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Competition in the market for NASDAQ securities ☆

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Abstract

The study investigates competition in the market for NASDAQ stocks during a recent period in US equity markets history when three major Electronic Communication Networks (ECNs)—Archipelago, Island, and Instinet—are identifiable in the Trade and Quote (TAQ) database. We show that the ECNs compete with NASDAQ's SuperMontage on the basis of quotes, execution times, and costs. The three ECNs differ due to uniqueness of their limit order books, cost schedules, and heterogeneity of trading clienteles. Informed traders are shown to prefer venues with sufficient liquidity over those that guarantee anonymity of executions. Despite high levels of segmentation, uneven regulation, and controversial order attraction practices, quote competitiveness is found to increase the probability of executions on all four venues.

0. Introduction

This study evaluates the market for NASDAQ stocks in the second quarter of 2003—a period marked by intense competition between NASDAQ's SuperMontage and three

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Electronic Communication Networks (ECNs): Archipelago, Instinet, and Island. During a period from April 2003 until early 2004, these three ECNs were capturing about 40% of trading volume in the 100 most active NASDAQ stocks. This period of increased fragmentation was followed by a wave of consolidation that began with Instinet and Island merging their books and seems to have reached its peak with the recent NASDAQ/Instinet and NYSE/Archipelago mergers. A period of intense competition may be again happening on a more global scale, given the cross-border merger between the NYSE and Euronext as well as NASDAQ's continuing attempts to acquire the London Stock Exchange the OMX, and other markets. In the national market, competitive pressures seem to be on the rise again, as new powerful ECNs (e.g., BATS and DirectEdge) have spawned. Therefore, an investigation of the segmented market circa 2003 may improve our understanding of competitive pressures in a decentralized and unevenly regulated marketplace.

The four venues this study investigates are characterized by significant differences in execution costs, times, order attraction strategies, and involvement in price discovery. The ECNs provide cheaper and faster executions, anonymity, fee rebates, and use sub-pennies to attract order flow. In the 20 to 40 most active NASDAQ stocks, ECN liquidity is substantial. However, in the stocks other than the most liquid, insufficient ECN liquidity induces informed traders to execute via SuperMontage. SuperMontage provides the most stable quotes and maintains them during periods of high volatility when the ECN quotations are often withdrawn. The ECNs actively execute trades during periods when their quotes are not the best; however, quotes remain a significant order attraction tool.

We expand upon the findings of Barclay, Hendershott, and McCormick (2003) who assume that the primary difference among markets lies in the classification into market makers and ECNs. We contribute to the literature by showing that although certain characteristics apply to ECNs as a group, a number of disparities arise from the factors related to each market individually. For instance, although ECN executions are cheaper than those on SuperMontage, there is a substantial variation across ECNs, as Instinet trades are cheaper than those on Island and Archipelago.

Another contribution this study makes to the literature is on the tradeoff between anonymity and sufficient liquidity. Several theoretical models (e.g., Röell, 1990; Fishman and Longstaff, 1992; Forster and George, 1992) suggest that anonymous trading systems attract informed traders. Barclay, Hendershott, and McCormick (2003) empirically confirm these suggestions by showing that volume on anonymous venues increases with informational asymmetries, and that anonymous trades have large permanent price impacts. Huang (2002) shows that ECNs post informative quotes and often lead price discovery. He attributes this finding to the anonymity of the venues. An opposing argument is developed in a recent study by Reiss and Werner (2005). These authors show that uninformed orders in the London inter-dealer market tend to gravitate towards anonymous trading systems, whereas informed orders are mostly executed on the non-anonymous public market. Reiss and Werner explain that when informational asymmetry is high, traders withdraw liquidity from anonymous venues, trying to avoid excessive adverse selection. Consequently, informed traders are forced to route their orders to the non-anonymous public market.

Along the lines of the Reiss and Werner argument, we suggest that traders with time-sensitive information will gravitate towards venues with liquidity that is sufficient to ensure fast executions. In other words, when liquidity on the anonymous venues is low, these traders will forgo an option to transact anonymously for an option to transact quickly.

Our investigation of price discovery and price impacts confirms this notion and shows that the distinction between the ECNs and market makers documented earlier in the literature (e.g., Huang, 2002; Barclay, Hendershott, and McCormick, 2003) becomes blurred in an environment of intense competition and fragmentation. In particular, division of the sample into trading activity quintiles allows us to show that the majority of price discovery in less active stocks takes place on SuperMontage, whereas informed trading in liquid stocks tends to occur on the anonymous ECNs. Conversely, when the ECNs display sufficient transient liquidity by being at the National Best Bid and Offer (NBBO) and quoting significant depths, they attract more informed order flow.

Our results imply that the primary market for NASDAQ stocks is not as quote-competitive as that for the NYSE-listed stocks. SuperMontage participates in the best quote on at least one side of the market about 90% of the time, which is more than any of the ECNs, but less than the 99% of the time as found by Blume and Goldstein (1997) and Bessembinder (2003) for the NYSE. Furthermore, we show that SuperMontage matches both sides of the NBBO only about half the time and is alone quoting the best bid or the best ask only 11% of the time, while the results in Bessembinder (2003) indicate that the NYSE matches both sides of the quote almost 90% of the time. Despite a relatively low degree of competitiveness, SuperMontage quotes often have price priority and maintain the NBBO during periods of increased volatility. The quotes from the three ECNs are competitive, but lack longevity and stability.

The three ECNs execute substantial shares of trades when they do not maintain the best quotes. We attribute this phenomenon to hidden liquidity, as ECN traders are allowed to conceal or reserve parts of submitted orders. Trades executed on venues with inferior quotes (especially those on SuperMontage) suffer from lower execution quality. Despite such trades are relatively common, quote competitiveness is shown to remain an important determinant of the probability of trade executions.

The remainder of the paper is organized as follows. Section 1 describes the four sample venues and provides a snapshot of the competitive environment circa 2003. Section 2 describes the sample and addresses several issues related to fragmentation. Section 3 analyzes trading costs and times, while Section 4 discusses price discovery, anonymity, and liquidity. Section 5 examines quote competition and the relationship between quotes and trade executions. Section 6 analyzes the determinants of trade executions, and Section 7 concludes.

1. Identification of trading venues and the competitive environment

During the investigated period, trades and quotes for NASDAQ stocks are reported via six venues: NASDAQ's SuperMontage, the American Stock Exchange (AMEX), the Cincinnati Stock Exchange (CSE), the NASD Alternative Display Facility (ADF), the Chicago Stock Exchange (CHX), and the Pacific Exchange (PE).[1] In 2002–2003, as a result of competition on fees between the CSE and SuperMontage, introduction of the ADF, and Archipelago's purchase of the equities trading branch of the PE, composition of order flow underwent substantial changes, allowing us to identify quotes and trades of the three largest ECNs: Island, Instinet, and Archipelago.

In March 2002, Island switched reporting of its trades to the Cincinnati Stock Exchange, in part to avoid NASD regulatory surcharges on trades reported through NASDAQ and

[1]The Cincinnati Stock Exchange changed its name to the National Stock Exchange on November 7, 2003.

to have the opportunity to share in CSE's data (tape) revenue.[2] Routing of the quotes through the CSE followed in October 2002. During our sample period, about 99% of trades and quotes reported through Cincinnati are coming from Island.[3]

In October 2002, the NASD introduced the ADF—a quotation collection, trade comparison, and trade reporting resource mandated by the US Securities and Exchange Commission (SEC) as an alternative to SuperMontage. During the time period of this study, Instinet reported trades and quotes through the ADF and overwhelmingly dominated the venue.[4] In February 2004, as a result of Instinet and Island merging their books, Instinet ceased reporting via the ADF, causing the activity on the venue to drop by 99%.[5] In this study, all trades and quotes reported to the ADF during our sample period are ascribed to Instinet.

In 2000, Archipelago partnered with the Pacific Exchange, Inc., and in early 2003, the exchange began disseminating Archipelago's trades and quotes in NASDAQ stocks. The migration of NASDAQ stocks to the Pacific Exchange started in February 2003 and was completed in early April 2003, making Archipelago (ArcaEx) the first fully open, electronic exchange to trade all NYSE, AMEX, PE, and NASDAQ securities.

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 securities. The Chicago Stock Exchange employs a competing specialist system, somewhat similar to the competing dealer system of NASDAQ. Specialists on AMEX also post quotes and execute trades in NASDAQ stocks. Although Chicago and AMEX participate in executions during our sample period, their combined share of volume is relatively trivial (only about 1.13%). We therefore do not include these two market centers in our analysis and instead focus on competition among the three major ECNs and SuperMontage. The remainder of this section describes competitive pressures among these four venues during the period of this study.

Instinet and Island. Following the merger in September 2002, Instinet and Island faced several important issues. Firstly, the management needed to develop a competitive strategy against SuperMontage and Archipelago that were cutting into Instinet and Island's revenues. Hoping to regain lost business, the two ECNs changed their fee structures. In addition, while historically Instinet was predominantly an institutional venue whereas Island catered to day traders, both started marketing their services to multiple clienteles. As the merger of the ECNs' books was not completed until February 2004, this study considers them as two separate venues.

Another matter of concern for Instinet and Island had to do with NASDAQ's attempts to get the ECNs to join SuperMontage. In 2003, when the market experienced an unprecedented increase in locked and crossed NBBOs, NASDAQ accused Island and Instinet of encouraging customers to lock and cross inside quotes. The ECNs did in fact provide such incentives by partially rebating access fees to the customers who submitted

[2]Tape revenue sharing allowed Island to offer the following: for every $1 received by CSE due to an Island trade, Island would provide $0.25 to the buyer and $0.25 to the seller. Island kept $0.25, and the CSE kept the remaining $0.25.

[3]We thank Bonnie Greenberg, Director of Corporate Communications at the Cincinnati Stock Exchange, for this information.

[4]While virtually all ADF activity during the sample period can be attributed to Instinet, not all Instinet trades were routed to the ADF, as some of them were reported through SuperMontage.

[5]We thank Tim McCormick, formerly of NASDAQ and currently at the SEC, for this information.

liquidity-providing orders instead of market orders (e.g., Shkilko, Van Ness, and Van Ness, 2007).[6] NASDAQ officials reportedly asked the SEC to make the ECNs stop originating non-positive NBBOs, "possibly [by] requiring the two huge ECNs to join the SuperMontage."[7] Island and Instinet, on the other hand, argued that locks and crosses benefited traders, as they were merely periods of zero costs. The SEC, for the most part, overlooked NASDAQ's pleas and only addressed the issue of locks and crosses in the recently approved Regulation NMS. The regulation advises market centers to reasonably avoid locking and crossing inter-market quotes.

Archipelago. In 2002, Archipelago bought two competing ECNs—REDIbook, which was about the same size as Archipelago, and a much smaller ECN called GlobeNet—and significantly increased the size of its business. Despite rapid growth, Archipelago claimed that it had the most efficient and economical structure as compared to main competitors. In 2003, the ECN took an unprecedented step and purchased the equities trading branch of the Pacific Exchange, becoming a stock exchange for listed and NASDAQ stocks. By acquiring exchange status, Archipelago managed to avoid NASD regulation governing OTC trading, such as, for instance, the bid rule that restricted short selling. In addition to a lighter regulatory burden, exchange status allowed Archipelago to save on clearing fees that it had had to pay while in the ECN status and to benefit from tape revenues. Archipelago partly passed the abovementioned savings to its subscribers by canceling clearing fees and lowering trading costs.

Low costs were not the only benefit of trading through Archipelago. Archipelago's smart routing algorithms were sophisticated and provided traders with additional security by sending orders to other markets if Archipelago's own liquidity was insufficient to guarantee best executions. Other major ECNs did not provide such a service, forcing market orders that were not immediately executable to post as limit orders. Although praised by the management, Archipelago's smart routing algorithm was, at times, criticized by traders for slowing executions. For instance, in absence of sufficient liquidity on Archipelago, the smart router would send an order out, for example, to SuperMontage, but if the order remained unfilled after a certain time (usually from 30 to 55 seconds), it would be cancelled and resubmitted to the venue with then the best quotes, often, again, SuperMontage.

Having freed itself from NASDAQ regulation and having acquired two sizeable competitors, Archipelago was still facing significant rivalry—both in the marketplace and in the courtroom—from Instinet and Island. In 2003, Archipelago accused Island and Instinet of discriminatory pricing policies and filed arbitration with the NASD. The arbitration was, in fact, a counter-claim in response to Island's allegations of Archipelago's not fully paying the fees for accessing Island's quotes. The source of the argument was in Island's two-tiered pricing structure. Island charged standard broker dealers (such as Merrill Lynch and Morgan Stanley) 19 cents per 100 shares accessed, while Archipelago was charged 50 cents.[8] Instinet had a similar two-tiered structure with 40 cents charged to

[6]Part of the access fee paid by the liquidity-removing side was used to fund the rebates. The practice eventually led to an escalation of access fees, driven by the need to pay increasingly higher rebates. Finally, a relatively stable industry equilibrium emerged, with access fees of 30 cents per 100 shares and rebates to liquidity providers of about 20 cents per 100 shares.

[7]"SEC Hears More on Locked Markets", by Gregory Bresiger, Traders Magazine, February 2003.

[8]"An ECN plot to corner market? Archipelago accuses duo of unfair practices," by Peter Chapman, Traders Magazine, May 2003.

standard broker dealers and 60 cents to Archipelago and other ECNs. Archipelago officials claimed that the two-tiered structure only applied to the ECNs that represented a competitive threat to Instinet and Island, and that smaller ECNs were allowed to pay lower fees.

SuperMontage. In response to the competitive pressures from the ECNs, NASDAQ unveiled SuperMontage in September 2002 to replace two trading systems, SuperSoes and SelectNet. At the time of our study, SuperMontage combined trades and quotes of the NASDAQ dealers, former SuperSoes and SOES systems, and multiple small ECNs (e.g., Attain and Brut) that chose to participate in the system.[9] As a result, while the trades and quotes coming from the Cincinnati Stock Exchange, the ADF, and the Pacific Exchange were virtually exclusively coming from ECNs, the trades and quotes reported by SuperMontage were a combination of dealer and ECN quotes. Thus, although much of the trades and quotes reported by SuperMontage at the time were from NASDAQ dealers, it is appropriate to consider SuperMontage a mixed system.

In terms of traders' interaction with dealer quotes, at the time of our study, SuperMontage was largely an heir to its predecessors, SuperSoes and SelectNet.[10] Prior to the creation of SuperSoes in July 2001, NASDAQ had two major electronic systems, SelectNet and the Small Order Execution System (SOES). SOES was an automated execution system primarily focused on small orders (up to 1,000 shares) from individuals; market makers were barred from using it. To trade with each other within the NASDAQ framework, market makers relied on SelectNet and the telephone.[11] SelectNet was an electronic, screen-based order routing system through which market makers or order entry firms could send a message to another market maker or ECN regarding a particular stock, specifying a price and the number of shares that they wished to trade. The recipient of the e-mail then had a fixed amount of time to respond. Although the recipient was expected to honor requests for their quoted price and size, the recipient could decline the entire trade or respond with a counteroffer.

SelectNet was an order delivery service, not an order execution system. As a result, receiving negotiations for orders through SelectNet was a slower, and arguably less risky, way to trade than automatic execution systems such as SuperSoes and SuperMontage that followed later.[12] To a certain extent, market makers used existing ECNs when looking for automatic executions, but could not use NASDAQ systems to access these ECNs automatically.

SuperSoes began in July 2001 as an enhancement to SOES to create a more encompassing automatic execution system. Unlike its predecessor, SuperSoes was not restricted to small orders or to retail investors and could be used by market makers to access quotes of other market makers. SuperSoes had a few flaws. First, although it could access market maker quotes, it did not consolidate orders into a central location. Therefore, it was still more of an automatic execution routing mechanism; the orders were still retained on the market makers' books. Second, ECNs, concerned about double

[9]Although initially small, Brut grew significantly over time. By the time that NASDAQ acquired Brut in 2004, Brut had increased to be as large as SuperMontage.

[10]We thank Frank Hatheway, Chief Economist of NASDAQ, and Jeffrey Smith, NASDAQ Director of Research, for their assistance with the following information and timeline.

[11]Market makers also made use of external ECNs, such as Instinet, for inter-dealer trades.

[12]As Huang (2002) and Barclay, Hendershott, and McCormick (2003) analyzed periods prior to the creation of either SuperSoes or SuperMontage, results in this paper may differ from those reported previously.

execution risk, would not accept "execution delivery" from SuperSoes. Instead, ECNs demanded "order delivery" by SelectNet so that they could verify that the shares were still available before accepting the order. As a result, NASDAQ market makers could not "hit" ECN quotes automatically, even though their own quotes were automatically accessible to everyone through SuperSoes. SelectNet continued to be actively used by market makers attempting to access ECN quotes.

SuperSoes and SelectNet were ultimately supplanted by SuperMontage in September 2002. SuperMontage contained the functionalities of both SuperSoes and SelectNet. It could both automatically execute an order against a market maker bid (as did SuperSoes) and deliver an order to buy or sell to an ECN (similar to SelectNet) provided that the ECN participated in SuperMontage. Archipelago, Island, and Instinet, however, chose not to participate and therefore could not be reached through SuperMontage.[13] SuperMontage could also access both pools of liquidity (market maker and participating ECN quotes) simultaneously for larger orders. In addition, unlike SuperSoes, SuperMontage created the potential for a true consolidated limit order book for NASDAQ stocks, where orders previously held by market makers on their own internal books were now consolidated in one place. SuperMontage quote display resembled those of the ECNs, but initially was not fully anonymous.[14] Reluctant to expose their quotes, NASDAQ dealers were posting the best quotes very selectively, often letting the SuperMontage ECNs establish the inside. In 2004, SuperMontage quotations became fully anonymous.

During our sample period, liquidity on Island, Instinet, and Archipelago was consistently high, benefiting traders with instantaneous fills. In the most active stocks, liquidity was often better than displayed, as Instinet and Island allowed posting orders without revealing their true size (a similar feature was also available on SuperMontage.) Traders expressed more and more disappointment with the dealer/specialist venues and were increasingly switching to the ECNs. In a survey conducted by Greenwich Associates, two thirds of buy side traders polled said they did not think that NASDAQ dealers added value in trading liquid stocks.[15] The respondents indicated that ECNs were not only providing better executions, better transparency, and lack of front-running, but could also guarantee anonymity—a feature SuperMontage was unable to offer. The SEC eventually approved NASDAQ's request to allow post-trade anonymity by the end of 2003, after our sample period. SuperMontage also attempted to introduce rebates of data services to its customers. The practice was at the time widespread on the regional exchanges. In fact, the Cincinnati Stock Exchange attracted Island by offering to rebate 75% of the cost of data services. After NASDAQ initiated rebates of 80% of its fees, the SEC asked the markets to put an end to the practice.

[13]Originally, these non-participating ECNs could not be reached at all through SuperMontage. However, by early 2005, NASDAQ was able to provide SuperMontage users the routing of orders out to Archipelago and INET through the broker-dealer Brut, which NASDAQ acquired in September 2004. A SuperMontage order that needed to be routed to Archipelago or INET was automatically transferred to the Brut broker-dealer, which was a subscriber to both Archipelago and INET.

[14]SuperMontage quotes had the option of being anonymous or attributed by the market participant's ID (MPID). Anonymous liquidity was displayed under the MPID "SIZE". An early problem with the anonymity feature, however, was that after the trade, the identity of the counterparty was revealed in the trade confirmation. It wasn't until 2004 that SuperMontage provided full pre- and post-trade anonymity.

[15]"At deadline," Traders Magazine, November 2003. Interestingly, according to NASDAQ officials, much of the liquidity on the ECNs was provided by NASDAQ dealers using the ECNs as alternative venues to work orders they received.

Decreased trader confidence in SuperMontage was accompanied by substantial losses of revenue by NASDAQ Transaction Services after the ECNs moved their trade reporting to the regional exchanges and the ADF. To regain some of the lost revenue, SuperMontage introduced a new rule that allowed non-dealer traders to submit non-marketable limit orders to the system, a feature previously available only to dealers.

In addition to trying to regain order flow lost to the ADF and the regional exchanges, NASDAQ faced problems caused by incomplete regulation. One of these was related to the ECNs' ability to display subpenny quotes. Smart routing systems recognized subpenny quotes as best quotes and sent orders to the ECNs, although the price advantage on the latter was not always accompanied with sufficient depth. Later in 2003, NASDAQ filed a petition with the SEC to conduct subpenny trading. The SEC addressed the issue in the Regulation NMS, in which it recommended markets to put an end to subpennies in stocks with prices greater than one dollar. The ECNs eliminated subpenny pricing in March 2004.

In summary, our sample period is characterized by strong competition between NASDAQ's SuperMontage and the three largest ECNs. Despite NASDAQ's efforts to level the playfield, uneven regulatory burden and inherent market structure differences allowed the ECNs to become increasingly competitive and to segment the market. The remainder of the paper investigates market quality and quote competition between the four venues to determine to what extent the aforementioned factors affected the trading public.

2. Sample

This study uses a sample of 100 stocks that comprise the NASDAQ-100 market index in the second quarter of 2003. The data for the study are extracted from (i) the Trade and Quote (TAQ) database, (ii) the Dash 5 database (reported in accordance with the SEC Rule 11Ac1-5), and (iii) CRSP data on market capitalization. Quotes and trades are matched to the same second. The sample is restricted to include only quotes and trades that occur during regular trading hours (9:30 a.m. to 4:00 p.m.). Additionally, we apply filters to remove observations that could be subject to errors. In particular, trades and quotes are omitted, if TAQ indicates that they are out of time sequence or involve an error or a correction. Quotes are omitted, if the ask and/or the bid are equal to (are less than) zero, or if the ask is equal to (is less than) the bid posted by the sane venue. Finally, trades are omitted if price and/or volume are equal to (are less than) zero.

Table 1 displays results on trading activity and distribution of volume among the four market centers. Panel A contains shares of trades divided into trade size categories, Panel B contains similarly divided shares of trading volume; and Panel C displays shares of trading volume divided into trading activity quintiles. The data reveal that SuperMontage executes about 52% of trades in the sample. The three ECNs—Instinet, Island, and Archipelago—complete, respectively, about 11%, 17%, and just under 20% of trades.[16]

We divide the sample into four trade size groups: (i) small trades (less than 500 shares); (ii) trades from 500 to 4,999 shares; (iii) trades from 5,000 to 9,999 shares; and (iv) large trades—those exceeding 10,000 shares. The vast majority, 88.62%, of large trades is reported via SuperMontage, although the venue's share of small trades is only 50.41% (Table 1, Panel A). Conversely, the ECNs exhibit decreasing trade share patterns from

[16]As mentioned earlier, we omit quotes and trades from AMEX and the Chicago Stock Exchange and do not include them in computations of total numbers of quotes and trades.

Table 1
Trade market shares

Reported are percentage shares of trades and trading volume. Results contain trades that are reported in TAQ between 9:30 a.m. and 4 p.m., during April–June 2003. Panel A contains market shares of trades aggregated into trade size categories; Panels B and C present shares of trading volume aggregated by, respectively, trade sizes and activity quintiles (with quintile 1 being the most active and quintile 5—the least active). *p*-Values are for the null hypotheses that market shares across trading venues, trade sizes, and activity quintiles are identical. The *p*-values are calculated across stock-market and stock-market-trade size observations

	SuperMontage	Arca	Island	Instinet	*p*-Value
Panel A: Share of sample trades by trade size (%)					
All trades	51.94	19.44	17.24	11.38	0.000
100–499	50.41	19.65	17.79	12.16	0.000
500–4,999	56.42	19.13	15.60	8.86	0.000
5,000–9,999	74.51	10.93	10.69	3.88	0.000
10,000 or more	88.62	5.24	4.39	1.75	0.000
p-Value	0.000	0.000	0.000	0.000	
Panel B: Share of trading volume by trade size (%)					
All trades	63.01	15.80	13.38	7.81	0.000
100–499	48.67	20.25	18.75	12.33	0.000
500–4,999	59.53	18.22	14.33	7.92	0.000
5,000–9,999	74.77	10.91	10.53	3.79	0.000
10,000 or more	92.88	3.27	2.71	1.14	0.000
p-Value	0.000	0.000	0.000	0.000	
Panel C: Share of trading volume by activity quintiles (%)					
Q1 (most active)	63.03	15.52	13.91	7.54	0.000
Q2	62.04	16.51	12.81	8.64	0.000
Q3	64.61	15.81	11.83	7.75	0.000
Q4	63.57	16.21	12.36	7.86	0.000
Q5 (least active)	62.76	16.51	12.55	8.18	0.000
p-Value	0.073	0.107	0.086	0.159	

small to large trade sizes. Similar results are found for shares of sample volume (Panel B). ECN volume shares are lower than their shares of trades, consistent with Barclay, Hendershott, and McCormick (2003) who show that ECN trades are smaller as compared to the market maker trades.

Although the stocks in our sample are the most active NASDAQ securities, their trading volumes exhibit substantial variation. For example, 3.8 billion shares of Microsoft (the most active stock) traded during the three-month sample period, while the number of traded shares of C.H. Robinson Worldwide, Inc. (the least active stock) was only 26.6 million. In Panel C of Table 1, we divide the sample into five trading volume categories. Quintile one contains the most active stocks; while quintile five contains the least active stocks. Although we would expect the ECNs to be more active in securities with higher trading volumes, the statistics in Panel C do not contain consistent patterns in volume shares among quintiles. In fact, an F-test fails to find statistically significant differences among volumes executed in different quintiles on Instinet and Archipelago. Sample statistics on the quintiles are provided in the Appendix. We find that more actively traded

stocks have larger trade sizes, higher market capitalization, and lower prices than their less active counterparts.

Table 1 also shows that, while Island's and Instinet's volume shares drop by about the same amount between the 100–499 and 500–4,999 categories (4.42% and 4.41%, respectively), Archipelago's share falls only by 2.03%. We hypothesize that, for these trade sizes, the limit order book on Archipelago may be deeper and may give the ECN the needed capacity to handle trades in the second size category.[17] To validate this conjecture, we investigate order executions and cancellations on the three ECNs. For an order to be executed by an ECN, a market or a limit order (or several orders) with an acceptable price has to be pending on the other side of the book. If the number and/or depth of the pending order(s) are/is insufficient, two possible scenarios may emerge. First, certain traders may be aware of the state of the book, and may route their orders elsewhere. Second, submitted orders are likely to be frequently cancelled, as the wait time may exceed traders' expectations.

We are unable to evaluate the first suggestion empirically, as data on routing decisions are unavailable. We however use Dash 5 data to examine the second suggestion. Table 2 contains the number of market and marketable limit orders executed on the ECNs as a percentage of all submitted orders of the same type.[18] The results show that, in all but one size category, Archipelago executes more orders before cancellation than Island and Instinet.[19] We conjecture that Archipelago's limit order book is, on average, deeper and more predictable than those of the two rival ECNs.

3. Trading costs and times

With SuperMontage garnering around 50% of trades in the sample stocks, and the remaining 50% of executions occurring on the ECNs, we ask: How competitive are the four venues on the basis of execution quality? To start answering this question, we use the effective half-spreads as a measure of execution costs.

Table 3 reports effective half-spreads for each trading venue in Panels A (by trade size) and C (by volume quintile). Overall, ECNs' costs are lower than those on SuperMontage, but vary quite substantially across the three networks. Effective half-spreads on Island average 1.30 cents per share, followed by Archipelago with 1.23, and Instinet with 1.17 cents. SuperMontage is the most expensive venue, with an average effective spread of 1.35 cents. Thus, although ECNs provide the benefit of cheaper executions, the differences in costs within the ECN group are substantial. While ECNs charge their customers access

[17]This suggestion is confirmed by the regression results in Table 11, in which we show 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.

[18]Island did not accept market orders during the sample period. In addition, orders larger than 9,999 shares are not reported in the Dash 5 database. See Lipson (2004), for a study of NYSE-listed stocks and market venues using Dash 5 data.

[19]According to the SEC Release 2005-151, "Instinet and Inet repeatedly published monthly execution reports containing inaccurate order execution quality information" including "the misclassification of shares, miscounting of cancelled shares, improper exclusion of orders, improper calculations based on erroneous times, improper categorizing of orders, inaccurate order execution information, incorrect calculation of spreads and other incorrect calculations" during the period from June 2001 through May 2004. Since our sample period falls into this time range, the results in Table 2 (and later in Table 4) should be interpreted with caution. We would like to thank the anonymous referee for directing our attention to this issue.

Table 2
Order execution on ECNs

Reported are percentage shares of orders that are executed by the ECNs during the sample period. Aggregate monthly data by stock symbol, execution venue, and order characteristic are obtained from the Dash 5 database compiled in accordance with the SEC Rule 11Ac1-5. Orders larger that 9,999 are not reported in the database. The results are displayed as percentage of non-cancelled orders executed on the venue of initial submission in the total number of orders covered by the venue. *p*-Values (calculated across stock-market and stock-market-order size observations) are for hypotheses that shares of executed orders across trading venues and order sizes are identical

	Arca	Island	Instinet	*p*-Value
Panel A: Executed market orders, % of submitted orders				
Overall	49.58	–	17.27	0.000
100–499	52.81	–	20.95	0.000
500–4,999	49.98	–	17.56	0.000
5,999–9,999	43.91	–	16.81	0.000
p-Value	0.000	–	0.000	
Panel B: Executed marketable limit orders, % of submitted orders				
Overall	52.65	42.59	50.47	0.000
100–499	56.26	45.75	57.51	0.000
500–4,999	51.61	42.83	49.92	0.000
5,999–9,999	54.71	40.25	47.92	0.000
p-Value	0.000	0.000	0.000	

fees that are not included in our data, we do not expect such fees to substantially affect trading costs, as a standard fee is only about 3 millicents. In addition, according to Shkilko, Van Ness, and Van Ness (2007), access fees are often partly rebated to the liquidity-providing orders.

We find substantial variation in trading costs across order sizes. Effective half-spreads generally increase with order size, ranging from 1.29 cents for the smallest trades to 2.68 cents for the largest. This increase is not uniform, as overall costs decrease between the two smallest categories and then rise. In other words, trades of fewer than 500 shares are more expensive to execute than those between 500 and 5,000 shares. This result is driven by trades executed on SuperMontage and corroborates the findings of Choe and Hansch (2006) who show that, in recent samples, small trades are the most informed. Choe and Hansch suggest that, as opposed to Barclay and Warner's (1993) and Chakravarty's (2001) findings for earlier periods, informed trades are small rather than medium-sized. Our data support Choe and Hansch's findings, suggesting that NASDAQ dealers may be aware of smaller trades' superior information.

Although trading costs generally increase with trade size on the ECNs and SuperMontage, trading costs on SuperMontage increase more precipitously. In the smallest size category, the gap between effective half-spreads on SuperMontage and Island (the most expensive ECN) is only 0.08 cents; but increases to 1.31 cents in the largest category. We attribute this phenomenon to differences in the number of printed large trades, about 89% of which execute on SuperMontage according to Table 1. Supplementary analysis (not reported) shows that large executions on the ECNs occur primarily in the most active stocks, in which liquidity may often be sufficient to match two large orders. As SuperMontage executes the overwhelming majority of large trades in the less liquid stocks, its costs are understandably higher.

Table 3
Effective and realized spreads

Panels A–D contain results on trading costs and market maker rents represented by, respectively, effective and realized spreads. Trades are signed using a combination of Ellis, Michaely, and O'Hara (2000) algorithm and, for locked and crossed NBBO episodes, the tick rule. Effective spreads are calculated as signed differences between the trade price and the corresponding quote midpoint. Realized spreads are calculated as signed differences between the trade price and a quote midpoint 10 minutes after the trade. Results are divided into size quartiles and volume quintiles in a fashion similar to that in the previous tables. Panel E contains percentage shares of trades executed with price improvement or outside the NBBO. *p*-Values (calculated across stock-market and stock-market-trade size observations) represent results of testing a null hypotheses that trading costs, rents, and percentage shares are identical across the venues

	All	SuperMontage	Arca	Island	Instinet	*p*-Value
Panel A: Effective half-spread by trade size (cents)						
All trade sizes		1.35	1.23	1.30	1.17	0.000
100–499 shares	1.29	1.36	1.22	1.28	1.16	0.000
500–4,999 shares	1.26	1.29	1.23	1.35	1.17	0.000
5,000–9,999 shares	1.70	1.78	1.29	1.43	1.64	0.000
10,000 or more	2.68	2.84	1.40	1.53	1.41	0.000
Panel B: Realized half-spread by trade size (cents)						
All trade sizes		1.25	1.03	1.04	1.02	0.016
100–499 shares	1.13	1.25	1.02	1.02	1.01	0.000
500–4,999 shares	1.15	1.22	1.05	1.12	1.05	0.000
5,000–9,999 shares	1.42	1.60	0.74	0.53	1.13	0.000
10,000 or more	2.11	2.29	0.90	0.42	0.70	0.000
Panel C: Effective half-spread by quintiles (cents)						
Q1 (most active)	0.73	0.77	0.67	0.69	0.62	0.000
Q2	1.25	1.36	1.07	1.10	1.04	0.000
Q3	1.58	1.75	1.28	1.29	1.25	0.000
Q4	2.07	2.32	1.65	1.80	1.57	0.000
Q5 (least active)	2.36	2.74	1.61	1.90	1.73	0.000
Panel D: Realized half-spread by quintiles (cents)						
Q1 (most active)	0.66	0.75	0.48	0.53	0.48	0.000
Q2	1.18	1.32	0.92	0.99	0.92	0.000
Q3	1.46	1.63	1.15	1.16	1.16	0.000
Q4	1.92	2.14	1.53	1.72	1.48	0.000
Q5 (least active)	2.23	2.58	1.52	1.81	1.66	0.000
Panel E: Executions at prices other than NBBO quotes (%)						
Price improved	24.36	24.14	10.67	54.27	22.98	0.000
Outside NBBO	7.05	7.46	5.13	8.39	6.07	0.000

Effective spreads aggregated into activity quintiles in Panel C display a smoother pattern as compared to the ones aggregated into trade size quartiles. Finding an increase in trading costs from the most to the least active quintiles is expected, considering higher inventory and adverse selection costs as well as lower liquidity in low-volume quintiles.

Realized spreads (market maker revenues contingent on the information content of executed trades) are reported in Panels B and D of Table 3. Revenues are the highest on SuperMontage at 1.25 cents per share and range from 1.02 to 1.04 cents on the ECNs. An *F*-test (not tabulated) indicates that differences among the ECNs' realized spreads are

insignificant. Realized spreads generally increase with trade size and decrease with trading activity. Nevertheless, the overall positive relationship between trade sizes and realized spreads is driven by the SuperMontage executions, while on the ECNs realized spreads generally decrease (although not uniformly) with trade sizes. We attribute this phenomenon to the specifics of large ECN executions discussed above.

Panel E of Table 3 reports the percentage shares of trades executed at prices within and outside the best quotes. We find that the sample venues often offer substantial price improvement. The percentage share of trades executed at prices superior to the inside quotes ranges widely on the three ECNs, from 54% on Island, 23% on Instinet, to only 11% on Archipelago. SuperMontage falls squarely in the middle, with price improvement of 24%. A much smaller share of trades, 7.05% across all venues, execute outside of the NBBO quotes. Interestingly, across all four venues, Island has both the largest percentage of price improved trades and the largest percentage of trades occurring outside the NBBO, while Archipelago has the least of either.

What causes ECN trading costs to be lower than those on SuperMontage? Although the answer to this question is largely beyond the scope of our data, we suggest several possible reasons for the phenomenon. One possibility is that the cost differences may be attributed to a lower level of intermediation on the ECNs. The networks do not rely on market makers to facilitate trading and thus manage to avoid certain costs of intermediation (e.g., inventory and adverse selection). The resulting cost savings may be therefore partly transferred to the customers in the form of lower effective spreads. Another possibility is that hidden orders contribute to price improvement and, hence, lower trading costs on the ECNs. Unfortunately, our data do not allow us to test these hypotheses.

It is also possible that subpenny pricing may play a major role in lower ECN costs. Accounting for subpennies has potential to entirely eliminate cost differences, as the difference between the highest and lowest effective spreads, as reported in Table 3, is only 0.18 cents. As TAQ data contain subpennies, we are able to test trading costs' dependence on subpennies by calculating adjusted effective spread measures with prices rounded to two decimals. If differences in trading costs are attributable to subpenny pricing, we expect adjusted trading costs on the venues that use subpennies to be closer to trading costs on venues that do not use subpennies. Contrary to this expectation, the results (not reported) indicate that subpenny adjustment does not change, let alone eliminate, trading cost differences. Although differences between the adjusted and the unadjusted trading cost measures exist, they are only in the thousandths of a cent. We therefore conclude that subpennies are not a major driving force of ECNs' lower costs.

According to Battalio, Hatch, and Jennings (2003), Boehmer (2005), and Boehmer, Jennings and Wei (2007), studies of market quality should consider execution speed in conjunction with execution costs. We therefore conduct an investigation of times between order receipt and order execution using data from Dash 5 reports.[20] To assure that SuperMontage participants, whose caliber varies from such heavyweights as Schwab Capital and Brut ECN to dozens of smaller players, are represented in the aggregate measures according to their share of volume, we weigh reported statistics by the number of shares executed by each participant.

[20]As noted in the previous footnote, according to the SEC Release 2005-151, Instinet and Inet provided incorrect Dash 5 information during our time period, so that the results in Table 4 should be treated with caution.

Table 4
Execution times

The table contains order executions times (times between order submission and execution) for each of the sample venues. Results are aggregated into order size terciles and activity quintiles and into order types (e.g., market and marketable limit orders). Dash 5 reports do not contain execution data for orders larger than 9,999 shares, therefore this size category is omitted. At the time of the study, Island did not accept market orders, therefore marketable limit orders are the only basis for comparison of Island's execution times. Dash 5 datasets provide market quality statistics for each SuperMontage participant individually, therefore we aggregate results from all participants when computing NASDAQ statistics. To avoid overvaluing small market makers and undervaluing the large ones, we weigh NASDAQ statistics by volumes executed by each participant during the sample period

	SuperMontage		Arca		Island		Instinet	
	Market	Marketable limit	Market	Marketable limit	Market	Marketable limit	Market	Marketable limit
Panel A: Execution times by order size (seconds)								
All	7.7	8.6	2.0	8.8	–	5.3	0.5	9.7
100–499	1.7	1.5	1.2	0.7	–	1.8	0.3	2.4
500–4,999	8.6	10.8	2.0	5.8	–	4.4	0.4	5.7
5,000–9,999	32.0	30.6	3.2	22.9	–	10.9	1.0	26.7
Panel B: Execution times by volume quintile (seconds)								
Q1 (most active)	6.3	7.2	1.0	2.5	–	2.7	0.2	4.2
Q2	7.5	8.2	1.6	3.9	–	3.7	0.3	4.5
Q3	7.9	7.7	2.0	7.2	–	5.1	0.4	6.4
Q4	10.3	10.6	2.8	13.1	–	5.8	0.8	10.4
Q5 (least active)	6.7	9.1	2.9	17.3	–	9.1	0.6	23.2

Results on execution times are provided in Table 4. Panel A of Table 4 confirms that market orders receive faster executions on the ECNs. It takes an average market order only half a second to be executed on Instinet, 2 seconds on Archipelago, and 7.7 seconds on SuperMontage. The 1.5-second difference between the two ECNs is likely caused by the fact that Instinet forces market orders that are not immediately executable to post. In fact, marketable limit orders on Instinet (that include posted ex-market orders) take the longest to execute, 9.7 seconds; followed by Archipelago with 8.8 seconds, SuperMontage with 8.6 seconds, and Island with 5.3 seconds. Island's marketable limit orders execute faster, likely because some are functionally market orders forced to be submitted as limit orders.

Although the statistics for marketable limit orders reported in the Dash 5 data may be subject to misinterpretation, we opt to include this order type in our analysis. Boehmer (2005) points out that expired or cancelled marketable limit orders are not included in Dash 5 reports, artificially decreasing reported execution times statistics. On the other hand, the statistics may be inflated by orders that are outstanding when the market moves away from the limit price, as such orders take longer to execute. Although we share these concerns, we include marketable limit order data into the analysis for the following reasons. First, Island does not accept market orders, making marketable limit orders the only order type that may be used to compare Island to the other venues. Second, concerns expressed in Boehmer are not as critical for our study as they are for his. As we are mostly concerned with executed orders (trades), the absence of data for orders that were not executed or excessive emphasis on orders filled during adverse market moves fit well into the framework of our study.

Execution times increase with order size, and differences among market centers are more apparent for large orders. While market orders smaller than 500 shares execute in a time range from 0.3 to 1.7 seconds, market orders in the largest reported category take much longer, with execution times ranging from 1 to 32 seconds. It is important to reiterate that the ECNs do not receive as many large orders as does SuperMontage. Therefore ECN statistics for larger order sizes may be driven by a few orders, possibly submitted during the limited periods of high own liquidity.

Panel B of Table 4 shows that executions are speedier for more active stocks. This pattern is not universal, as market order executions in quintile 4 on SuperMontage take considerably longer than those in quintile 5. Similar nonlinearity appears in the market order results for Instinet. We examine this issue closer and find that the phenomenon is driven by only two stocks on a few trading days. When we exclude these stocks from the sample (not reported), the pattern levels out.

4. Information, liquidity, and anonymity

Microstructure studies (e.g., Huang, 2002; Barclay, Hendershott, and McCormick, 2003) argue that, due to anonymity, ECNs attract more informed trades and contribute more to price discovery than NASDAQ market makers. We add to these findings by suggesting that, under certain conditions, execution quality and speed concerns could supercede those of anonymity and become issues of foremost importance to informed traders. In particular, if ECN depth is insufficient, a trader with time-sensitive information may submit her order to a venue that provides less anonymity, but faster executions.

We begin with price impacts, a measure that compares the quote midpoint ten minutes after an execution with the midpoint at the time of execution and determines the information load of a trade. We use two measures of price impact, conventional and adjusted. The adjusted measure is used to correct for a potential problem with serial correlation in trade reports mentioned by Huang and Stoll (1997). Large orders are often reported as smaller trades if executed against smaller orders. As informativeness often increases with order size, one large informed order may be printed as a string of smaller informed trades. Every one of these trades will have a high price impact, inflating an aggregate measure of price impact.

The traditional price impact measure is calculated as a signed difference between the midpoint ten minutes after a trade and the midpoint accompanying the trade. Adjustment for the serial correlation is done similarly to Huang and Stoll (1997). We first identify trades as buyer- or seller-initiated using a mixture of the Ellis at al. (2000) technique for periods of positive NBBOs and a tick rule for the periods when the NBBO is locked or crossed. We then identify sequences of buyer- or seller-initiated trades that occur at the same price on the same venue without a change in the bid or ask quotes and collapse these trades into one. We acknowledge that such an approach is not perfect, as it may over- or under-correct for serial correlation, especially as large market orders may "walk the book" before fully executing. In addition, the approach is unable to correct for order splitting mentioned in Chowdhry and Nanda (1991) and Menkveld (2004), who suggest that traders and smart routing systems may split large orders and route them to different market centers.

Table 5 contains conventional and adjusted price impact measures in, respectively, Panels A and B. The data generally support previous studies, as price impacts of ECN

Table 5
Price impacts and information shares

The table contains price impacts aggregated by trade size quartiles (Panels A and B) and trading activity quintiles (Panel C) as well as information shares aggregated by activity quintile (Panel D). Two price impact measures are used. The conventional measure calculates price impacts as signed differences between a quote midpoint ten minutes after trade execution and the midpoint at the time of execution. The adjusted measure aggregates buyer- or seller-initiated trades executed on the same venue at the same price to control for serial correlation caused by order shredding. Information shares are calculated for each stock using a vector error correction model (VECM) described in Hasbrouck (1995). The computed information shares are then collapsed into trading volume quintiles and mean shares for each venue are reported together with the min-max range in square brackets. *p*-Values (calculated across stock-market and stock-market-trade size observations) indicate results of testing null hypotheses that price impacts and mean information shares are identical across market centers

	All	SuperMontage	Arca	Island	Instinet	*p*-Value
Panel A: Price impact by trade size (*cents*)						
All trade sizes		0.10	0.20	0.26	0.14	0.000
100–499 shares	0.15	0.11	0.20	0.26	0.15	0.024
500–4,999 shares	0.11	0.07	0.18	0.23	0.12	0.000
5,000–9,999 shares	0.28	0.18	0.50	0.90	0.51	0.000
10,000 or more	0.57	0.55	0.55	1.11	0.71	0.000
Panel B: Adjusted price impact by trade size (*cents*)						
All trade sizes		0.06	0.10	0.11	0.09	0.000
100–499 shares	0.04	0.05	0.03	0.04	0.07	0.002
500–4,999 shares	0.08	0.06	0.08	0.10	0.09	0.000
5,000–9,999 shares	0.24	0.08	0.26	0.39	0.27	0.000
10,000 or more	0.46	0.06	0.70	0.95	0.25	0.000
Panel C: Price impact by quintiles (*cents*)						
Q1 (most active)	0.07	0.02	0.19	0.16	0.14	0.000
Q2	0.07	0.04	0.15	0.11	0.12	0.000
Q3	0.12	0.12	0.13	0.13	0.09	0.014
Q4	0.15	0.18	0.12	0.08	0.09	0.000
Q5 (least active)	0.13	0.16	0.09	0.09	0.07	0.000
Panel D: Information shares by quintile (*%*)						
All		0.318	0.237	0.222	0.224	0.002
Q1		0.301	0.240	0.227	0.232	0.023
		[0.46–0.14]	[0.36–0.17]	[0.39–0.06]	[0.32–0.17]	
Q2		0.340	0.241	0.216	0.202	0.010
		[0.49–0.13]	[0.32–0.19]	[0.39–0.03]	[0.33–0.14]	
Q3		0.336	0.222	0.220	0.221	0.018
		[0.49–0.10]	[0.28–0.16]	[0.35–0.06]	[0.31–0.13]	
Q4		0.349	0.214	0.215	0.222	0.012
		[0.51–0.07]	[0.31–0.12]	[0.33–0.06]	[0.31–0.14]	
Q5		0.457	0.214	0.135	0.194	0.004
		[0.59–0.10]	[0.33–0.12]	[0.28–0.03]	[0.28–0.12]	

trades are higher than those of SuperMontage trades. We also find a confirmation of Choe and Hansch (2006) notion of small trades being more informative in contemporary trading environment. As Panel A shows, price impacts of trades in the smallest category are larger than of those in the next category across all venues. Island tends to execute the most informed trades, with price impacts of 0.26 cents, followed by Archipelago, with 0.20 cent

impacts, and Instinet, with an average impact of 0.14 cents. SuperMontage price impacts are the smallest at around 0.10 cents.

When adjusted price impacts are used, the patterns change in two notable ways. Firstly, price impacts decrease across the board, indicating that the adjustment procedure is able to correct for the upward bias discussed earlier. Secondly, size-related changes in price impacts become monotone, leading us to conclude that high information load of small trades observed in Panel A is largely caused by serial correlation.

Panel C contains results of separation of price impacts into trading volume quintiles. Overall, the data indicate that trades in less active quintiles are more informed, with price impacts ranging from 0.07 cents for quintile 1–0.13 cents in quintile 5 when computed across all venues. This result is expected, as visibility of the most active stocks may attract uninformed traders. Informativeness decreases with trading activity on SuperMontage, and increases on the ECNs. This result supports our earlier suggestion that informed traders do not send their orders to the ECNs unconditionally, but rather make routing decisions on the basis of liquidity on the receiving venue. In case of actively traded stocks, the ECNs are able to supplement anonymity with increased liquidity, which makes the networks attractive. In lower trading volume quintiles, however, ECN liquidity may be insufficient, causing informed traders to route to SuperMontage.

To investigate the matter further, we use the Vector Error Correction Model (VECM) of transaction prices (e.g., Hasbrouck, 1995) to calculate the venues' information shares. The shares are determined on a stock-by-stock basis for all four markets with all possible combinations. Subsequently, the stocks are divided into quintiles, and maximum of maxima, minimum of minima, and mean information shares are determined for the quintiles as well as for all stocks. Results are displayed in Panel D of Table 5 in the form of information share means and ranges, with the lower bound corresponding to the lowest information share for a stock in a quintile and the upper bound to the highest. Results confirm some of the findings in Panel C, while disagreeing with the others. In particular, SuperMontage share of informed trading increases as we move to less actively traded stocks. On the ECNs, the pattern is reversed, with information shares falling as we move to lower volume quintiles. Archipelago information shares are generally higher than those of the other two ECNs, confirming our earlier conjecture that informed traders may avoid executing through Instinet and Island due to lower depths of the limit order books of the two ECNs.

Results on price impacts in Panels A through C and on information shares in Panel D may seem to disagree on the locus of price discovery. Price impacts indicate that the ECNs execute the most informed trades, whereas, according to the VECM, SuperMontage emerges as the venue with the highest information share: 31.8% as compared to about 23–24% for the ECNs. The discrepancy could be due to the mere fact that SuperMontage has a larger overall volume share. With price impact being a "per trade" measure, and information share being an aggregate measure, it is possible that SuperMontage information share is high due to the fact that it executes more than 60% of the trading volume.[21] In addition, the discrepancy may be due to vulnerability of the price impact measure to liquidity changes caused by large orders. Such orders extensively consume liquidity as they walk the book, causing ECNs quotes and quote midpoints to change.

[21]We thank the anonymous referee for suggesting this explanation.

The VECM approach uses trade prices instead of quote midpoints, thus avoiding excessive reliance on displayed quotes and leading to the conclusion that SuperMontage trades are, in fact, more informed.

Univariate results in Table 5 imply that informed traders choose execution venues on the basis of expected liquidity. These traders anticipate the most active stocks to be sufficiently liquid on all venues, whereas the less active securities are expected to be the most liquid on SuperMontage. Traders' liquidity expectations may be based on previous trading experience as well as general knowledge of the venues' liquidity attraction practices and order flow. In the remainder of this section, we question the validity of the univariate results and suggest that informed traders may be actively monitoring liquidity on the ECNs and may be making routing decisions on the basis of both expected and observable temporary liquidity. To support this suggestion, we investigate how the venue of execution and transient liquidity on this venue affect price impacts across activity quintiles.

To isolate expected liquidity, we examine each of the trading activity quintiles separately. For each quintile, we use three sets of models: model 1 that controls only for expected liquidity; model 2 that controls for transient liquidity in addition to expected liquidity, and model 3 that controls for the exclusivity of transient liquidity in addition to expected liquidity. Exclusivity of liquidity is postulated when the executing venue is alone at the NBBO. In total, Table 6 contains coefficient estimates for 15 models (three models for each of the five activity quintiles).

In the basic model (model 1), price impacts of buyer-initiated trades are regressed on three execution location indicator variables: *Arca, Island, and Instinet* (SuperMontage is used as a base venue) and several controls.[22] The controls include three trade size variables: *size*1, *size*2, *size*3 (*size*4 being base size); a proxy for market-wide quote competitiveness – *nbbo_width*; as well as volume and volatility variables that characterize trading environment during the ten minutes preceding the trade, respectively *vol*_10 and *volat*_10.

In models 2 and 3, the basic structure is extended to include six variables that interact execution location indicators with two liquidity characteristics: presence at the inside ask (*Venue_nbbo*) and quoted ask depth (*Venue_depth*). Presence at the inside ask in model 2 is controlled for with an indicator variable that equals to 1 if the executing venue's quote is at the inside ask immediately before the trade. Model 3 uses a similar dummy variable only if the executing venue's quote is alone at the inside ask immediately before the trade. *Depth* is the ask depth of the most recent quote posted by the venue. The models control for the components of the interaction variables; however, the coefficients for these controls are not reported in the tables to preserve space. All variables other than the indicators are standardized by their sample means. The regression models control for stock-specific fixed effects and non-spherical errors.

Model 1 captures the effect of expected liquidity on informativeness of trades. Results in Table 6 show that informed traders anticipate the ECNs to have more liquidity in more active stocks. With SuperMontage as the base group, coefficients of *Arca, Island*, and *Instinet* change from positive to negative, as we move towards the less active quintiles. This sign change indicates that, ceteris paribus, Island and Instinet trades in the 20 most active stocks (Archipelago trades in the 40 most active stocks) are more informed than SuperMontage trades. SuperMontage, on the other hand, executes more informed trades in the three less active quintiles.

[22]Results for seller-initiated trades are qualitatively similar and are not reported.

Table 6
Determinants of trade informativeness

The table contains results of regressing price impacts of buyer-initiated trades on execution location indicators, liquidity proxies, and several conventional controls. We use three model specifications for each of the five trading activity quintiles. Model (1) controls for expected liquidity, whereas models (2) and (3) account for transient liquidity. Model (2) proxies for transient liquidity with a dummy variable that equals to 1 when the executing venue is at the NBBO immediately prior to an execution, whereas model (3) uses a dummy variable equal to 1 when the executing venue is alone at the NBBO immediately prior to an execution. Both models (2) and (3) control for displayed depth on the executing venue immediately prior to an execution. The models control for the components of the interaction variables (e.g., being at the NBBO, being alone at the NBBO, and displayed depth), but the coefficients are not tabulated to preserve space. The models also controls for trade size, NBBO width, trading volume, and price volatility in the 10 minutes prior to the execution. All variables other than the indicators are standardized by their sample means. The models control for stock-specific fixed effects and non-spherical errors by allowing the procedure to assume clustering across stocks and using the Huber-White estimator. Coefficients different from zero at 0.1 and lower levels are denoted with an asterisk (*)

	Q1 (most active)			Q2			Q3			Q4			Q5 (least active)		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Intercept	0.054*	0.052*	0.047*	0.076*	0.076*	0.071*	0.094*	0.112*	0.097*	0.066*	0.078*	0.082*	0.069*	0.097*	0.099*
ArcaEx	0.002*	0.002*	0.002*	0.005*	0.003*	0.003*	−0.002*	−0.002*	−0.003*	−0.005*	−0.003*	−0.004*	−0.010*	−0.007*	−0.008*
Island	0.001*	0.001*	0.002*	0.000	0.000	0.000	−0.005*	−0.003*	−0.004*	−0.005*	−0.003*	−0.004*	−0.003*	−0.001*	−0.001*
Instinet	0.003*	0.002*	0.002*	0.000	0.000	0.000	−0.004*	−0.003*	−0.003*	−0.003*	−0.002*	−0.003*	−0.004*	−0.001*	−0.002*
Arca_nbbo		0.000	0.004*		0.002*	0.003*		0.001*	0.002*		0.001*	0.001*		0.002*	0.006*
Island_nbbo		0.000	0.002		0.001	0.010*		0.001	0.032*		0.000	0.007*		0.005	0.080*
Instinet_nbbo		0.000	0.006*		0.001*	0.018*		0.003*	0.011*		0.002*	0.001*		−0.003	0.012*
Arca_depth		0.003*	0.003*		0.034*	0.003*		0.044*	0.042*		0.002*	0.001*		0.001	0.001
Island_depth		0.003*	0.003*		0.005	−0.003		0.006	−0.007		0.001	0.001		0.001	0.001
Instinet_depth		0.010*	0.010*		0.026*	0.008*		0.046*	0.047*		0.001*	0.001*		0.001	0.001
*size*1	0.008*	0.007*	0.008*	0.005*	0.003*	0.003*	0.006*	0.010*	0.010*	0.016*	0.008*	0.009*	0.008	0.000	0.001
*size*2	0.004*	0.004*	0.004*	0.007*	0.003*	0.004*	0.010*	0.015*	0.014*	0.010*	0.002	0.003	0.007	−0.003	−0.002
*size*3	−0.001	−0.004*	−0.001*	0.001	−0.002	−0.002	0.015*	0.018*	0.017*	0.006	0.002	0.003	0.000	−0.009	−0.008
nbbo_width	−12.517*	−6.517*	−8.853*	2.356*	1.143*	0.249*	1.074*	0.545*	0.313*	0.970*	1.296*	1.061*	9.914*	4.663*	3.946*
*vol*_10	−0.166*	−0.146*	−0.145*	−0.300*	−0.293*	−0.294*	−0.458*	−0.391*	−0.398*	−0.280*	−0.221*	−0.224*	−0.667*	−0.703*	−0.688*
*volat*_10	0.852*	0.657*	0.688*	0.689*	0.424*	0.448*	0.767*	0.562*	0.584*	0.695*	0.487*	0.500*	0.392*	0.290*	0.300*

The execution venue effect does not disappear in models 2 and 3, as signs and statistical significance of *Arca, Island*, and *Instinet* coefficients remain unchanged when transient ECN liquidity is controlled for. Despite the robustness of the main effect, results in models 2 and 3 confirm our dynamic monitoring hypothesis, as transient liquidity is shown to have a positive effect on the ECN trade informativeness in the low activity quintiles. For example, a -0.003 coefficient of *Arca* indicator variable in model 3 for quintile 3 shows that trades executed on Archipelago are usually less informed than those executed on SuperMontage. Nonetheless, this effect is diminished if Archipelago is alone at the NBBO, as the coefficient of the interaction dummy is 0.002. Further, the main coefficient of the *Arca* indicator is overpowered if Archipelago's book is deep, as the coefficient of the depth interaction variable is 0.042. This relationship is observable across all volume quintiles and is often stronger in models that control for exclusivity of transient liquidity (models 3), with several exceptions attributable largely to Island.

In summary, Table 6 shows that although informed traders often make routing decisions on the basis of expected liquidity, evidence of sufficient transient liquidity on Archipelago, Island, and Instinet is able to attract informed orders to the ECNs even in the stocks, for which informed trading usually happens on SuperMontage. Thus, our multivariate results support both the anonymity/sufficient liquidity tradeoff and the dynamic monitoring hypotheses.

5. Quote competition and trade execution

Previous sections demonstrate that the ECNs offer significant competitive advantages by providing traders with relatively low execution costs, high speeds, and anonymity of executions. The data show that these advantages attract informed order flow to the ECNs, albeit only in the most active stocks. Although not the most cost- and time-competitive venue, NASDAQ's SuperMontage offers dealer-supported liquidity – an important benefit in a segmented market. A question that we ask next is: Does the rivalry among the four venues extend into quote competition? Blume and Goldstein (1997) and Bessembinder (2003) show that quote competitiveness is an important characteristic of the market for the NYSE-listed securities. There is, however, not much evidence on the extent of quote competition in the market for NASDAQ stocks. Quote competitiveness in the NASDAQ marketplace may differ from that in the NYSE marketplace, as the former is more segmented than the latter.

In the market for NASDAQ securities, ECNs originate a nontrivial share of quotes. ECN quotes are largely determined by limit orders, some of which may not display full depth, while others may be fleeting (see, for instance, Hasbrouck and Saar, 2005) or forced to post and therefore subject to frequent cancellations. In addition, if the inside depth is low, the ECN quotes may be subject to frequent changes, as they will be quickly consumed by liquidity demanders. Thus, a major drawback of the limit order-driven quotes is their instability. A positive feature of such ECN quotes, however, is that they often represent traders' true price schedules. Conversely, dealers' quotes that, in part, determine the inside on SuperMontage may not fully reflect prices that dealers are willing to offer or take. As shown by Chung, Chuwonganant, and McCormick (2004), preferencing remains a notable issue even after decimalization, as it deprives dealers of incentives to post competitive quotes. High level of preferencing has potential to increase execution costs, especially in the less active stocks, for which ECN quotations are not sufficiently competitive.

The remainder of this section investigates the degree of quote competition between SuperMontage and the three ECNs.

In order to measure quote-based competition among the four trading venues, we start by examining the extent of their participation in the NBBO. We differentiate among the following levels of competitiveness: *at inside bid and/or ask*—presence at one or both sides of the NBBO; *at both inside bid and ask*—presence at both sides of the NBBO; *alone at inside ask (bid)*—presence at either the best ask or the best bid by itself; and *alone at both bid and ask*—formation of the entire NBBO by itself.

Table 7 shows the percentage of time (Panel A) that the venues spend at each level of competitiveness and percentage of trades (Panel B) executed at each level. The most active quoting venue, SuperMontage, quotes at least one side of the NBBO almost 90% of the time, with about 87% of trades executed during these periods. The ECNs, especially Instinet and Archipelago, contribute a great deal to quote competition: they are on either or both sides, respectively, 85% and 82% of the time. Island's NBBO participation is lower, as the venue is quote-competitive only slightly over half the time. Quoting activity of all market centers falls quite dramatically when it comes to being on both sides of the NBBO. SuperMontage is still the leader, determining the inside quotes over 50% of the time, while the ECN participation ranges from about 13% (Island) to about 34% (Archipelago and Instinet). Results in Table 7 do not support our earlier suggestion of SuperMontage inferior competitiveness when it comes to quoting, as the venue quotes both sides of the NBBO more often than any of the three non-member ECNs. This result may be driven by the quotes from Attain, Brut, Bloomberg Tradebook and other SuperMontage ECNs, since TAQ reports do not distinguish quotes posted by these ECNs from those of NASDAQ dealers.

Table 7
Quote-based competition

Reported are measures of quote competitiveness. A venue is at inside bid and/or ask, if it participates in formation of one or both sides of the NBBO. A venue is at *both inside bid and ask*, when it participated in formation of both sides of the NBBO. A venue is *alone at inside ask or bid*, if it forms either side of the NBBO on its own. A venue is *alone at both bid and ask*, if it forms the entire NBBO by itself. A quote has *time priority*, if it is alone at the inside, or has been posted earlier that all other inside quotes. Statistical tests reject the null hypothesis that percentage shares are identical across venues

	SuperMontage	Arca	Island	Instinet
Panel A: Time-weighted averages, % of trading time				
At inside bid and/or ask	89.92	81.86	52.51	85.25
At both inside bid and ask	50.24	33.64	13.09	34.18
Alone at either inside ask or bid	11.55	6.08	2.82	7.29
Alone at both bid and ask	0.97	0.38	0.08	0.43
Panel B: Trade-weighted averages, % of sample trades				
At inside bid and/or ask	86.52	71.85	54.17	80.92
At both inside bid and ask	50.31	28.98	13.40	31.93
Alone at inside ask	18.51	9.34	5.58	12.57
Alone at both bid and ask	3.57	1.02	0.23	1.16
Panel C: Time priority, % of quotes posted by a venue				
	51.47	36.73	21.75	37.35

We continue with a discussion of time priority of the best quotes. We count a quote as having time priority across the four venues if (i) it is alone at the NBBO, or (ii) it is not alone, but has been submitted before the rest of currently outstanding NBBO quotes. The second condition makes it difficult for the ECNs to maintain time priority, as every incoming market order has the potential to consume currently outstanding limit orders and the corresponding quotes. "Flickering" of ECN quotes may cause traders who are concerned with getting their orders executed at prices displayed at the time of submission to be reluctant to route to the ECNs. Our results in Panel C of Table 7 show that the share of ECN quotes with time priority varies from only about 22% on Island to about 37% on Instinet and Archipelago, whereas more than 51% of SuperMontage quotes have time priority.

The issue of posting and maintaining the best quotes is further investigated in a set of logistic regression models in Table 8. Similarly to Bessembinder (2003), we test two model specifications for each of the sample venues. In the first specification (Panel A of Table 8), the dependent variable equals to one if the venue's ask quote is alone at the NBBO. The second specification (Panel B) focuses only on quote updates, with the dependent variable equal to one, if the venue's ask quote update establishes a new NBBO. Results for the bid quotes are qualitatively similar and are not reported.

Both specifications use independent variables that control for contemporaneous and preceding quoting and trading conditions. In particular, these variables include trading volume and price volatility during the 10 minutes preceding a quote or a quote update (*vol*_10 and *volat*_10, respectively), the contemporaneous (lagged in Panel B) width of the NBBO spread (*nbbo_width* and $nbbo\_width_{t-1}$), and the quote size (*qsize*). We control for inherent liquidity and clientele effects with activity quintile dummies (quintile 3 is used as a base). All non-dummy independent variables are standardized by their stock-day sample means, and the model is tested and adjusted for the stock-specific fixed effects and non-spherical errors.

For an ask quote posted by venue X to be alone at the NBBO, one of the following conditions needs to apply: (i) venue X posts an ask quote that improves the existing NBBO ask without being immediately matched by one of the remaining three venues, or (ii) all venues but X withdraw their NBBO ask quotes, leaving venue X's quote alone at the best ask. The first condition is more likely to materialize during periods of high volume, as market makers (traders) will submit price improving quotes (orders) to signal their willingness to trade (to ensure price priority). The second condition is also likely during the periods of high volume, as ECN quotes will be consumed by incoming orders, whereas dealer quotes will be withdrawn for inventory reasons. Panels A and B confirm this expectation, as the coefficients of *vol*_10 are positive in both specifications.

When uncertainty is high, traders and dealers are reluctant to maintain the best quotes, let alone submit them, and the venues that appear alone at the NBBO are the ones that are slower with quote updates or the ones with better informed traders and/or market makers. The positive coefficient on *volat*_10 in Panel A of Table 8 shows that, during periods of high volatility, SuperMontage is more likely to be left alone at the NBBO; while the negative coefficients for Archipelago, Island, and Instinet indicate that they are less likely to be alone at the NBBO during volatile times. Although we do not dismiss the suggestion that NASDAQ dealers may take a while to update their quotes, it may also be that they are more likely than the bulk of ECN traders to be informed of the nature of informational events that cause volatility and may therefore maintain inside quotes even during periods

Table 8
Quotations alone at the NBBO

The table contains coefficients from the logistic regression models, with the dependent variables equal to 1 if an ask quotation submitted by one of the four sample venues is alone at the NBBO (Panel A) and equal to 1 if an ask quote update causes one of the sample venues' being alone at the NBBO (Panel B). The following dependent variables are used: trading volume and price volatility during the 10 min preceding the quote (quote update), the NBBO width corresponding to (preceding) the quote (quote update), quote size, four indicator variables that control for trading activity quintiles, and 9 indicator variables (not tabulated) controlling for the time of the day. Quintile 3 is a base quintile. All variables other than indicators are standardized by their stock-day means. The models control for stock-specific fixed effects and non-spherical errors by allowing the procedure to assume clustering across stocks and by using Huber–White estimator. (p-Values are noted below each coefficient in parentheses.) Superscripts ***, **, and * denote, respectively, significance at 0.01, 0.05, and 0.10 levels

	SuperMontage	Arca	Island	Instinet
Panel A: Quotations alone at the NBBO				
*vol*_10	0.008***	0.015***	0.006***	0.015***
	(0.000)	(0.000)	(0.000)	(0.000)
*volat*_10	0.110**	−0.102***	−0.096***	−0.109***
	(0.028)	(0.000)	(0.000)	(0.000)
nbbo_width	−0.081***	−0.066***	−0.024***	−0.061***
	(0.000)	(0.000)	(0.000)	(0.000)
qsize	−0.080***	−0.017***	−0.015***	−0.017***
	(0.000)	(0.000)	(0.000)	(0.000)
$q1$ (*most active*)	−0.114***	0.056***	0.017***	0.030***
	(0.000)	(0.000)	(0.000)	(0.000)
$q2$	−0.045***	0.014***	0.001	0.000
	(0.000)	(0.000)	(0.501)	(0.837)
$q4$	0.006***	−0.008***	−0.004***	−0.010***
	(0.000)	(0.000)	(0.000)	(0.000)
$q5$ (*least active*)	0.046***	−0.070***	−0.010**	−0.050***
	(0.000)	(0.000)	(0.029)	(0.000)
Panel B: Quote updates only				
*vol*_10	0.003***	0.003***	0.003***	0.005***
	(0.000)	(0.000)	(0.000)	(0.000)
*volat*_10	−0.002*	−0.021*	−0.040*	−0.047***
	(0.087)	(0.092)	(0.079)	(0.007)
nbbo_width $_{t-1}$	0.023***	0.016***	0.008***	0.016***
	(0.000)	(0.000)	(0.000)	(0.000)
qsize	−0.024***	−0.011***	−0.011***	−0.007***
	(0.000)	(0.000)	(0.000)	(0.000)
$q1$ (most active)	−0.021***	0.012***	0.011***	0.016***
	(0.000)	(0.000)	(0.000)	(0.000)
$q2$	−0.009***	0.002***	0.002***	0.005***
	(0.000)	(0.000)	(0.000)	(0.000)
$q4$	0.003***	−0.002***	0.000	−0.001**
	(0.000)	(0.000)	(0.741)	(0.027)
$q5$ (*least active*)	0.011***	−0.014***	−0.001***	−0.001***
	(0.000)	(0.000)	(0.000)	(0.000)

of uncertainty. In the specification that only considers quote updates (Panel B), the negative coefficients on *volat*_10 indicate that volatility is negatively related to the probability of a quote-improving update on all four venues. This is expected, as most

traders prefer for the uncertainty to be resolved before revealing their intentions to the marketplace.

Wider inside spreads create incentives to submit NBBO-improving quotes, as such superior quotations may attract order flow to the posting market. This is confirmed by the positive coefficients of $nbbo\_width_{t-1}$ in Panel B for all venues. Similar logic applies to the specification in Panel A: when the NBBO is wide, traders on the markets that are not currently on the inside may be inclined to step in and gain price priority. Such actions will decrease the probability of a single market being alone at the inside, which is confirmed by the negative coefficients of *nbbo_width* in Panel A. Quote size is found to be negatively related to both probability that a quote is alone at the NBBO and the probability of competitive quote updates. The result is expected in the environment of significant segmentation, hidden liquidity, and abundance of fleeting orders. Traders and market makers are reluctant to display the full depth of their best quotes to avoid being targeted by informed traders. In addition, quotes with low depths may not be as closely monitored by the submitters as the deeper ones, increasing the probability that such quotes will end up alone at the NBBO when other venues pull away.

The trading activity quintile indicator variables provide additional evidence on differences in quoting behavior and trading clienteles discussed in the previous section. We find that SuperMontage quotes have higher chances of being left alone at the NBBO in the less active stocks, whereas the ECNs are more likely to quote NBBO alone in the first two quintiles. The results are similar when we look at the quote updates. SuperMontage is more likely to improve the best quotes in the less active stocks, whereas the bulk of quote improvement by the ECNs is concentrated in the more active quintiles.

Table 8 shows that quotes posted by SuperMontage and the ECNs depend on preceding trades. In Table 9, we inquire whether a reverse relationship holds; in particular, whether trading depends on quotes. For each trade, we determine location of the quote on the executing venue relative to the NBBO and find a notable difference across market centers. While both SuperMontage and the ECNs execute the majority of trades when their quotes are at the inside, the ECNs execute a rather significant share of trades during periods when their quotes are away from the inside. In particular, while only 4.05% of SuperMontage trades occur when the venue is not at the NBBO, shares of such trades on Archipelago, Inland, and Instinet range from 12.51% to 39.23%. This finding may be attributed to either hidden or insufficient liquidity. The ECNs allow traders to submit orders with hidden depth, and a trade may execute against the hidden part of an order after the quote represented by the order has been consumed. In the second case, an order that starts executing against an inside limit order finishes being executed against orders with inferior prices, as it "walks the book." Trades resulting from both of these scenarios may appear in TAQ as executed while the venue's quote is away from the NBBO, if quotes from other venues remain on the inside.

To elaborate on the issue of quote competitiveness, we inquire how competitive the quotes posted by the executing venues are relative to the contemporaneous quotes posted by other venues. Panels B and C of Table 9 contain the results of this inquiry, with executing venues listed horizontally and non-executing—vertically. For customer buy orders (Panel B), we calculate an average distance between ask quotes on the non-executing venues and the ask quote on the executing venue. For the customer sell orders (Panel C), we subtract quotes on the non-executing venues from the bid quote of the executing venue. Each distance is weighed by the corresponding trading volume. If the

Table 9
Quotes and executions

Reported in Panel A are the shares of trading volume executed by each venue when at one of the three levels of quote competitiveness: *at both inside bid and ask* contains trades completed while a venue is quoting both sides of NBBO; *at either best ask or bid* contains trades completed when a venue is quoting either the inside bid, or ask; *at neither best bid nor ask* contains trades completed while a venue is not quote-competitive. The *F*-tests (calculated across stock-market observations) reject the null hypothesis that percentage shares of trades are identical across the sample venues for all cases. In Panels B and C, we compute mean distances between quotes posted by the venues executing trades (listed horizontally) and contemporaneous quotes of the other venues (listed vertically). In Panel B, we calculate distances by subtracting the ask quote on the executing venue from the quotes posted by other venues. In Panel C, we subtract bid quotes posted by other venues from the bid quote of the executing venue

	SuperMontage	Arca	Island	Instinet
Panel A: Percentage volume conditional on quotes				
Both inside bid and ask	75.59	65.12	52.27	72.55
Either best ask or bid	20.36	16.55	8.50	14.93
Neither best bid nor ask	4.05	18.32	39.23	12.51
Panel B: Customer purchases and ask quotes				
SuperMontage		0.03	0.02	0.02
Arca	−0.02		0.00	−0.01
Island	−0.01	0.01		0.00
Instinet	−0.01	0.01	0.01	
Panel C: Customer sales and bid quotes				
SuperMontage		0.03	0.02	0.03
Arca	−0.02		0.00	0.01
Island	−0.02	−0.01		0.01
Instinet	−0.02	0.01	0.00	

executing venue has the best ask/bid at the time of execution, the distances in Table 9 should be positive. Results corroborate and reinforce those in Panel A, as we observe that only SuperMontage quotes are, on average, the best when executions happen on the venue. ECN executions occur, on average, when SuperMontage provides better quotes.

Our findings in Table 9 show that, on average, the ECNs execute trades when there is at least one market with a better quote—SuperMontage. In Table 10, we attempt to determine whether executions that occur when a venue does not have the best quotes differ from those that occur when the venue's quotes are on the inside. We separate sample trades into two sub-samples: one that includes only customer sells (buys) executed when venue quotes the best bid (ask), and the other that contains customer sells (buys) executed when venue does not quote the best bid (ask). The same-stock trades from the two sub-samples are then matched according to the following two characteristics: (i) executed on the same market and (ii) belong to the same size category. We divide the sample into ten trade size categories similar to Bessembinder (2003).

Results in Table 10 show that execution quality is relatively low when trades occur on venues that post non-competitive quotes. In particular, the difference in effective spreads between the non-NBBO and NBBO executions ranges from 0.78 cents on SuperMontage to 0.12 cents on Archipelago and is positive and significant in all cases. Venues that maintain competitive quotes provide higher degrees of price improvement and execute

Table 10
Trades on and away from the NBBO market

The table contains market quality statistics for trades executed on the market with the best quotes and for a matched sample that consists of trades executed on the same market when its quotes are not the best. To be eligible for a match, both trades must be in the same stock, be completed on the same market, and be drawn from the same trade size category. The ten trade size categories are as in Bessembinder (2003): fewer than 300 shares; 300–499 shares; 500–899 shares; 900–1,499 shares; 1,500–2,499 shares; 2,500–4,999 shares; 5,000–9,999 shares; 10,000–19,999 shares; 20,000–29,999 shares; and over 30,000 shares. Paired t tests are used to determine whether the differences between "at NBBO" results and their matches are statistically significant. All pairs but the ones for trade sizes are statistically different, as indicated by the asterisks

	SuperMontage		Arca		Island		Instinet	
	NBBO	Matched Non-NBBO	NBBO	Matched Non-NBBO	NBBO	Matched Non-NBBO	NBBO	Matched Non-NBBO
Trade size, # shares	1,430	1,415	968	966	554	551	576	579
Effective spread, ¢	1.31	2.09*	1.19	1.31*	1.21	1.45*	1.13	1.37*
Price impact, ¢	0.09	0.32*	0.18	0.32*	0.20	0.33*	0.11	0.35*
Price improved, %	23.94	6.19*	13.16	6.03*	58.35	22.46*	27.74	5.70*
Outside NBBO, %	2.95	56.78*	2.54	16.68*	3.03	16.69*	1.53	37.82*

fewer transactions outside the NBBO. Trades executed on venues with non-competitive quotes are, on average, more informed than those executed on competitive venues. This finding indicates that informed traders do not always make routing decisions on the basis of the best quotes, and may use criteria such as depth and/or execution anonymity.

In summary, our results show that, although ECN quotations are competitive, SuperMontage quotes are, on average, superior when it comes to executions. SuperMontage is at both inside ask and bid more often than any of the ECNs, and its quotations are the most stable. SuperMontage is often the only venue at the NBBO during the periods of high volatility. SuperMontage is also the most active venue when it comes to quoting less frequently traded stocks. Overall, results in this section support those discussed previously: ECN advantages such as faster and cheaper executions and competitive quotes only benefit the twenty to forty most active securities. For less frequently traded stocks, SuperMontage provides the essential benefit of dealer-supported liquidity that the ECNs are unable to offer.

6. Determinants of trade executions

The survey of trading costs, speeds, price discovery, trading clienteles, and quote competitiveness presented in the earlier sections provides an important insight into the extent and nature of competition among venues that trade NASDAQ securities. In this section, we complete the picture of this competitive marketplace by combining previously discussed factors into a model of trade executions.

Similarly to Bessembinder (2003), we use a set of four logistic regressions, with the dependent variable equal to one if a trade is executed on one of the four venues: SuperMontage, Archipelago, Island, or Instinet. For instance, in the model for SuperMontage, the dependent variable equals to 1 for trades executed on SuperMontage and 0 for trades executed elsewhere. Trades are divided into customer buys and sells and modeled separately. Regression outcomes for both groups lead to similar conclusions;

hence, we only report the results for customer buys. A vector of independent variables includes three indicator variables that control for the state of the quotes on the venue being modeled: (i) quoting the NBBO (*at_nbbo*), (ii) being alone at the NBBO (*alone*), and (iii) having time priority (*prior*); (iv) a variable for quote depth (*depth*), variables for the (v) trading volume (*vol_10*) and (vi) volatility (*volat_10*) in the 10 minutes preceding a trade, (vii) a trade size variable (*size*), (viii) a price impact variable (*pimpact*), and (ix–xvii) nine indicator variables (not tabulated) for the intra-day intervals. All regressors other than the indicators are standardized by their sample means. The model accounts for fixed effects and non-spherical errors by allowing for clustering across stocks and employing the Huber-White estimator.

We expect venues that post quotes at the NBBO to have a higher probability of executing a trade, as non-preferenced orders should be attracted to venues with the best quotes. The results confirm this expectation, as coefficients of the *at_nbbo* variable are positive and significant in all four specifications. The effect is the weakest on SuperMontage, likely because of the dealers' preferencing practices. Being alone at the NBBO also has a positive effect on the probability of executions, with the coefficients of *alone* indicator variable being positive and significant for all four venues.

A quote that has time priority is expected to positively influence the probability of an execution on the venue that maintains such a quote. As more traders are likely to be aware of the best quote that has been outstanding for a period of time (even if only for several seconds) than of the matching quote that was just posted, the older quote is likely to attract additional order flow. The data agree with our expectations, as the coefficients of *prior* are positive and significant for all venues. Quotes with larger depths are expected to increase the probability of trade executions, as such quotes are less likely to be depleted while an order is in transit. This notion is partly confirmed by the interaction results in Table 6 that showed that ECN quotes with large depths are able to attract informed order flow that is otherwise routed to SuperMontage. Models in Table 11 corroborate this finding by delivering positive coefficients on the *depth* variables in all four specifications.

Increased trading volume (*vol_10*) is expected to have a positive effect on the probability of ECN executions, as, during active trading periods, liquidity on the limit order books should be high. As the models control for volatility, the *vol_10* variable only represents the high volume periods that are not accompanied by informational events. Volatility in the preceding 10 minutes (*volat_10*), on the other hand, is expected to decrease probability of executions on the ECNs due to the limit order books' susceptibility to frequent quote changes caused by limit order executions. Results in Table 11 confirm our expectations on the execution–volume relationship, as *vol_10* acquires a positive coefficient in the ECN specifications and a negative one for SuperMontage. The results on volatility are much weaker, with the coefficients on *volat_10* marginally significant only in the specifications for Island and Instinet. We attribute the weakness of volatility coefficients to the fact that the models include the *at_nbbo* and *prior* dummies and thus control for stability of the NBBO quotes. Trade size affects the probability of ECN executions negatively, as order matching software utilized by the networks often splits large orders into smaller trades.

Previous discussion shows that although informed traders prefer transacting via anonymous ECNs, liquidity and potential execution quality remain a serious concern. Results in Tables 5 suggest that informed traders use the ECNs only to trade the most

Table 11
Determinants of trade executions

Reported are the coefficients resulting from four logistic regressions, with the dependent variables equal to 1, if the executing venue is one of the four venues being examined in the study: SuperMontage, Archipelago, Island, or Instinet, and is equal to 0 otherwise. The displayed results are for the customer buy trades. Those for the customer sells are qualitatively similar and are omitted for the sake of brevity. The vector of independent variables consists of three indicator variables for (i) being at the NBBO, (ii) having time priority, and (iii) being alone at the NBBO; quoted depth, trading volume and volatility in the 10 min preceding the trade, trade size, trade's price impact, and nine dummy variables (not reported) that control for intraday patterns. All variables except indicators are adjusted by their sample stock-day means. The model is adjusted for stock-specific fixed effects and non-spherical errors. The regression coefficients for the intercepts are not tabulated. Coefficients for the independent variables are represented by their marginal effects. The global null hypothesis is tested with the Wald test. Goodman–Kruskal γ is used as a quasi-fit measure. (p-Values are noted below each coefficient in parentheses.) Superscripts ***, **, and * denote, respectively, significance at 0.01, 0.05, and 0.10 levels.

	SuperMontage	Arca	Island	Instinet
Quote competition variables				
at_nbbo	0.189***	0.337***	0.341***	0.310***
	(0.000)	(0.000)	(0.000)	(0.000)
alone	0.327***	0.418***	0.363***	0.480***
	(0.000)	(0.000)	(0.000)	(0.000)
prior	0.043***	0.004***	0.012***	0.001***
	(0.000)	(0.000)	(0.000)	(0.003)
depth	0.022***	0.139***	0.093***	0.089***
	(0.000)	(0.000)	(0.000)	(0.000)
Trade-related variables				
*vol*_10	−0.814***	0.529***	0.537***	0.620***
	(0.000)	(0.000)	(0.000)	(0.000)
*volat*_10	0.005	−0.001	−0.002*	−0.001*
	(0.484)	(0.792)	(0.092)	(0.079)
size	0.921***	−0.381***	−0.519***	−0.720***
	(0.000)	(0.000)	(0.000)	(0.000)
pimpact	−0.035	0.038**	0.041**	0.022*
	(0.163)	(0.029)	(0.017)	(0.084)
Wald's Pr $>\chi^2$	0.000	0.000	0.000	0.000
Goodman–Kruskal γ	0.611	0.918	0.840	0.814

liquid stocks and switch to SuperMontage for trades in the less active quintiles. Table 6 shows, however, that contingent on sufficient transient liquidity, informed traders may route to the ECNs. Since the models in Table 11 account for such transient liquidity by controlling for the presence at the NBBO and quoted depth, we expect the *pimpact* variable to mostly reflect the effect of anonymity of ECN executions. Thus, the coefficients of *pimpact* are expected to be positive for the ECN and negative for the SuperMontage. Our expectations are, for the most part, confirmed, with the ECN coefficients being positive and significant. The SuperMontage coefficient, however, is insignificant, most likely due to the SuperMontage ECNs.

In summary, regression models in Table 11 confirm our findings in the previous sections. Although the four major venues in the market for NASDAQ stocks differ on the basis of execution quality, perceived liquidity, and anonymity, quote competitiveness remains an important factor in attracting order flow.

7. Conclusion

This study investigates competition in the fragmented market for NASDAQ securities circa 2003. During this period, the marketplace was in its most segmented stage in recent years; with three non-primary venues capturing about 40% of trading volume. We show that the three identifiable ECNs: Archipelago, Instinet, and Island substantially differ from SuperMontage in that their trades are cheaper and quicker. In addition, the three ECNs provide the important benefit of anonymity and are able to supply substantial liquidity, albeit primarily in the 20 to 40 most active stocks. In the less liquid stocks, insufficient ECN liquidity induces informed traders to execute via SuperMontage. Further, we show that SuperMontage assumes the market making function, as it provides the most stable quotes and maintains these quotes during periods of high volatility when the ECN quotations are often withdrawn. The ECNs actively execute trades during periods when their quotes are not at the NBBO; however quotes remain a significant trade attraction tool.

This study examined trading in NASDAQ stocks during a period of significant fragmentation and competition. Since then, there has been a period of substantial consolidation, with the merger of Island and Instinet into INET in late 2003, NASDAQ's merger with Brut ECN in 2004, and NASDAQ's subsequent purchase of Instinet/INET in 2005. As a result of these mergers, NASDAQ's market share, which had fallen substantially over time, has rebounded.

A larger question is whether consolidation or competition is more important for market quality. While beyond the scope of this paper, we do note that even during the intensely competitive period examined in this study, the relative benefits of competition accrued to very few stocks. Only the most active of the most active stocks appear to have benefited from this extreme form of competition. For less frequently traded stocks, SuperMontage provided the essential benefit of dealer-supported liquidity that the ECNs were unable to offer. In many cases, SuperMontage demonstrated evidence of either lower trading costs, aggressive quoting behavior, or price discovery, although the ECNs, primarily Instinet and Archipelago did provide significant quote competition. Even so, SuperMontage quotes were superior in terms of executions, and tended to be more stable during periods of high volatility. Although this environment was one where both SuperMontage and the ECNs existed, there is some evidence that the ECNs benefited from the existence of SuperMontage and its quotes more than the other way around.

Ultimately, the extreme competition noted in this paper from the ECNs did damage NASDAQ's market share and order flow, and the profitability of NASDAQ as a market, particularly as some aspects of the regulatory environment was dissimilar for the ECNs and NASDAQ. The subsequent effort by NASDAQ to reclaim market share provides some indication that such fragmentation was, in the long term, untenable. Overall, based on the global trend of more and more marketplaces around the world moving to some sort of designated market maker system, the benefits of consolidation and coordination appear to outweigh the benefits of active external competition and fragmentation of order flow that might arise, particularly for less liquid securities.

Appendix A

Summary statistics for the sample stocks when grouped into quintiles based upon trading activity are shown in Table A1. Quintile 1 contains the most active stocks, while

Table A1

Quintile		Trades, #	Volume, # shares	Price, $	Trade size, shares	Market capitalization, $ million
1 (most active)	Mean	32,081	24,800,483	16.26	747.86	40,097
	Std. dev.	18,970	18,321,371	10.89	314.60	66,467
2	Mean	17,526	7,769,197	29.45	446.34	15,734
	Std. dev.	4,177	1,505,026	21.02	100.56	22,950
3	Mean	10,063	3,887,378	31.20	392.84	8,379
	Std. dev.	1,775	366,881	14.68	115.29	4,265
4	Mean	6,081	1,918,356	33.48	308.36	5,135
	Std. dev.	1,448	596,147	17.51	60.52	3,436
5 (least active)	Mean	3,062	885,273	36.07	267.99	3,298
	Std. dev.	1,094	556,853	11.17	58.49	1,191

quintile 5 contains the least active. Statistics include an average daily number of trades, daily volume, price, trade size, and market capitalization. All data except that for the market capitalization are derived from the TAQ database. Market capitalization data come from CRSP.

Averages are calculated by symbol-date, aggregated across dates, and assigned into quintiles.

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