a market's volume conditional on its quotes (Table V). Sample orders are categorized by the venue of completion, and for each trade, a location of the quote relative to the NBBO is determined. Panel A presents the results for all trades and reveals the existence of two distinct groups of exchanges that differ by the position of their quotes relative to the NBBO when attracting orders. While NASDAQ and the ECNs obtain the majority of their order flow when posting the best quotes, AMEX and Chicago show an entirely different pattern: the most of their executions occur when the exchanges are not posting the inside quotes. The results on AMEX and Chicago are consistent with the preferencing and internalization argument of Huang and Stoll (1996) and a higher percentage of larger, perhaps institutional orders, executing on the two exchanges.

Interestingly, 75.59% of NASDAQ trades are executed during the periods when the exchange quotes both sides of the NBBO. From Table IV, these periods only account for 55.87% (=50.24/89.92) of the venue's inside-forming activity. A similar relationship is observed for the ECNs. For instance, Island executes 57.27% of its trades during the period that covers just 24.93% of the time the ECN participates in quoting. The results for Instinet and Archipelago show that they also execute orders more actively when present at the both sides of NBBO:

72.55% and 71.12% of trades during the 40.09% and 41.10% of the overall participation time, respectively for Instinet and Archipelago. These findings indicate that not only being at the inside determines whether an ECN gets a trade, but also the trading itself directly influences the position of the quotes ECNs submit to the montage. For instance, during the periods of higher volume caused by aggressive submissions of limit orders (see Peterson and Sirri (2002) for an analysis of aggressive limit order placements), the inside quotes are likely to converge. In these situations, it may seem as if quoting at the inside increases the ECN's order inflow, while, in fact, the increased order flow narrows the inside spread. For NASDAQ, the scarcity of trading during the periods when the dealers do not quote the entire NBBO is caused by the fact that investors are reluctant to trade with a dealer who may possess information about a stock that causes him/her not to be willing to quote both sides.[29]

Another noteworthy finding is the high proportion of trades executed by ECNs when not at the inside. As stated earlier, due to the occasional thinness of the inside depth on ECNs, especially Island, large market orders (often the ones in the 501-5,000 trade size category) are frequently truncated and executed at the prices that do not match the inside quotes. We attribute a relatively high degree of executions when an ECN is not posting the best quotes to this phenomenon. The largest proportion of executions when not posting the inside quotes is in the second trade-size category, the one to which we earlier ascribed the majority of the truncated trades. For instance, Panel C shows that, on Island and Archipelago, respectively, 56% and 30% of 500 to 4,999-share trades occur when the ECNs are not posting the best quotes. Note also that the share of trades executed on the AMEX when the venue is not posting the best quotes increases with the trade size, which is consistent with our earlier conjecture that a large portion

[29] A dealer also might not be willing to quote both sides because of inventory considerations. Nonetheless, when traders cannot be sure about the dealer's motives, they may prefer not to trade at all.

of AMEX's order flow may be preferenced. On the ECNs, the share of trades completed when the networks post the inside quotes is rising with the trades size, adding credence to our earlier speculation that large market orders are only routed to the ECNs when there is substantial inside depth for them to be completed at the NBBO prices.

V. Locked and Crossed Markets

The National Best Bid and Offer (NBBO) quotes are not provided by the TAQ database, making it necessary to reconstruct them using the quotes from the six exchanges. A fairly unexpected result of such a reconstruction was the fact that the data reveal frequent negative and zero NBBO spreads. In particular, we find that, in June 2003, 12.43% of all spreads are zero and 2.24% are negative (Table VI). The results also show that non-negative spreads are not attributable to any particular set of days and are fairly consistent across the three sample months (panel A) as well as on a daily basis (panel B contains the daily results for June). This phenomenon is inconsistent with theories proclaiming spreads to be a natural compensation to the market makers for liquidity and immediacy (Demsetz, 1968) or for the execution, inventory, and adverse selection costs they encounter (Stoll, 2000). The Security Traders Association (STA) acknowledges that locked and crossed markets are an issue on NASDAQ. The problem, blamed mostly on ECN access fee rebates, is also discussed in Clary (2003). In their constant quest for liquidity, ECNs reward the liquidity-providing limit orders with rebates (usually 2 mils (millicents) of a 3-mil access fee). Market orders, on the other hand, do not get rebates and are charged the entire fee amount.[30] Thus, traders executing their orders through ECNs are often

[30] Island ECN does not accept market orders, but accepts marketable limit orders instead. These limit orders inherently lock the NBBO.

tempted to submit a limit ask (bid) order at the outstanding bid (ask) NBBO price and get a rebate after the trade completion.[31]

Even though we find that the spreads are crossed or locked in more than 14% of the cases, there is no evidence that the markets are locked for extended periods of time. An examination of NBBO quotes shows that although markets lock or cross quite frequently (about once every minute), they do so for short periods of time (no longer than 10 seconds). This is consistent with rebates being a cause of non-positive spreads. In fact, if a zero spread is created by a limit order posting on one of the ECNs, the problem should be resolved as soon as this limit order is executed. Since computer trading systems halt executions during non-positive spread periods and trades are completed manually, it is in the interest of all market participants to promptly unlock (uncross) NBBO spread.

We next determine which exchanges are affected by the non-positive spread occurrences. We conduct an analysis similar to the one presented in Table IV to investigate the exchanges' quote participation during locked and crossed markets. Our findings are provided in Table VII, where Panel A contains the results for zero spreads, and Panel B – for negative spreads. The data reveals that quotes of NASDAQ and Instinet are affected by the locked market instances the most, respectively, 7.53% and 7.42% of trading time (8.37% and 8.70% of the overall time the venues participate in forming of the NBBO). Archipelago and Island participate in quoting during the zero-spreads periods a little less, respectively, 5.74% and 4.41% of trading time (7.01% and 8.40% of the time these markets quote). Quoting activity of AMEX is affected by locked markets more often than that of the other venues, 11.17% (= 3.45 / 30.90) of the market's participation in the NBBO occurs during the periods of zero spreads.

[31] For a detailed study of locked and crossed markets on NASDAQ and the NYSE, see Shkilko, Van Ness, and Van Ness (2004).

Generally, software employed by the market centers to facilitate trading is designed to avoid non-positive spreads. In the simplest case, this software is supposed to prevent a potentially locking or crossing quote from being posted by a market participant. Our results show, however, that these systems do not always perform as intended. Note, for instance, that on Instinet 0.28% of zero and 0.06% of negative spreads (time-weighted) occur when the venue participates in forming both sides of the NBBO. In these instances, Instinet locks and crosses the inter-market without interaction with the other venues. Some evidence of creating the zero-spread situations is also found on ArcaEx: 0.01% of the trading time the exchange posts identical quotes on both sides of the market.

We show that NASDAQ and ECNs are affected by locked markets to about the same degree. A slightly different pattern emerges for crossed markets: negative spreads occur most often when Chicago is participating in the formation of the NBBO. The exchange participates in negative spreads 2.57% of the total quoting time or 61.05% of time it quotes at the NBBO.

VI. Determinants of Trade Execution

Only 51.59% of our sample trades are executed on NASDAQ, while 48.41% are captured by the other five market centers. Although the survey of quoting activity presented in the previous section provides certain insights on the inter-market quote competition, we supplement the analysis with a multiple logistic regression model that provides us with an opportunity to study the determinants of trade execution.

We use the multinomial logistic regression specification for an unordered response, where the dependent variable is the exchange where the trade occurs. Trades are divided into customer buys and sells and examined separately. The regression outcome for both groups is conceptually similar; therefore we provide only the results for customer buys. A vector of regressors includes the following: dummy variables capturing whether an exchange is at the best bid or ask (six variables, one for each venue, for best bid; and six – for best ask), inter-market order imbalance, number of trades in the preceding 10 minutes, trade size, and a dummy variable indicating if the inter-exchange market NBBO quote is crossed or locked at the time of trade execution. The model accounts for fixed effects and non-spherical errors by allowing for clustering across stocks and employing the Huber-White estimator.

The following relations between the dependent variable and the regressors specified above are expected. If exchange A posts an *ask* quote at the NBBO, a customer buy trade should have a higher probability of being executed on that exchange. On the other hand, inside *ask* quotes for all exchanges other than A should decrease the probability of a trade being executed on A, indicating competition among trading venues through posting of the best quotes.

An expected relationship between the inside *bid* quotes and customer buy orders is dichotomous. On one hand, a *bid* quote should not affect the customer buy trade execution, so the relation between an exchange's posting of a bid quote at NBBO and the probability of getting a trade by that exchange should be zero. Another scenarios however, as discussed in Section IV, is that traders may avoid dealer/specialist venues that post quotes only on one side of the inside, while the probability of ECNs being on both sides of the NBBO is proportional to the trading volume. If this reasoning holds true, we should expect a positive relationship between the aforementioned variables.

The *order imbalance* regressor is constructed for the inter-market based on the accumulated difference since the beginning of a trading day between customer buy and customer sell trades. Positive order imbalance indicates that more securities have been sold that bought from the beginning of the day. Generally, we expect a buying or a selling trend to continue, so the coefficient for this variable is expected to be positive for all trading venues.

We expect the relationship between the *number of trades during the immediately preceding ten minutes* and the dependent variable to be positive if regional markets are more likely to execute a trade when the inter-exchange market is liquid. A positive relationship would also be consistent with the fact that ECNs are able to post better quotes when trading is more intensive. The relationship could be negative if a market is trying to avoid informed traders, the presence of which may be indicated by increased trading volume.

The outcome of the multiple logistic regression is provided in Table VIII. The model delivers results in the form of marginal effects that are reported *relative to NASDAQ*. For instance, Island's chances of executing a customer buy trade are 8.38% higher that NASDAQ's, *ceteris paribus*, if Island's ask quote is at the NBBO. Similarly, if the inter-market is crossed or locked, Island's chances of executing a buy trade are 6.07% higher that those of NASDAQ.

The procedure delivers negative intercepts for all trading venues indicating that, everything else constant, NASDAQ has a higher probability of trade execution than the other five venues. Nonetheless, the results demonstrate that rival markets, especially ECNs, are generally capable of competing for trades by posting competitive quotes. Archipelago's and Instinet's chances of executing a trade exceed those of NASDAQ by, respectively, 10.17% and 2.76% if the ECNs is at the best ask. While Island and Archipelago are very quote-competitive, Instinet's executions do not drastically increase as a result of posting the best quotes. We attribute this result to the lower frequency of Instinet's order execution mentioned earlier. With lower execution rates, the ECN loses one of its major advantages – speed. Also, informed orders are easier to hide when the volume is higher, therefore informed traders are likely to prefer the other two ECNs. The results also show that AMEX and Chicago are not quite competitive with NASDAQ in terms of posting the best quotes. As mentioned previously, AMEX and Chicago likely receive most of their order flow due to the preferential agreements, making them unwilling to be competing on quotes. Interestingly, posting of the inside quotes by the ECNs increases their chances of additional executions by a larger percent than posting of the inside quotes by NASDAQ decreases these chances. Thus, by quoting the best ask, NASDAQ is able to decrease the chances of a trade being completed on Island, Instinet, and ArcaEx only by 1.8%, 0.9%, and 3.02%, respectively. Notably, NASDAQ's presence at the NBBO does not change or changes only slightly the chances of an order executing by AMEX or Chicago.

In some instances we find that an exchange may get a trade if another exchange posts the best quote. The most vivid example of this phenomenon is the 2.68% increase of Archipelago's chances of executing a trade when Instinet's ask quote is at the NBBO. This one-sided symbiosis is unexpected; however we hypothesize that these trades might result from re-routing of some trades to ArcaEx when Instinet has substantial order flow. The infrequent cases of symbiosis and preferencing aside, we generally find that the exchanges compete against each other on the basis of quotes.

Table VIII also presents evidence that by posting the best *bid*, exchanges are able to attract additional customer *buys*. This confirms our reasoning that traders prefer to transact with market makers, if the latter quote both sides of the NBBO. Order imbalance has an expected positive sign, and coefficients for all exchanges are positive and significant: if an exchange has been selling a security since the open, this security is likely to be under a buying pressure, and therefore another customer buy trade has a higher probability of being brought to market and executed. As predicted, increases in trading volume in the previous 10 minutes make the ECNs more competitive and raise their chances of executing a trade. If trading volume in the last 10 minutes is higher than the average volume by 10 trades, the chances of execution by Island, Instinet, and Archipelago become higher than those of NASDAQ by 2.9%, 2.3%, and 11.1%, respectively. Coefficients for the trade size variable are in line with the discussion of ECNs' problems providing sufficient liquidity for large trades. The results indicate that a 100-share increase in trade size lowers the chances of trading on Island, Instinet, and Archipelago by 1.81%, 1.73%, and 0.70%, respectively. Executions on AMEX and Chicago either do not seem to be affected or are slightly positively related to volume, again confirming our hypothesis of preferential agreements between the market makers on these two venues and their clients.

The non-positive spread variable appears significant and positive only for Island. For all other venues, the fact that the NBBO spread is not positive does not seem to affect trade executions. Although not the only exchange responsible for locking and crossing the inter-market, Island is the only one that benefits from the phenomenon, most likely due to executions of marketable limit orders.

Collectively, the logistic regression results confirm some earlier conjectures concerning ECNs such as their generally high ability to compete for order flow on the basis of quotes, increased competitiveness during the periods of higher volume, and weakness in providing sufficient liquidity for large orders. We also show that the order flow on AMEX and Chicago almost entirely depends on the preferential agreements the exchanges have with certain traders, as none of the determinants of order routing appears economically significant for the two market centers.

VII. Conclusion

This study investigates competition of various market centers for trading of NASDAQ-listed securities. We find that due to decimalization and an increase in the number of trading venues competing for order flow the inter-market has recently become notably fragmented with only slightly more than half of trades being executed through NASDAQ, while a substantial share of order flow is possessed via the three major ECNs: Island, Instinet, and Archipelago.

We show that all six participating markets differ from one another, and separation of the venues into specialist/dealer and electronic limit order book categories fails to fully capture the differences among the venues. We find that while ECNs as a group generally have lower trading costs than the dealer/specialist exchanges, trading through Island is notably cheaper than trading through Archipelago. We surmise that in case of the ECNs the depth of the limit order book determines the type of trading clienteles that the networks service and show that a comparatively low depth on Island and Instinet, at times, diverts informed traders from these two market centers, partially re-routing informed order flow to Archipelago, NASDAQ, AMEX and Chicago exchanges.

The results also reveal that quote competition on the NASDAQ inter-market is significantly more rigorous than that on the NYSE inter-market. ECNs, especially Archipelago, are highly competitive on quotes: the networks participate in the NBBO formation to almost the same degree as NASDAQ dealers. ECNs however also receive a notable share of order flow during periods when they do not post the best quotes. We attribute this phenomenon to informed traders' sacrificing the best price for the anonymous transacting that ECNs are able to provide, and to the fact that larger market orders routed to the ECNs are truncated during execution due to low inside depth.

We find that approximately 14% of the NBBO spreads are either locked or crossed during our three-month sample period. We suggest that a significant number of the non-positive spreads is caused by the traders' seeking to receive rebates used by the ECNs as a reward for submissions of limit orders. Nonetheless, the only venue that is able to attract additional order flow during the non-positive spread periods is Island.

We use a multiple logistic regression to analyze trade executions. As opposed to simple models of discrete choice, this unordered regression provides valuable insight into the execution process by evaluating all trading venues at once. The results show that the ECNs are perfectly capable of competing with NASDAQ on quotes, while AMEX and Chicago use non-price methods to attract trades. The model also reveals that the venues are able to attract more orders while participating in both sides of the NBBO. On dealer/specialist exchanges, this phenomenon is caused by the fact that investors are unwilling to trade with a dealer who might have information that causes him to only quote one side. On the ECNs, however, higher trading volume often causes the quotes to converge, creating an illusion of low spread – high volume causality, while the relationship is, in fact, reversed.

Overall, this study suggests that although competition among trading venues is able to reduce trading costs; it may also appear harmful for market participants, as certain venues become unable to provide quality executions in a timely manner due to decreases in the limit order book depth. Recently, NASDAQ officials have been undertaking steps to make the market more ECN-like and thus attract more trading activity by raising the level of trading anonymity. We show however that natural market forces have already partially redirected informed order flow to NASDAQ and propose that introducing more anonymity may exacerbate this process, leading the inter-market back to the cream-skimming era.

References

Angel, James J., and Simon Z. Wu, Calling the open: price discovery evidence from Nasdaq, NASDAQ working paper 2001-01.

Barclay, Michael, Terrence Hendershott, and Timothy McCormick, 2003, Competition among trading venues: Information and trading on electronic communication networks, *Journal of Finance* 58, 2637-2665.

Barclay, Michael, and Terrence Hendershott, 2003, Price discovery and trading after hours, *Review of Financial Studies*, 16, 1014-1073.

Bessembinder, Hendrik, 2004, Quote-Based Competition and Trade Execution Costs in NYSE-Listed Stocks, *Journal of Financial Economics*, forthcoming.

Bessembinder, Hendrik, 2003, Issues in assessing trade execution costs, *Journal of Financial Markets* 6, 233-257.

Blume, Marshall E., and Michael A. Goldstein, 1992, Displayed and effective spreads by market, *Rodney L. White Center for Financial Research Working Paper* 27-92, University of Pennsylvania.

Blume, Marshall E., and Michael A. Goldstein, 1997, Quotes, order flow, and price discovery, *Journal of Finance* 52, 221-244.

Cao, Charles, Eric Ghysels, and Frank Hatheway, 2000, Price discovery without trading: evidence from the Nasdaq pre-opening, *Journal of Finance* 55, 1339-1365.

Cao, Charles, Oliver Hansch, and Xiaoxin Wang, The informational content of an open limit order book, Working paper, Penn State University.

Clary, I., 2003, Midweek News Update, Securities Industries News, March 31, 2003.

Davies, Ryan, 2003, The Toronto Stock Exchange Preopening Session, *Journal of Financial Markets* 6, 491-516.

Demsetz, Harold, 1968, The cost of transacting, *Quarterly Journal of Economics* 82, 33-53.

Ellis, Katrina, Roni Michaely, and Maureen O'Hara, 2000, The accuracy of trade classification rules: Evidence from Nasdaq, *Journal of Financial and Quantitative Analysis* 35, 529-552.

Harris, Frederick, Thomas McInish, and Robert Wood, 2002, Common factor components vs. information shares: A reply, *Journal of Financial Markets* 5, 341-348.

Hasbrouck, Joel, 1995, One security, many markets: Determining the contributions to price discovery, *Journal of Finance* 50, 1175-1199.

Hendershott, Terrence, and Charles Jones, 2005, Island goes dark: Transparency, fragmentation, and regulation, *Review of Financial Studies*, forthcoming.

Huang, Roger D., 2002, The quality of ECN and Nasdaq market maker quotes, *Journal of Finance* 57, 1285-1319.

Huang, Roger D., and Hans R. Stoll, 1996, Dealer versus auction markets: A paired comparison of execution costs on NASDAQ and the NYSE, *Journal of Financial Economics* 41, 313-357.

Lee, Charles M. C., 1993, Market integration and price execution for NYSE-listed securities, *Journal of Finance* 48, 1009-1038.

Lee, Charles M. C., and Balkrishna Radhakrishna, 2000, Inferring investor behavior: Evidence from TORQ data, *Journal of Financial Markets* 3, 83-111.

Lipson, Mark, 2004, Competition among market centers, Working paper, University of Georgia.

Petersen, Mitchell, and David Fialkowski, 1994, Posted versus effective spreads: Good prices or bad quotes? *Journal of Financial Economics* 35, 269-292.

Peterson, Mark A., and Eric R. Sirri, 2002, Order submission strategy and the curious case of marketable limit orders, *Journal of Financial and Quantitative Analysis* 37, 221-241.

Securities and Exchange Commission, 2000, Testimony concerning preserving and strengthening the national market system for securities in the United States, May 8.

Shkilko, Andriy V., Bonnie F. Van Ness, and Robert A. Van Ness, 2004, Locked and crossed markets on NASDAQ and NYSE, Working paper, University of Mississippi.

Stoll, Hans R., 2000, Friction, *Journal of Finance* 55, 1479-1514.

Table I

Trade Market Shares

Reported are percentage shares of trades, trading and dollar volumes executed on each of the six sample trading venues. We consider only the trades that were completed in the 100 largest NASDAQ-listed common stocks, between 9:30 a.m. and 4 p.m. EST, during the period of April-June 2003. Trades are divided into four categories according to the trade size. *p*-Values indicate the results of testing a hypothesis that percent market shares across trade size categories are identical. Paired *t*-tests indicate whether the differences in market shares between the pairs of trade size categories (considered separately for each trading venue) are statistically significant.

	NASDAQ	AMEX	Chicago	Island	Instinet	Archipelago
Panel A: Market share, % of sample trades						
All trades	51.59	0.02	0.66	17.12	11.30	19.31
100 to 499	50.14^{a,a,a}	0.01^{a,a,a}	0.54^{a,a,a}	17.69^{a,a,a}	12.09^{a,a,a}	19.54^{b,a,a}
500 to 4,999	55.78^{a,a}	0.04^{a,a}	1.09^{a,a,b}	15.42^{a,a}	8.76^{a,a}	18.91^{a,a}
5,000 to 9,999	73.56^{a}	0.06^{a}	1.21^{a}	10.55^{a}	3.83^{a}	10.79^{a}
10,000 or more	87.43	0.25	1.10	4.33	1.73	5.17
p-value	*0.000*	*0.037*	*0.000*	*0.000*	*0.000*	*0.000*
Panel B: Market share, % of sample trading volume						
All trades	62.30	0.08	1.05	13.23	7.72	15.62
100 to 499	48.34^{a,a,a}	0.01^{a,a,a}	0.67^{a,a,a}	18.62^{a,a,a}	12.25^{a,a,a}	20.11^{a,a,a}
500 to 4,999	58.79^{a,a}	0.05$^{-,a}$	1.20^{a,a}	14.15^{a,a}	7.82^{a,a}	17.99^{a,a}
5,000 to 9,999	73.81^{a}	0.06^{a}	1.22^{c}	10.39^{a}	3.74^{a}	10.77^{a}
10,000 or more	91.47	0.29	1.23	2.67	1.12	3.22
p-value	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
Panel C: Market share, % of sample dollar volume						
All trades	60.91	0.09	1.05	12.88	8.58	16.49
100 to 499	47.99^{a,a,a}	0.02^{a,a,a}	0.68^{a,a,a}	18.03^{a,a,a}	12.70^{a,a,a}	20.59^{a,a,a}
500 to 4,999	58.83^{a,a}	0.08^{c,a}	1.20^{a,a}	13.01^{a,a}	8.20^{a,a}	18.68^{a,a}
5,000 to 9,999	77.47^{a}	0.09^{a}	1.28^{a}	7.49^{a}	3.57^{a}	10.10^{a}
10,000 or more	93.86	0.32	1.49	1.41	0.92	2.00
p-value	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*

Superscripts ^{a}, ^{b}, ^{c} indicate statistical significance at, respectively, 0.01, 0.05, 0.10 levels.
Superscript $^{-}$ denotes absence of statistical significance.

Table II

Order Execution on ECNs

Reported are the percentage shares of orders that are executed by the electronic communications networks during the sample period. The aggregate data for stock symbols, execution venues, and order characteristics are obtained from the Dash-5 database compiled in accordance with SEC Rule 11Ac1-5. Orders larger that 9,999 are not reported by the database and therefore are not reported. The results are reported as shares of non-cancelled orders executed on the venue they had been submitted to in the total number of orders of the same type reported as covered by this venue.

	Island	Instinet	Archipelago
Panel A: Executed market orders, % of submitted orders			
Overall	-	17.27	49.58
100-499	-	20.95	52.81
500-4,999	-	17.56	49.98
5,999-9,999	-	16.81	43.91
Panel B: Executed marketable limit orders, % of submitted orders			
Overall	42.59	50.47	52.65
100-499	45.75	57.51	56.26
500-4,999	42.83	49.92	51.61
5,999-9,999	40.25	47.92	54.71

Table III

Execution Costs and Information Shares

Reported are averages of trade execution cost statistics (in cents) computed across sample quotes and trades in the 100 largest NASDAQ-listed common stocks that were completed between 9:30 a.m. and 4 p.m. EST, in April, May and June 2003. The *effective half-spread* is the amount by which the trade price exceeds (for customer buys) or is below (for customer sells) the midpoint of the contemporaneous NBBO quote. The *realized half-spread* is the difference between the trade's price and the quote midpoint ten minutes after the trade. Information shares are calculated using the vector error correction model (VECM) that delivers the lower and upper bounds of the estimated information shares. A trade is recorded as *price improved* when a customer buy (sell) is executed at a price below (above) the best contemporaneous ask (bid) quote. A trade is executed *outside NBBO* when the price is above (below) the NBBO ask (bid) quotes for customer buys (sells). Trades are designated as customer buys and sells according to the algorithm described by Ellis, Michaely, and O'Hara (2000). *p*-Values indicate the results of testing a hypothesis that the results across trading venues are identical. Paired *t*-tests inquire whether the differences between the pairs of exchanges are statistically significant. Asterisk indicates whether the information share bound is significantly different from zero.

	NASDAQ	AMEX	Chicago	Island	Instinet	Archipelago	*p*-value
Panel A: Effective half-spread, cents							
Overall	$1.10^{a,a,a,a,a}$	$1.90^{a,a,a,a}$	$1.04^{a,a,a}$	$0.71^{a,a}$	0.84^{a}	0.93	*0.000*
100 to 499 shares	$1.00^{a,a,a,a,a}$	$2.37^{a,a,a,a}$	$0.95^{a,a,b}$	$0.64^{a,a}$	0.84^{a}	0.92	*0.000*
500 to 4,999 shares	$1.44^{b,a,a,a,a}$	$1.36^{c,a,a,a}$	$1.21^{a,a,a}$	$1.01^{a,b}$	0.82^{a}	0.97	*0.000*
5,000 to 9,999 shares	$0.74^{a,a,a,a,a}$	$1.84^{a,a,a,a}$	$0.67^{b,c,b}$	$0.51^{a,b}$	0.60^{b}	0.56	*0.042*
10,000 or more	$0.68^{a,a,a,a,a}$	$2.02^{b,a,a,a}$	$1.01^{a,a,a}$	$0.52^{a,b}$	0.45^{a}	0.58	*0.000*
Panel B: Realized half-spread, cents							
Overall	$0.79^{a,a,a,a,a}$	$2.47^{a,a,a,a}$	$0.75^{a,a,a}$	$0.46^{a,-}$	0.42^{a}	0.47	*0.000*
100 to 499 shares	$0.61^{a,a,a,a,a}$	$3.00^{a,a,a,a}$	$0.74^{a,a,a}$	$0.36^{a,a}$	0.41^{b}	0.43	*0.000*
500 to 4,999 shares	$1.37^{a,a,a,a,a}$	$1.92^{a,a,a,a}$	$0.76^{b,a,b}$	$0.90^{a,a}$	0.49^{a}	0.63	*0.000*
5,000 to 9,999 shares	$0.61^{a,b,a,a,b}$	$1.57^{a,a,a,a}$	$0.54^{-,b,-}$	$0.31^{-,-}$	0.12^{c}	0.45	*0.142*
10,000 or more	$0.76^{a,a,a,a,a}$	$2.40^{a,a,a,a}$	$0.94^{a,a,a}$	$-0.14^{-,a}$	-0.25^{a}	0.19	*0.000*
Panel C: Information shares, %							
Upper bound	0.56*	0.55*	0.63*	0.27*	0.31*	0.38*	
Lower bound	0.13	0.04	0.09	0.08*	0.18*	0.13*	
Panel D: Executions at prices other than NBBO quotes							
Percent price improved	$24.14^{a,a,a,a,a}$	$15.91^{a,a,a,a}$	$9.11^{a,a,a}$	$54.27^{a,a}$	22.98^{a}	10.67	*0.000*
Percent executed outside NBBO	$7.46^{a,a,c,ba}$	$34.50^{a,a,a,a}$	$10.62^{a,a,a}$	$8.39^{a,a}$	6.07^{b}	5.13	*0.000*

Superscripts ^{a}, ^{b}, ^{c} indicate statistical significance at, respectively, 0.01, 0.05, 0.10 levels.
Superscript $^{-}$ denotes absence of statistical significance.

Table IV
Quote-based Competition Statistics

Reported is the summary of measures of quote competitiveness of the sample market centers. Quotations being investigated were placed in the 100 largest NASDAQ-listed common stocks, between 9:30 a.m. and 4 p.m. EST, in April, May and June 2003. An exchange is *at inside bid and/or ask*, if it participates in formation of one or both sides of the NBBO. An exchange is at *both inside bid and ask*, when it participated in formation of both sides of the NBBO. An exchange is *alone at inside ask or bid*, if it single-handedly forms either side of the NBBO. An exchange is *alone at both bid and ask*, if it forms the NBBO by itself. In Panel A, results are weighted by the amount of time between two consecutive quotations. In Panel B, results are weighted by the number of trades executed while a quotation is in effect. A quotation has *time priority*, if it is alone at the inside, or has been placed earlier that all other inside quotes. A(n) bid (ask) *quote matches the NBBO* at time t, if the quote is posted at time t, appears equal to the bid (ask) inside quote, and the inside quote is equal to the inside quote at time $t-1$. A(n) bid (ask) *quote improves NBBO* at time t, if the quote is posted at time t, appears equal to the bid (ask) inside quote, and the bid (ask) inside quote is higher (lower) that the bid (ask) inside quote at time $t-1$. A(n) bid (ask) *quote is left alone at NBBO* at time t, if the quote is posted at time $t-n$, where $n > 0$, the quote appears equal to the bid (ask) inside quote, and the bid (ask) inside quote is lower (higher) than the bid (ask) inside quote at time $t-1$; or the bid (ask) inside quote is equal to the bid (ask) inside quote at time $t-1$, but the quote appears alone at NBBO starting at time t. p-Values indicate the results of testing a hypothesis that the measures across different trading venues are identical.

	NASDAQ	AMEX	Chicago	Island	Instinet	Archipelago	*p*-value
Panel A: Time-weighted averages, % of trading time							
At inside bid and/or ask	89.92	30.90	4.21	52.51	85.25	81.86	*0.000*
At both inside bid and ask	50.24	22.72	0.54	13.09	34.18	33.64	*0.000*
Alone at inside ask	11.18	1.90	0.65	2.83	7.48	6.58	*0.000*
Alone at inside bid	11.91	2.00	0.63	2.80	7.01	5.57	*0.000*
Alone at both bid and ask	0.97	0.05	0.00	0.08	0.43	0.38	*0.000*
Panel B: Trade-weighted averages, % of sample trades							
At inside bid and/or ask	86.52	30.74	3.08	54.17	80.92	71.85	*0.000*
At both inside bid and ask	50.31	15.24	0.07	13.40	31.93	28.98	*0.000*
Alone at inside ask	18.20	5.21	0.35	5.50	12.70	9.99	*0.000*
Alone at inside bid	18.81	5.10	0.28	5.65	12.43	8.68	*0.000*
Alone at both bid and ask	3.57	0.34	0.00	0.23	1.16	1.02	*0.000*
Panel C: Time priority, % of quotes posted by a venue							
Time priority at bid	50.38	14.20	1.45	21.65	37.74	37.09	*0.000*
Time priority at ask	52.56	14.44	1.29	21.85	36.96	36.37	*0.000*
Panel D: NBBO matching and altering, % of quotes posted by a venue							
Quote matches NBBO	5.85	6.85	4.09	9.91	11.61	5.61	*0.000*
Quote improves NBBO	2.72	3.81	2.16	2.13	3.06	2.23	*0.000*
Quote is left alone at NBBO	3.41	10.49	21.88	5.10	3.73	1.99	*0.000*
Panel E: Quote matching and altering, % of similar cases							
Quote matches NBBO	29.97	4.85	0.04	17.35	35.24	42.53	*0.000*
Quote improves NBBO	42.71	8.25	0.07	11.42	28.43	51.83	*0.000*
Quote is left alone at NBBO	40.70	17.28	0.51	20.79	26.38	35.03	*0.000*

Table V

Percentage of Volume Conditional on Quotes

Reported are the shares of trading volume executed by each exchange during four different states of quote competitiveness. As previously, we consider only the quotes and trades that were posted and completed in the 100 largest NASDAQ-listed common stocks, between 9:30 a.m. and 4 p.m. EST, during the period of April-June 2003. We differentiate among four stages of quote competitiveness: *at both inside bid and ask* includes trades completed while an exchange was quoting at the both sides of NBBO; *at best ask (bid) only* includes trades completed when an exchange was quoting just the inside ask (bid); *at neither best bid, nor ask* includes the trades completed while an exchange is not quote-competitive. The results are divided into panels according to the trade size. Paired *t*-tests inquire whether the differences between the shares of *at best ask only* and *at best bid only* are statistically significant.

	NASDAQ	AMEX	Chicago	Island	Instinet	Archipelago
Panel A: All trades						
At both inside bid and ask	75.59	27.28	1.06	52.27	72.55	65.12
At best ask only	10.42	2.16	0.34	4.26	8.02	8.52
At best bid only	9.94	2.06	0.27	4.24	6.91	8.03
At neither best bid, nor ask	4.05	68.49	98.33	39.23	12.51	18.32
Panel B: 100 to 499 shares						
At both inside bid and ask	65.42	52.69	0.69	46.39	63.18	62.14
At best ask only	14.34	6.47	0.60	5.58	10.10	10.95
At best bid only	13.97	6.50	0.49	5.63	9.11	10.46
At neither best bid, nor ask	6.27	34.34	98.22	42.40	17.61	16.45
Panel C: 500 to 4,999 shares						
At both inside bid and ask	76.99	40.12	1.32	37.08	80.21	56.26
At best ask only	10.06	4.28	0.36	3.48	6.23	7.03
At best bid only	9.41	3.99	0.32	3.44	5.20	6.57
At neither best bid, nor ask	3.54	51.60	97.99	56.00	8.36	30.14
Panel D: 5,000 to 9,999 shares						
At both inside bid and ask	79.61	45.44	1.45	81.17	83.57	78.15
At best ask only	9.11	4.05	0.21	2.23	6.40	7.60
At best bid only	8.27	2.04	0.11	2.03	4.00	6.85
At neither best bid, nor ask	3.02	48.47	98.23	14.57	6.03	7.41
Panel E: 10,000 or more shares						
At both inside bid and ask	81.54	17.51	0.63	85.59	82.38	84.33
At best ask only	7.76	0.61	0.11	1.66	6.63	5.45
At best bid only	7.55	0.71	0.02	1.46	3.38	4.84
At neither best bid, nor ask	3.14	81.17	99.23	11.29	7.61	5.38

Superscripts [a], [b], [c] indicate statistical significance at, respectively, 0.01, 0.05, 0.10 levels.
Superscript [-] denotes absence of statistical significance.

Table VI

Locked and Crossed Markets

The table examines the shares of zero and negative NBBO spreads in quotations placed between 9:30 a.m. and 4:00 p.m., for the 100 largest NASDAQ-listed stocks, in June 2003. A zero NBBO spread occurs when an inside ask quote equals to the inside bid quote. When a zero NBBO spread is in effect, the market is considered to be locked. A negative NBBO spread occurs when an inside ask quote is lower that a contemporaneous inside bid quote. When a negative NBBO spread is in effect, the market is considered to be crossed. The results are tested for consistency, and *p*-values indicate the results of testing a hypothesis that the shares of negative, zero, and non-positive spreads are identical.

Panel A; All Months

Month	Negative spreads, %	Zero spreads, %	Total non-positive spreads, %
April	2.13	11.47	13.60
May	2.28	12.36	14.64
June	2.24	12.43	14.67

Panel B: June

Date	Negative spreads, %	Zero spreads, %	Total non-positive spreads, %
2-Jun	2.60	13.74	16.34
3-Jun	1.40	13.07	14.47
4-Jun	1.27	13.56	14.83
5-Jun	2.16	12.49	14.65
6-Jun	6.75	12.99	19.75
9-Jun	1.67	13.72	15.39
10-Jun	1.64	13.63	15.27
11-Jun	1.80	13.48	15.28
12-Jun	1.74	12.13	13.88
13-Jun	3.21	12.33	15.54
16-Jun	1.20	12.10	13.31
17-Jun	2.00	13.09	15.09
18-Jun	3.75	13.14	16.88
19-Jun	3.72	12.57	16.29
20-Jun	2.03	10.87	12.90
23-Jun	2.25	11.33	13.59
24-Jun	1.63	11.09	12.72
25-Jun	2.02	10.58	12.59
26-Jun	1.33	11.51	12.84
27-Jun	1.59	11.87	13.46
30-Jun	1.29	11.81	13.10
Mean	2.24	12.43	14.67
p-value	*0.40*	*0.67*	*0.54*

Table VII
Posting of Quotes During Locked and Crossed Markets

Reported is the summary of measures of quote competitiveness during the periods of non-positive NBBO spreads. Quotations being investigated were placed in the 100 largest NASDAQ-listed common stocks, between 9:30 a.m. and 4 p.m. EST, in June 2003. An exchange is *at inside bid and/or ask*, if it participates in formation of one or both sides of the NBBO. An exchange is at *both inside bid and ask*, when it participated in formation of both sides of the NBBO. An exchange is *alone at inside ask or bid*, if it single-handedly forms either side of the NBBO. An exchange is *alone at both bid and ask*, if it forms the NBBO by itself. Panel A, presents the results for the locked market instances (zero NBBO spreads); while Panel B presents the results for the crossed market instances (negative NBBO spreads). Results are weighted by the amount of time between two consecutive quotations.

Panel A: Time-weighted averages for zero spread instances, % of trading time						
	NASDAQ	AMEX	Chicago	Island	Instinet	Archipelago
At inside bid and/or ask	7.53	3.45	0.11	4.41	7.42	5.74
At both inside bid and ask	0.00	0.00	0.00	0.00	0.28	0.01
Alone at inside ask	1.80	0.49	0.02	0.92	1.99	1.66
Alone at inside bid	2.05	0.52	0.03	0.96	2.15	0.88
Alone at both bid and ask	0.00	0.00	0.00	0.00	0.02	0.00
Panel B: Time-weighted averages for negative spread instances, % of trading time						
At inside bid and/or ask	0.98	1.01	2.57	0.49	1.02	0.87
At both inside bid and ask	0.00	0.00	0.00	0.00	0.06	0.00
Alone at inside ask	0.17	0.40	0.12	0.10	0.29	0.17
Alone at inside bid	0.23	0.39	0.59	0.10	0.23	0.15
Alone at both bid and ask	0.00	0.00	0.00	0.00	0.03	0.00

Table VIII

Determinants of Trade Routing

Reported are the results of a multinomial logistic regression for an unordered response, with the dependent variable equal to 0, if an exchange of execution is NASDAQ, and is equal to 1, 2, 3, 4, and 5 for, respectively AMEX, Chicago, Island, Instinet, and Archipelago. Analysis considers customer buy trades that occurred from 9:30 a.m. to 4 p.m., EST, on five consecutive dates (June 2nd through June 6th, 2003). The regressors are: dummy variables for each exchange indicating that the venue is at the NBBO (6 dummies for best ask and 6 dummies for best bid), inter-market order imbalance, number of trades in the preceding 10 minutes, volume (in hundreds of shares), and a dummy variable indicating that the inter-exchange market is crossed or locked. The probabilities are modeled according to the Newton-Raphson maximum likelihood algorithm. The model is adjusted for fixed effects and non-spherical errors by allowing the procedure to assume clustering across stocks and to use the Huber-White estimator. Regression coefficients are presented only for the intercept. Results for the regressor are represented by the marginal effects, where the superscripts indicate the outcome of significance testing.

	AMEX	Chicago	Island	Instinet	Archipelago
Intercept	-9.4003	-5.3641	-1.4179	-1.6507	-1.2198
At best ask:					
NASDAQ	0.0000	-0.0001*	-0.018***	-0.0090***	-0.0302***
AMEX	0.0000*	0.0003	0.0060	-0.0052	0.0013
Chicago	0.0000	0.0099***	-0.0013	-0.0054	-0.0030
Island	0.0000	0.0005***	0.0838***	-0.0077	0.0040**
Instinet	0.0000***	0.0004***	-0.0007*	0.0276***	0.0268***
Archipelago	0.0000***	0.0003***	0.0033***	-0.0073	0.1017***
At best bid:					
NASDAQ	0.0000**	0.0002	-0.0111***	-0.0058***	0.0008
AMEX	0.0000***	0.0009**	-0.0078	0.0078	-0.0077
Chicago	0.0000	0.0025***	-0.0047	0.0008	0.0169
Island	0.0000	0.0002*	0.0348***	-0.0010	0.0158
Instinet	0.0000	0.0001	-0.0113***	0.0033	0.0101
Archipelago	0.0000	-0.0002	-0.0121***	0.002**	0.0323***
Order imbalance	0.0000***	0.0004***	0.0108***	0.0073***	0.0099***
# of trades in preceding 10 minutes	0.0000	0.0001***	0.0029***	0.0023***	0.0111***
Trade size, 100 shares	0.0000	0.0001**	-0.0181***	-0.0173***	-0.0070***
Non-positive spread	0.0000	-0.0002	0.0607***	0.0008	-0.0194

*** Significant at 0.01 level
** Significant at 0.05 level
* Significant at 0.10 level