The Quality of ECN and Nasdaq Market Maker Quotes

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ABSTRACT

This paper compares the quality of quotes submitted by electronic communication networks (ECNs) and by traditional market makers to the Nasdaq quote montage. An analysis of the most active Nasdaq stocks shows that ECNs not only post informative quotes, but also, compared to market makers, ECNs post quotes rapidly and are more often at the inside. Additionally, ECN quoted spreads are smaller than dealer quoted spreads. The evidence suggests that the proliferation of alternative trading venues, such as ECNs, may promote quote quality rather than fragmenting markets. Moreover, the results suggest that a more open book contributes to quote quality.

THIS PAPER EXAMINES THE QUALITY of quotes posted by electronic communication networks (ECNs) and by Nasdaq market makers for actively traded Nasdaq stocks. An important dimension of quote quality is price leadership, or price discovery, which is accomplished by timely submission of informative quotes. An informative quote reflects an asset's unobservable full-information value or fundamental value. Full-information value is distinct from the observable price, which can be decomposed into two components, one reflecting full-information value and one reflecting transitory effects. The latter consists of price movements due to the bid-ask bounce, temporary order imbalances, inventory adjustments, and rounding effects.

A study of the quality of ECN and Nasdaq market maker quotes is important because there are important differences between the two trading environments. ECNs are computer-mediated markets that disseminate limit orders from their subscribers and execute trades by matching orders. Instinet and Island are the two most liquid ECNs. Instinet was the first ECN and is mainly used by institutional traders and Nasdaq market makers as an alternative trading venue. By contrast, day traders often use Island to lay off

their positions. The distinctive features of ECNs are the absence of designated market makers and the ability of subscribers to trade anonymously. If ECN volume is great enough, liquidity traders may be attracted to ECNs because matched trades avoid the cost of bid-ask spreads. Further, if ECN quotes move first when volume is relatively large, this may be a manifestation of informed traders' preference for a liquid and anonymous trading environment.

Although trading mechanisms are judged on the basis of both price discovery and competitive transaction costs, much research has been devoted to the analysis of trading costs while the price discovery process has been relatively neglected.[1] Since quotes are widely disseminated, and since they provide input into investors' decisions, the timeliness of information reflected in the quotes is an important issue.

Knowing about quote quality is as important as knowing the size of the spread for both investors and regulators. Some market structures may generate larger or more frequent temporary price distortions, or may be prone to error. Further, both policy makers and traders are concerned with market stability and would like to know whether such distortions are associated with heightened price volatility, including bubbles and sudden market crashes.

An issue that is of current interest is whether the proliferation of alternative trading venues such as ECNs has adversely affected the price formation process by fragmenting markets.[2] Market fragmentation occurs when orders, which are dispersed over multiple trading centers, do not interact with one another. In a recent speech, Alan Greenspan, the Chairman of the Board of Governors of the Federal Reserve System remarked, "Concerns that this fragmentation will harm the price discovery process, investors' ability to obtain the best executions, and overall market liquidity are driving many policy questions. . . . Fragmentation thus raises both questions about the quality and completeness of the price discovery process and concerns that investors' orders to buy and sell securities may not be executed at the best price or the lowest cost. Fragmentation also creates the impression, and perhaps the reality, that separate pools of liquidity yield a lower volume of liquidity in the aggregate."[3] A central theme in this statement is price discovery when markets proliferate. This paper addresses this theme by examining the quotes submitted by alternative trading systems and Nasdaq market makers to determine whether both venues are contributing to quote quality.

The Nasdaq market structure relies on the competition between market makers to keep trading costs low and to promote price discovery. To further enhance the level of competition, the Securities and Exchange Commission (SEC) implemented the Order Handling Rules (OHR) in 1997. One provision

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[1] See Schreiber and Schwartz (1985) for a discussion of the price discovery objective in trading systems.

[2] Even trading hours have become disjoint with alternative trading venues taking the lead in extending trading beyond the usual time period.

[3] Remarks made before the 2000 Financial Markets Conference of the Federal Reserve Bank of Atlanta held in Sea Island, Georgia, October 16, 2000.

of the OHR, the Limit Order Display Rule, requires a market maker to display a customer's limit order if it is priced at or better than the market maker's current quote. This permits customers to compete directly with dealers' quotes.[4] Further, the SEC also imposes restrictions on quotes sent to ECNs. The ECN Rule requires that the best quotes offered by dealers to ECNs must be included in the Nasdaq national best bid and offer (NBBO) montage.[5] The OHR permit an analysis of bid and ask quotes submitted to the Nasdaq quote montage by ECNs and market makers.

An analysis of which venue provides more timely and informative quotes also is relevant to the recent debate on expanding pretrade transparency beyond the OHR. Nasdaq has proposed the so-called "Super Montage" that reflects not only the best price of each market participant, but two price levels away as well.[6] The structural design of ECNs induces quote-setting behavior that reveals more of the limit order book than do market makers.[7] For example, Island makes its entire limit order book available on its web site. If ECNs' quotes are found to be more informative and timely than market makers', the study would provide support for revealing more of the limit order book.

In contrast to the vast theoretic literature on trading costs, there are relatively fewer models of price discovery. Pure inventory models, such as Ho and Stoll (1983), do not consider informed trading and do not consider the role of price discovery by market makers. Adverse selection models, such as Kyle (1985) and Admati and Pfleiderer (1988), focus on the behavior of informed traders, but in these models, market makers do not actively engage in the price discovery process. In contrast, Leach and Madhavan (1992, 1993) model the price discovery behavior of market makers through intertemporal price experimentation. They note that price experimentation is a feature of specialist markets but is unlikely to exist in competing dealer markets, where a free-rider problem arises when other dealers observe the resulting price changes.

The empirical literature on price discovery is more extensive. The present paper is most closely related to the previous work on price discovery in multiple-trading environments. Garbade and Silber (1979) conclude that regional exchanges contribute to price discovery. Harris et al. (1995) use an error correction model to examine the discovery in IBM prices on the New York, Midwest, and Pacific Stock Exchanges. Harris, McInish, and Wood (1997) apply the common long-memory procedure of Gonzalo and Granger (1995) to estimate the relative contribution of the New York Stock Exchange (NYSE) to price discovery. The same methodology is used by Ding et al.

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[4] The words market makers and dealers are used interchangeably although, strictly speaking, only the former are registered with Nasdaq and are required to post two-way quotes.

[5] With the implementation of Regulation ATS in 1999, the biggest ECNs, including Instinet, transmit the best bid and offer quotes of all clients, and not just market makers, to the Nasdaq quote montage.

[6] The New York Stock Exchange has also proposed creating its own ECN called NYSeDirect+ to provide automatic execution for limit orders of 1,099 shares or less.

[7] The quote-setting behavior of ECNs is discussed in the following section.

(1998) to compare the contribution to price discovery of a Malaysian firm, Sime Darby Berhad, on the Kuala Lumpur Stock Exchange and on the Stock Exchange of Singapore.

The evidence presented in Section III of the present paper is most closely related to Hasbrouck's (1991, 1995) work on price discovery in multiple markets. The paper adopts Hasbrouck's measure of "who moves first" by estimating a Nasdaq quote participant's share of the variance of innovations in the common permanent price. When these innovations are due to information about the fundamental determinants of an asset's value, the participant's contribution is referred to as its information share. Hasbrouck compares the information shares of the NYSE and non-NYSE markets. He finds that for the 30 Dow stocks, the NYSE has almost the entire information share. The present paper differs from the earlier literature by focusing on the contribution to price discovery by examining the quote quality of competing Nasdaq dealers and ECNs.

This paper also uses an alternative measure of price leadership, Barclay and Warner's (1993) weighted price contribution (WPC) measure. Barclay and Warner used this methodology to identify which trades move prices, and it is used here to identify the venue contributing meaningful price movements. The WPC has the advantage of providing a single measure that can be used in cross-sectional analyses.

The study uses the Nastraq data set. The transactions data include bid and ask quotes identified by market participants. The analysis is based on a sample of the 30 most active stocks during two time periods, July 1998 and November 1999.

The Nastraq data set identifies quote data by Nasdaq participants, but it does not identify the trade data by participant. Unfortunately, the question of where information enters the market cannot be examined without the trade data. Thus, this paper cannot directly address the question of where informed traders might choose to trade.

An analysis of the most active Nasdaq stocks shows that ECNs not only post informative quotes, but also, compared to market makers, ECNs post quotes rapidly and are more often at the inside. Additionally, ECN quoted spreads are smaller than dealer quoted spreads. The evidence suggests that the proliferation of alternative trading venues, such as ECNs, may promote quote quality rather than fragmenting markets. Moreover, since ECNs reveal more of the limit order book than market makers, the results also suggest that there are benefits from the increased pretrade transparency provided by a more open book.

The remainder of the paper is organized as follows. Section I discusses more fully the differences in the market structure and the quote setting behavior of ECNs and Nasdaq market makers. Section II follows with a description of the data set. Section III presents the results based on information shares and includes a synopsis of the relevant cointegration econometrics. Section IV presents the results based on WPCs and also considers additional aspects of quote quality. The paper ends with a conclusion in Section V.

I. Market Structure and Quote-Setting Behavior

The Nasdaq market relies on competition between dealers for price discovery. To promote this competition, Nasdaq makes it easy for dealers to initiate market making in a stock or to withdraw from it. Wahal (1997) documents substantial initiation and withdrawal by market makers over time in Nasdaq stocks, with increases (reductions) in the number of market makers being associated with declines (increases) in spreads.[8]

While easy entrance and withdrawal from the Nasdaq market facilitates price formation, other attributes of the Nasdaq trading structure may conspire against it. Huang and Stoll (1996) find execution costs on Nasdaq to be greater than those on the NYSE and attribute the higher costs to the prevailing institutional arrangements that mitigate incentives for price competition. In particular, before the OHR were implemented in 1997, dealers did not display customers' limit orders, so that public limit orders could not compete with dealer quotes. In addition, dealers could post one price on Nasdaq while submitting more favorable prices to an alternative trading venue, such as Instinet, which is only accessible to the subscribers. These features may have adversely affected price discovery on the Nasdaq system. With the implementation of the OHR, public limit orders that are at the inside must be posted, and the best ECN quotes are disseminated and may be executed on the Nasdaq system. The integration of public and ECN order flow into the Nasdaq market may have resulted in better quote quality.

There are crucial differences between ECNs and traditional Nasdaq market makers. Unlike traditional market makers, ECNs have no designated market makers who expedite trades. This means that customer orders can be directly crossed with one another.[9] While this feature is especially attractive to liquidity traders, the lack of market makers means that quotes may be very far from the market, and thus uninformative, if liquidity deteriorates.

Traders are anonymous on ECNs, but not on Nasdaq. Anonymity facilitates the mingling of informed traders with liquidity traders, as in Admati and Pfleiderer (1988), resulting in better price discovery as information is incorporated into quotes. Therefore, the anonymity feature has the potential to encourage price leadership by ECNs at the expense of Nasdaq market makers.

A distinctive feature of the Nasdaq market is the presence of order preferencing arrangements. There are two forms of order preferencing. One form, internalization, is accomplished by sending orders to captive market makers. The second form is payment for order flow. In this case, orders submitted to Nasdaq may be preferenced to a specific dealer through SelectNet. In return for the order flow, which usually consists of retail orders, the dealer provides payment either in cash or in service to the broker. In either case, orders are sent to market makers who promise to match the NBBO. Con-

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[8] Huang and Masulis (1999) also find that spreads in the foreign exchange multiple dealer market drop with the entry of more dealers.

[9] The matching is possible for marketable limit orders.

trary to popular belief, preferenced dealers who do not have the best prices are not obligated to match the best bid or offer available for every order. As discussed by Smith (1999), the obligation for best execution only extends to those with whom the market maker maintains a customer relationship. With the order preferencing arrangements, there is less incentive to compete on price, since the market maker posting the best quotes may not receive the order. Moreover, the market maker may maintain a wider spread to discourage preferencing from unwelcome clients. In this environment, the information content of dealer quotes is suspect. In contrast, ECNs generally receive payment from brokers for order flow. The fee charged by ECNs may limit the uninformed retail order flow from brokers.[10]

The differences between ECNs and Nasdaq market structures generate important differences in how quotes are set by the two sets of quote participants. When an order arrives, an ECN quote may be revised for one of two reasons. First, if the order crosses with an order already in the limit order book, then the original order is canceled and replaced with the next best quote in the book. Second, if the order improves on the best quote available in the book, then the original quote is canceled and replaced by the new order. The two cases, an execution and a revealed desire to trade at a better price, both lead to quote submissions. On the other hand, if the order does not cross or set the quote, it joins the limit order book and no quote change occurs.

The quote-setting process for Nasdaq market makers is very different from the ECNs' process. The evidence presented below shows that quoted spreads on the ECNs are less than half the width of quoted spreads posted by Nasdaq market makers. This suggests that ECN quotes are more like effective spreads than Nasdaq quoted spreads and reflect information in recent trades. Market makers may choose to trade at better prices than their quotes. Thus, an execution through a market maker may not lead to a change in quotes, and quotes do not necessarily reflect the information in recent trades. Also, given that effective spreads are smaller than quoted spreads on Nasdaq, it is not clear that the market maker quotes reflect their desire to trade.

The difference in the quote-setting behavior between ECNs and Nasdaq market makers means that there are far more quote submissions from the former than from the latter. This is just a reflection of the difference in how the quotes are set in the two venues. As discussed above, most transactions on an ECN are likely to lead to a quote submission, which is not the case for market maker transactions. The evidence below bears this out and also shows that volume on ECNs is smaller, even though quotes are more frequent.

It is important to emphasize that the price discovery inferred from quotes does not necessarily reflect the venue where the informed trader trades. Informed traders may execute large volume through Nasdaq market makers, and, yet, since Nasdaq market makers have very wide quotes, the quotes themselves may move very little. On the other hand, the structure of the ECNs ensures that quote changes are more closely associated with transac-

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[10] The only exception to date is Island, which pays for (nonmarketable) limit orders.

tions. Therefore, the market maker quotes may not fully reflect the information that is being generated through trading activity at market makers.

There are also important differences among ECNs. Instinet is used by market makers who want to trade anonymously at their true reservation prices. On the other hand, Island is popular with day traders. Day traders, who are also referred to as Small Order Execution System (SOES) bandits, are informed traders who pick off market makers that are slow in updating their quotes.[11] As discussed by Harris and Schultz (1998), SOES traders often lay off their positions using Instinet or SelectNet, a Nasdaq order routing system. For day traders, timing is a crucial determinant in the choice of trading venue since their trading strategy calls for rapid buys and sells. With the development of ECNs, a popular alternative to Instinet or SelectNet is to trade through Island. Day traders are more likely to participate when there is heavy order flow on Island, thereby increasing the probability of finding an instant match. Island also makes available its entire order book on the Web. An issue that is of some interest is whether the presence of day traders improves or distorts the information in ECN quotes.

II. Data

The data is obtained from Nastraq, the Nasdaq trade and quote data set maintained by the NASD. It contains trade data, inside quote data, individual market maker quote data, and ECN quote data. Most importantly, the data identifies the participant posting bid and ask quotes.[12] The empirical analysis examines individual dealer and ECN quote data for July 1998 and November 1999. Comparison of the two sample periods, one-and-a-half years apart, provides some evidence on the robustness of our results. Each monthly sample includes data for the 30 stocks with the highest share volume during that month. The share volume figures are obtained from the Nasdaq web site. The stocks included in each sample are listed in Appendix A and consist primarily of technology and Internet firms.

The data is used to provide an analysis of quote quality. A focus on quote quality is especially appropriate in the current market setting, in which it is possible for a market maker to trade at the NBBO without posting NBBO quotes because of internalization, preferencing, and payment for order flow. Use of quote data also has the advantage of minimizing the problem of infrequent trading, since quote submissions are more frequent than trades. Higher quote frequency permits the specification of a smaller time interval in aligning the data across Nasdaq quote participants. An analysis of the time between successive quotes suggested that a one-minute time interval is feasible. A standing quote, which is the previously available quote within the day, is used if a quote is missing in a time interval. Consequently, in the

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[11] The behavior of SOES bandits is analyzed in several papers. For example, Battalio, Hatch, and Jennings (1997) examine the price volatility around SOES trading and Harris and Schultz (1998) examine their trading profits.

[12] However, ECNs are not required to post two-way quotes.

following analysis of information shares, all participants have the same number of quotes.[13]

The large number of Nasdaq market makers precludes analysis of individual dealers. Instead of using representative dealers, this study groups dealers into categories: major wholesalers, big wire houses, and key institutional brokers. The complete list of the dealers in each group is provided in Appendix B. Examples of major wholesalers are Knight/Trimark Securities and Mayer & Schweitzer. Examples of big wire houses, which are integrated retail and full discount brokers, are Dean Witter Reynolds and Merrill Lynch. Examples of the most important institutional brokers are Donaldson, Lufkin and Jenrette Securities, and Goldman Sachs. All the remaining Nasdaq market makers are grouped under "other market makers" category. This last category allows an examination of the behavior of small market makers. Appendix B also lists the individual ECNs. There are 9 ECNs in the July 1998 sample and 10 in the November 1999 sample.

Table I provides summary statistics for the sample, grouped by Nasdaq quote participants. The July 1998 sample includes over 5.5 million bid-ask spreads, and the November 1999 sample exceeds 9.3 million observations.[14] The first three rows in each panel of Table I contain statistics for ECNs. Instinet and Island account for more than 90 percent of all ECN quoted spreads in July 1998 and more than 93 percent in November 1999. As a group, ECNs submit more quotes to the Nasdaq market than all the traditional market makers combined, with the difference being greater in the later period. The difference between the number of quotes submitted by ECNs and Nasdaq dealers is probably understated. The number of quotes submitted to Nasdaq by an ECN is less than the number of best bid and ask quotes that cannot be crossed internally. This is because some ECN subscribers have the option of not submitting their quotes to the Nasdaq quote montage. The relatively larger number of quote submissions by Island is probably due to the presence of day traders who make rapid quote adjustments. The large number of ECN quote submissions reflects the limit order book structure of ECNs. As discussed in Section I, ECN trades are likely to result in a quote change. Among the traditional market makers, the smaller dealers post more quotes than all the major dealers combined.

Table I reveals dramatic differences in quoted spread width. Instinet and Island have the smallest mean and median quoted spreads. Following Instinet and Island in spread size are the wholesalers and wire houses. These two dealer categories reverse their relative positions in the two monthly samples. "Other ECNs" have wider spreads than Instinet and Island, and institutional brokers' spreads are even larger. The "other market makers" have the widest spreads. It also appears that while Instinet and Island spreads have declined, those of all the others have increased. As discussed in Sec-

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[13] As shown below, the ECNs have much more frequent quote submissions than other participants.

[14] In Table I, one-sided quotes are deleted. In the analysis that follows, bids and asks are examined separately and one-sided quotes are included.

Table I
Summary Statistics on Bid-Ask Quotes

The table presents statistics on number of spread submissions, quoted spreads, and depths by Nasdaq quote participants. The bid and ask sizes are in hundreds.

Group	# of Spread Submissions	Mean Quoted Spread	Median Quoted Spread	Mean Ask Size	Median Ask Size	Mean Bid Size	Median Bid Size
			Panel A: July 1998				
Instinet	757,228	0.4061	0.1875	22	10	21	10
Island	1,879,627	0.4315	0.1875	13	10	11	10
Other ECNs	268,567	1.2394	0.7500	10	6	9	5
Wholesaler	725,445	0.9605	0.6250	10	10	9	10
Wire house	328,850	0.7792	0.5000	11	10	10	10
Inst. broker	374,591	1.2691	0.7500	10	10	10	10
Other mkt. makers	1,188,941	1.7965	1.2500	8	10	8	10
			Panel B: November 1999				
Instinet	1,850,110	0.3223	0.1250	26	10	23	10
Island	2,951,670	0.3002	0.1875	15	10	13	10
Other ECNs	339,106	1.3398	0.5625	15	7	14	7
Wholesaler	1,317,830	0.9635	0.5000	7	3	6	2
Wire house	485,850	1.1679	0.6250	9	10	7	10
Inst. broker	558,612	1.3678	0.7500	7	10	7	10
Other mkt. makers	1,796,885	2.3012	1.5000	5	1	4	1

tion I, the tighter ECN spreads are due to the quote-setting behavior of ECNs, whereby ECN quotes more readily reflect information in the trades. Therefore, quoted spreads on ECNs are more like the smaller effective spreads. Of course, the differences in quoted spreads in Table I do not imply a true difference in effective spreads across participants. However, quoted spreads are still important for those traders who usually execute at the quotes.

Table I also presents depth, or quote size, statistics. Based on mean quote size, Instinet has by far the biggest depth and "other market makers" the smallest depth. Whereas the depth appears to have increased over time for ECNs, market makers' depth appears to have declined.[15] Because of institutional preferencing arrangements, the market makers' depth figures probably understate the firmness of the quotes.

Instinet and Island clearly stand out among the ECNs. They dominate by submitting the vast majority of quotes, having the smallest quoted spreads, and maintaining the biggest depth. Instinet and Island also cater to very different clienteles. Accordingly, Instinet and Island are examined individually. Because the quoted spreads of "other ECNs" are so wide, about three or four times that of Island and Instinet, the remainder of the paper excludes the "other ECNs" category. An earlier version of this paper finds that the "other market makers" make negligible contributions to price discovery. Thus, the present version excludes the "other market makers" category from further analysis.[16]

III. Information Shares of ECNs and Market Makers

Do dealers and ECNs post informative quotes? Do quotes on the same stock but from different participants contain common information on the underlying asset value? Do ECNs contribute to price discovery? An investigation of these questions provides insight into the effect of important institutional changes in the markets. Because ECNs offer a structurally different trading venue, we would like to know whether ECN prices are linked to traditional dealer prices. Moreover, we would like to know whether the presence of institutional preferencing arrangements hinders the price discovery process by encouraging quotes that are outside the NBBO.[17]

A. Cointegration Econometrics

This section reviews the pertinent cointegration econometrics for estimating information shares.[18] Let p_t be an $(n \times 1)$ vector of prices from n groups.

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[15] The median depth of the "other market makers" shows the effects of the reduction in the minimum quote size requirement for Nasdaq securities to 100 shares after July 1998.

[16] The results in the earlier version are consistent with those reported below.

[17] In contrast to quotes, trade prices are assumed to satisfy these presumptions, since arbitrage across markets would ensure that all trade prices reflect the same information. Indeed, insofar as each market promises to match the NBBO, price priority is generally maintained across markets. It is violated when an order in a market trades through prices in other markets.

[18] For more detailed reviews see, for example, Campbell and Perron (1991) and Banerjee et al. (1993).

If the prices are nonstationary, their future time path depends on past effects. Specifically, assume that all prices follow a random walk so that they are integrated of order one or I(1). This means that Δp_t is I(0), and is a stationary process.

Although the various prices are individually nonstationary, we expect them to be related to one another if they are all prices for the same underlying asset. This means that a linear combination of the prices may be stationary. We say that prices are cointegrated if there exists a nonzero vector b such that $b'p_t = e_t$ is stationary. The vector b is called a cointegrating vector and e_t can be interpreted as a deviation from long-run equilibrium. When e_t is stationary, prices do not drift too far from one another, suggesting that pricing errors are corrected over time.

There may be more than one cointegrating vector. For n prices, there may be up to $n - 1$ independent cointegrating vectors. This would be the case if all the prices have the same permanent component that follows a random walk.

The Granger Representation Theorem (Engle and Granger (1987)) proves that cointegrated variables could be equivalently represented either as a vector autoregression (VAR) in levels, or as an Error Correction Model (ECM), or as a vector moving average (VMA) representation. Suppose p_t can be expressed as a VAR:

$$p_t = \varphi_0 + \varphi_1 p_{t-1} + \ldots + \varphi_q p_{t-q} + \varepsilon_t, \tag{1}$$

where $E(\varepsilon_t) = 0$,

$$E(\varepsilon_t \varepsilon_\tau') = \begin{cases} \Omega & t = \tau \\ 0 & \text{otherwise.} \end{cases}$$

Then there exists an ECM:

$$\Delta p_t = -\pi p_{t-1} + \pi_1 \Delta p_{t-1} + \pi_2 \Delta p_{t-2} + \ldots + \pi_{q-1} \Delta p_{t-q+1} + \varepsilon_t, \tag{2}$$

where

$$\pi_j = -\sum_{i=j+1}^{q} \varphi_i \quad \text{for } j = 1, \ldots, q-1$$

$$\pi = I_n + \sum_{i=1}^{q} \varphi_i.$$

Alternatively, the cointegrated system can be formulated as a VMA by using the Wold decomposition theorem:

$$\Delta p_t = \Lambda(L) \varepsilon_t, \tag{3}$$

where $\Lambda(L) = \sum_{i=0}^{\infty} \Lambda_i L^i$.

The VMA representation can be rewritten as

$$\Delta p_t = \Lambda(1)\varepsilon_t + (1 - L)\sum_{i=0}^{\infty}\left(-\sum_{j=i+1}^{\infty}\Lambda_j\right)L^i\varepsilon_t, \tag{4}$$

where $\Lambda(1) = (I_n + \sum_{i=1}^{\infty}\Lambda_i)$. The matrix $\Lambda(1)$ contains the sums of all the moving average coefficients.[19] Thus, it provides the total impact of innovations on prices from all the Nasdaq quote participants. It can also be shown that $\Lambda(1)$ has rank $n - r$, where r is the number of cointegrating vectors of p_t.

Integrating (4) leads to the common trends representation proposed by Stock and Watson (1988):

$$p_t = p_0 + \Lambda(1)\sum_{i=1}^{t}\varepsilon_i + \Lambda^*(L)\varepsilon_t, \tag{5}$$

where $\Lambda^*(L)$ is a polynomial matrix with elements that are scalar polynomials in the argument L. The vector p_0 denotes the initial constant prices. The last term in (5) is a stationary process. The second right-hand term captures the stochastic trends common to prices from all dealers and is the driving force that results in cointegration. When p_t has $n - 1$ cointegrating vectors, the loading matrix $\Lambda(1)$ has rank 1. This means that all the rows of $\Lambda(1)$ are identical, showing the common cumulative impact on prices of innovations to the cointegrated system. Campbell and Mankiw (1987) and Cochrane (1988) have proposed alternative measures of persistence in p_t based on the common stochastic trend in (5). This paper uses the duality between the VAR representation (1) and the model (5) to estimate the long-run impact matrix $\Lambda(1)$.

A.1. Information Shares

If price innovations are due to new information, the term $\Lambda(1)\sum_{i=1}^{t}\varepsilon_i$ captures the permanent impact of new information on prices. This impact excludes all transient price effects: for example, bid-ask bounces and inventory adjustments. Hasbrouck (1991, 1995) proposes a measure of a market's contribution to price discovery based on this observation. Specifically, the total variance of the common stochastic trend is $\Lambda\Omega\Lambda'$, where Λ is any row in $\Lambda(1)$, and Ω is the $(n \times n)$ variance–covariance matrix of the innovations. Therefore, a measure of the share of this total variance that can be attributed to dealer j is

$$S_j \equiv \frac{\Lambda_j^2 \Omega_{jj}}{\Lambda\Omega\Lambda'}, \tag{6}$$

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[19] It is the $(n \times n)$ polynomial matrix $\Lambda(z)$ evaluated at $z = 1$.

where Λ_j is the jth element of Λ and Ω_{jj} is the jth diagonal element of Ω. The information share is a measure of price leadership. Indeed, the matrix π in the ECM (2) is often interpreted as providing information on the speed of adjustment to any deviation from long-run equilibrium.

The measure (6) is complicated by the fact that price innovations are generally correlated across Nasdaq participants so that Ω is not a diagonal matrix. This problem often arises in time-series econometrics and a typical approach is to diagonalize the matrix. This is frequently accomplished by finding the Cholesky factorization of Ω:

$$\Omega = FF', \tag{7}$$

where F is a unique lower triangular matrix. Using F, the price innovations can be orthogonalized as

$$\varepsilon_t = Fu_t, \tag{8}$$

where u_t has zero mean and its covariance is the identity matrix. This is equivalent to making the ith element of u_t orthogonal to all the innovations that precede it in the ordering. Therefore, the proportion of the information attributable to a participant would depend on its position in the vector. The first participant in the ordering would have the maximum information share and the last dealer would have the minimum. By changing the ordering, the upper and lower bounds of the information share of each participant can be estimated.

B. Information Content of Competitive Quotes

Do quotes from each market contain information about the underlying permanent asset value? To investigate this question, the analysis examines the stationarity characteristics of quotes. In general, prices contain errors that obscure the underlying full-information asset value. The pricing errors tend to be corrected over time and follow stationary processes. On the other hand, the information content of prices renders them nonstationary. The information-driven component is assumed to follow a random walk, which is a unit root process. This section examines whether quotes from Nasdaq market makers and ECNs contain unit roots.

There are numerous unit root tests in the literature. One of the most popular is the Augmented Dickey–Fuller test of unit root. The test involves estimating the following regression:

$$\Delta p_t = \gamma p_{t-1} + \sum_{i=2}^{l} \beta_i \Delta p_{t-i+1} + \eta_t, \tag{9}$$

where Δp_t is the first difference in prices. The appropriate number of lags (l) can be selected by using the Akaike information criterion (AIC). The null hypothesis of unit root specifies $\gamma = 0$, and Dickey and Fuller (1979) provide the critical values for the "t-tests."

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Table II

Tests of Unit Roots
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The table shows the Augmented Dickey–Fuller unit root "*t*-tests" of bid quotes by Nasdaq quote participant and by representative stock. Lags refer to the number of lags used in the test as determined by the Akaike Information Criterion. The "*t*-test" 1 percent critical value is -2.58, the 5 percent critical value is -1.95, and the 10 percent critical value is -1.62.

	Apple Computer July 1998 Sample		Applied Materials November 1999 Sample	
	Number of Lags	*t*-statistic	Number of Lags	*t*-statistic
Bid quotes				
Instinet	19	0.973	1	0.371
Island	20	0.982	3	0.359
Wholesaler	12	0.917	4	0.321
Wire house	6	0.682	4	0.231
Institutional broker	11	0.662	4	0.309
Change in quotes				
Instinet	20	-27.07	0	-111.43
Island	19	-27.66	2	-68.18
Wholesaler	11	-31.99	3	-58.94
Wire house	5	-44.67	3	-59.42
Institutional broker	10	-35.56	3	-56.95

Each set of unit root tests consists of estimating (9) for the quotes and the change in quotes on Instinet, Island, and the three groups of Nasdaq market makers. Since there are 30 stocks in each sample, this produces a total of 600 regressions for either the bid or the ask for each sample period. Given the large number of estimates and the similarity of the results, Table II presents only the results for the first stock, selected alphabetically in each monthly sample. The results in Table II are for bid quotes.[20] It shows the number of lags used in the regression and the "*t*-statistic" for each stock by different Nasdaq quote participants. The first five rows for each stock are the results of unit root tests for quote levels. The null of unit root is not rejected in every case. An implication of H1 is that if quotes are I(1), then first differences in quotes are stationary. The last five rows for each stock in Table II present the unit root tests of quote changes. In all cases, the null hypothesis of unit root is strongly rejected. The results suggest that quotes submitted by various Nasdaq participants contain information content. Therefore, despite the volatile nature of technology and Internet stocks, the increased number of alternative trading systems, and the presence of institutional preferencing arrangements, the markets have not fragmented to the point that quotes are uninformative.

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[20] Most of the results in the paper are presented only for bid quotes to avoid repeating similar results obtained for ask quotes.

C. Common Information in Competitive Quotes

In fragmented markets, quotes are primarily determined by supply and demand conditions within each trading venue. By contrast, proper price discovery requires that quotes from the various participants not only be informative but that they also reflect common information on the underlying asset. This means that quotes on the same asset must be cointegrated. Quotes from individual participants may be mispriced because of trading noise. However, in the long run, mispricing attracts orders that eliminate these errors. A cointegrating vector characterizes just such a long-run equilibrium condition.

When quotes from five participants are examined, cointegration among the quotes requires a total of four independent cointegrating vectors, the maximum possible. Proper price discovery stipulates the maximum because the relevant information driving the permanent price is common to all quotes on the stock. One common stochastic trend means four independent cointegrating vectors, and vice versa.

There are two main approaches to testing for cointegration. The first approach is the Engle–Granger (1987) two-step methodology, which requires the estimation of the ECM. A disadvantage of this approach is that the result of the cointegration test may depend on the participant chosen for the purpose of normalizing the cointegrating vector. The normalization is done to fix one of the components of the cointegrating vector at unity, because the cointegrating vector is not unique. The methodology is also difficult to apply to situations with more than two cointegrating vectors.

The second approach, used in this paper, is the Johansen (1988) maximum likelihood methodology. It does not have the disadvantages noted with the Engle–Granger approach. The estimation uses the duality between the VAR representation (1) and the ECM formulation (2) to test for cointegration. The results reported are based on estimating (1) with four lags.[21]

Johansen (1988) observes that the rank of the matrix π in (2) determines whether or not the quotes from various participants are cointegrated, and it determines the number of cointegrating vectors. Specifically, he provides two test statistics:

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{n} \ln(1 - \hat{\lambda}_i) \tag{10}$$

and

$$\lambda_{max}(r, r + 1) = -T \ln(1 - \hat{\lambda}_{r+1}), \tag{11}$$

where the n characteristic roots are ordered such that $\lambda_1 > \lambda_2 > \ldots > \lambda_n$ and T is the number of observations. The statistic λ_{trace} tests the null hypothesis that the number of cointegrating vectors is less than or equal to r against

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[21] Experimenting with different lags produces similar results.

Cointegration Tests

The table presents the results of Johansen cointegration tests for bid quotes of representative stocks.

Null H_0	Alternative H_1	Test Value	90% Critical Value
	Panel A: Apple Computer, July 1998 Sample		
	$\lambda_{trace}(r) = -T \sum_{i=r+1}^{n} \ln(1 - \hat{\lambda}_i)$ test		
$r = 0$	$r > 0$	2,538.96	55.54
$r \leq 1$	$r > 1$	1,745.70	36.58
$r \leq 2$	$r > 2$	1,097.87	21.58
$r \leq 3$	$r > 3$	501.04	10.35
$r \leq 4$	$r > 4$	0.70	2.98
	$\lambda_{\max}(r,r+1) = -T \ln(1 - \hat{\lambda}_{r+1})$ test		
$r = 0$	$r = 1$	793.27	18.96
$r = 1$	$r = 2$	647.83	15.00
$r = 2$	$r = 3$	596.83	11.23
$r = 3$	$r = 4$	500.35	7.37
$r = 4$	$r = 5$	0.70	2.98
	Panel B: Applied Materials, November 1999 Sample		
	$\lambda_{trace}(r) = -T \sum_{i=r+1}^{n} \ln(1 - \hat{\lambda}_i)$ test		
$r = 0$	$r > 0$	3,230.25	55.54
$r \leq 1$	$r > 1$	2,108.83	36.58
$r \leq 2$	$r > 2$	1,110.85	21.58
$r \leq 3$	$r > 3$	255.86	10.35
$r \leq 4$	$r > 4$	0.18	2.98
	$\lambda_{\max}(r,r+1) = -T \ln(1 - \hat{\lambda}_{r+1})$ test		
$r = 0$	$r = 1$	1,121.41	18.96
$r = 1$	$r = 2$	997.98	15.00
$r = 2$	$r = 3$	855.00	11.23
$r = 3$	$r = 4$	255.68	7.37
$r = 4$	$r = 5$	0.18	2.98

the alternative that it is greater than r. The statistic $\lambda_{\max}$ tests the null hypothesis that the number of cointegrating vectors equals r against the alternative that it is equal to $r + 1$.

The test results for all 30 stocks in each of the two samples are consistent with four cointegrating vectors. To illustrate, Table III reports the results for the first of the alphabetically arranged 30 stocks in each sample. The results for the two firms are similar; the quotes from the five groups of participants are cointegrated and the order of cointegration is four.

Table IV presents the estimated cointegrating vectors for the two firms shown in Table III, as an illustration of the estimated long-run equilibrium

Table IV
Cointegrating Relations

The table presents the cointegration vectors identified using Johansen cointegration procedures for bid quotes of representative stocks. *BA* are bid quotes for Instinet, *BB* are bid quotes for Island, *BC* are bid quotes for wholesalers, *BD* are bid quotes for wire houses, and *BE* are bid quotes for institutional brokers. The vectors are normalized by setting the coefficient for *BE* to unity.

Panel A: Apple Computer, July 1998 Sample
$BE_t + 0.476BD_t - 1.612BC_t + 0.253BB_t - 0.115BA_t = 0$
$BE_t - 0.443BD_t + 0.608BC_t - 1.082BB_t - 0.085BA_t = 0$
$BE_t - 2.414BD_t + 0.998BC_t + 1.185BB_t - 0.768BA_t = 0$
$BE_t - 16.061BD_t - 6.899BC_t - 0.401BB_t + 22.347BA_t = 0$

Panel B: Applied Materials, November 1999
$BE_t + 0.061BD_t - 0.738BC_t - 0.013BB_t - 0.309BA_t = 0$
$BE_t - 1.428BD_t + 1.225BC_t + 0.045BB_t - 0.845BA_t = 0$
$BE_t + 1.371BD_t + 2.056BC_t - 0.255BB_t - 4.165BA_t = 0$
$BE_t + 0.335BD_t + 1.171BC_t - 9.832BB_t + 7.328BA_t = 0$

conditions. Setting the coefficient of the institutional brokers' bid quote to unity normalized the four cointegrating vectors for each firm. The vectors show that quotes from all the participants are intimately related by the underlying common trend.

D. Contribution to Price Discovery

Do ECNs, or Nasdaq dealers, or both contribute to price discovery? In part, the answer to this question depends on where informed traders choose to trade. Informed traders may prefer the anonymity of ECN trading. If liquidity traders prefer to trade on ECNs, then informed traders will also want to trade on ECNs to mingle their trades with liquidity trades. Liquidity traders will prefer ECNs because their trade may execute against another order, thus avoiding the cost imposed by a market maker spread. However, this will only happen if there is adequate order flow to ensure that their order will probably be executed. Otherwise, the liquidity trader faces costs associated with nonexecution. On the other hand, the absence of dealers who commit their own capital to make a market may make ECNs less liquid and adversely affect quote quality. Designated market makers may provide firm meaningful quotes when liquidity traders will not. Liquidity traders will not submit limit orders to ECNs when their expected nonexecution costs exceed their execution cost savings.

The estimation methodology exploits the duality between the VAR representation (1) and the VMA formulation (3) to estimate the information share (6), using the covariance matrix of innovations diagonalized by the Cholesky

factorization procedure. Varying the ordering of the participants produces the maximum and minimum bounds on the information shares of the participants. Since an estimate of the information share's standard error is difficult to obtain, the analysis follows Hasbrouck (1995) in using the cross-sectional variation in the information share to determine the statistical significance of the estimates.

Table V, Panels A and B, present the information shares of the 30 most active stocks during July 1998 and November 1999, respectively. The shares represent the participant's relative contribution to the variation in the innovation of long-memory trend. Care must be exercised in interpreting the upper and lower bounds since they do not provide a single estimate of information share. The two panels show that the two ECNs, Instinet and Island, contribute to the price discovery process. Based on their mean lower bounds, Instinet and Island contribute at least 17 percent (16 percent) and 10 percent (17 percent) to price discovery during July 1998 (November 1999), respectively. These information shares exceed their share of trading volume.[22] The results indicate that both the market makers and institutional traders who use Instinet as well as the day traders who use Island post timely and informative quotes.

It is interesting to compare rankings across Nasdaq quote participants, assuming that the upper and lower bound information shares are valid indicators of actual information shares. We expect the information share attributed to ECNs to vary by stock, since the reliance on ECNs varies by stock. Yet the two ECNs have the highest shares in more than half of the 30 most active stocks during July 1998 and in every case except two during November 1999. There are also numerous cases in which Instinet's or Island's lower bound is greater than the Nasdaq market makers' upper bounds. The rankings based on the upper and the lower bounds are the same in almost every case for the 1998 sample and are identical in every case for the 1999 sample. Comparing the two ECNs, Instinet quotes contribute more to price discovery than Island quotes during July 1998. The November 1999 sample suggests that Island quotes have become relatively more informative, and that recently, the two ECNs are about equally important in the price discovery process. Among the Nasdaq market makers, the major wire houses tend to be top contributors more often than the wholesalers and the institutional brokers. However, wire houses' information shares appear to have declined relative to wholesalers' information shares from July 1998 to November 1999.

IV. Price Contributions of ECNs and Market Makers

The previous section uses cointegration econometrics to identify the venue providing the most timely and informative quotes. This section addresses

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[22] Trading volume is discussed in Table IX below.

the same issue by estimating the weighted price contributions (WPCs) of ECNs and Nasdaq market makers. The WPCs rely on the averaging process over time to remove or mitigate the effects of transitory price movements, whereas the cointegration analysis explicitly accounts for these movements. However, the cointegration analysis provides bounds on the information shares of each participant, while the WPC measure has the advantage of providing a single measure of price leadership.

Barclay and Warner (1993) propose the WPC measure to identify which trades move prices. Specifically, they use the WPC to estimate the extent to which price changes are associated with trades of various sizes. Cao, Ghysels, and Hatheway (2000) use the WPC to determine the price contribution of the Nasdaq preopening market to the daily price change. Barclay and Hendershott (2000) use it to investigate the price contribution of three after-hours time periods to the close-to-open price change.

The WPC is used here to identify the source of price movements. The WPC of participant j in stock i is computed as

$$WPC^{i,j} = \sum_{t=1}^{T} \left(\frac{|\Delta p_t^i|}{\sum_{t=1}^{T} |\Delta p_t^i|} \right) \left(\frac{\Delta p_t^{i,j}}{\Delta p_t^i} \right), \tag{12}$$

where p_t^i is the inside bid or ask of each stock i on day t and Δp_t^i is the daily quote change. The price change used here is from bid to bid (ask to ask), and the price change is credited to the venue that originated the second quote. The term $\Delta p_t^{i,j}$ is the sum of all quote changes for quotes emanating from venue j for firm i on day t. The second factor in parentheses on the right side of (12) is the relative contribution of quote participant j to the quote change on day t in stock i. This factor is weighted by the contribution of the absolute quote change during day t to the cumulative absolute quote change over the entire sample period.

The estimated WPCs are presented in Table VI. The means over the 30 stocks in each of the two sample periods show that the two ECNs are the first and second to post informative quotes, being price leaders in 23 stocks during July 1998 and 22 stocks during November 1999. Comparing the two ECNs, Instinet is the price leader more frequently than Island, but the difference between the two appears to have diminished over time. Among the Nasdaq market makers, quotes from wholesalers provide more timely information than those from wire houses and institutional brokers. The WPCs and the information shares in the previous section provide similar evidence regarding the relative importance of ECNs and Nasdaq market makers in the price discovery process, as well as regarding the relative ranking of the two ECNs. A major difference is that the price leader for an individual stock in Table VI varies substantially more between the two sample periods than the information shares do.

A modified version of the WPC can also be applied to the complete time series of quotes from the five participants in order to compare price leader-

Table V

Contributions to Price Discovery: July 1998 and November 1999

Panel A of the table presents the bid upper bound and lower bound information shares of Nasdaq quote participants for 1998 and Panel B presents the same information for November 1999. An asterisk identifies the biggest information share among the participating groups.

Symbol	Upper Bound					Lower Bound				
	Instinet	Island	Wholesaler	Wire House	Inst. Broker	Instinet	Island	Wholesaler	Wire House	Inst. Broker
Panel A: July 1998										
AAPL	0.319	0.231	0.348*	0.312	0.307	0.143*	0.108	0.140	0.112	0.123
AFCI	0.340	0.144	0.141	0.465*	0.293	0.191	0.083	0.049	0.242*	0.132
AMAT	0.527*	0.257	0.342	0.207	0.142	0.255*	0.096	0.159	0.081	0.051
AMGN	0.290	0.044	0.155	0.423	0.432*	0.156	0.020	0.078	0.223	0.240*
AMZN	0.796	0.867*	0.213	0.099	0.106	0.072*	0.007	0.018	0.011	0.013
ASND	0.644*	0.186	0.196	0.108	0.331	0.356*	0.063	0.056	0.037	0.135
COMS	0.175	0.414*	0.310	0.305	0.184	0.085	0.226*	0.157	0.146	0.082
CSCO	0.397	0.445	0.378	0.489*	0.186	0.097	0.133*	0.074	0.132	0.026
DELL	0.392	0.832*	0.182	0.484	0.196	0.073	0.245*	0.003	0.050	0.008
EGGS	0.160	0.930*	0.567	0.131	0.140	0.016	0.341*	0.048	0.000	0.000
ERICY	0.136	0.086	0.556	0.579*	0.441	0.033	0.023	0.157	0.166*	0.088
HBOC	0.292	0.220	0.305	0.519*	0.223	0.115	0.090	0.096	0.227*	0.072
INTC	0.757*	0.242	0.419	0.371	0.206	0.254*	0.038	0.065	0.039	0.023
LCOS	0.365	0.710*	0.379	0.347	0.134	0.083	0.241*	0.050	0.046	0.021
MSFT	0.753*	0.348	0.274	0.428	0.186	0.243*	0.059	0.026	0.066	0.023
NOVL	0.365*	0.224	0.294	0.130	0.174	0.264*	0.170	0.197	0.095	0.109
NSCP	0.439	0.584*	0.357	0.343	0.168	0.122	0.168*	0.061	0.076	0.029
NXTL	0.414*	0.041	0.183	0.310	0.252	0.317*	0.030	0.109	0.204	0.164
ORCL	0.565*	0.177	0.214	0.142	0.215	0.378*	0.089	0.102	0.068	0.108
PMTC	0.505	0.347	0.603*	0.522	0.425	0.092	0.037	0.107*	0.052	0.030
PSFT	0.231	0.343	0.283	0.578*	0.234	0.069	0.124	0.079	0.230*	0.047
QWST	0.101	0.133	0.315	0.449*	0.315	0.061	0.077	0.180	0.249*	0.170
SPLS	0.633*	0.031	0.138	0.134	0.202	0.546*	0.017	0.092	0.095	0.127
SUNW	0.369	0.115	0.215	0.473*	0.334	0.161	0.042	0.074	0.222*	0.128
TCOMA	0.483*	0.013	0.160	0.222	0.260	0.399*	0.001	0.121	0.168	0.187
TLAB	0.125	0.053	0.329	0.353	0.464*	0.072	0.033	0.187	0.181	0.256*
WAMU	0.477	0.164	0.341	0.426	0.526*	0.139*	0.036	0.044	0.102	0.123
WCOM	0.528*	0.124	0.324	0.371	0.231	0.263*	0.042	0.095	0.132	0.063
XCIT	0.373	0.741	0.622	0.919*	0.237	0.005	0.041	0.001	0.165*	0.000
YHOO	0.345	0.795*	0.399	0.264	0.087	0.035	0.306*	0.054	0.044	0.011
Mean	0.410	0.328	0.318	0.363	0.254	0.170	0.100	0.089	0.122	0.086
Std. dev.	0.187	0.281	0.134	0.179	0.112	0.132	0.091	0.054	0.076	0.071
Std. error of mean	0.034	0.051	0.025	0.033	0.020	0.024	0.017	0.010	0.014	0.013

	Panel B: November 1999									
AMAT	0.853*	0.320	0.248	0.163	0.262	0.350*	0.034	0.032	0.020	0.028
AMGN	0.920*	0.688	0.798	0.904	0.835	0.020*	0.015	0.001	0.015	0.008
AMTD	0.295	0.818*	0.422	0.132	0.105	0.062	0.308*	0.064	0.016	0.015
AMZN	0.425	0.933*	0.365	0.050	0.096	0.050	0.373*	0.005	0.000	0.006
ATHM	0.579	0.763*	0.273	0.134	0.106	0.137	0.237*	0.028	0.019	0.011
CIEN	0.258	0.681*	0.300	0.108	0.194	0.085	0.345*	0.092	0.030	0.051
CMGI	0.385	0.845*	0.533	0.177	0.030	0.056	0.239*	0.059	0.016	0.000
COMS	0.345	0.654*	0.300	0.108	0.147	0.121	0.313*	0.093	0.027	0.041
CORL	0.090	0.919*	0.668	0.277	0.203	0.000	0.231*	0.038	0.023	0.003
CPWR	0.280	0.203	0.215	0.315*	0.209	0.186	0.223*	0.117	0.144	0.138
CSCO	0.844*	0.782	0.411	0.311	0.210	0.111*	0.067	0.015	0.009	0.013
DELL	0.882*	0.741	0.259	0.116	0.083	0.203*	0.088	0.005	0.002	0.004
EGRP	0.183	0.893*	0.354	0.036	0.020	0.036	0.507*	0.057	0.003	0.001
GBLX	0.524*	0.218	0.346	0.421	0.136	0.242*	0.029	0.110	0.157	0.032
IFMX	0.195	0.472*	0.390	0.134	0.122	0.102	0.285*	0.237	0.064	0.055
INTC	0.904*	0.507	0.413	0.231	0.139	0.262*	0.029	0.017	0.017	0.009
MSFT	0.929*	0.716	0.570	0.368	0.295	0.121*	0.037	0.012	0.000	0.008
NETA	0.530*	0.446	0.247	0.143	0.150	0.244*	0.172	0.085	0.050	0.064
NITE	0.262	0.831*	0.446	0.222	0.219	0.031	0.266*	0.060	0.026	0.018
NOVL	0.587*	0.418	0.321	0.254	0.111	0.245*	0.092	0.098	0.069	0.031
NXTL	0.610*	0.100	0.257	0.146	0.266	0.364*	0.024	0.116	0.067	0.127
ORCL	0.747*	0.629	0.585	0.276	0.258	0.143*	0.054	0.008	0.009	0.009
PSFT	0.263	0.628*	0.223	0.246	0.039	0.095	0.348*	0.094	0.127	0.014
QCOM	0.640	0.647*	0.436	0.215	0.024	0.144	0.160*	0.055	0.032	0.006
QWST	0.318	0.552*	0.309	0.172	0.046	0.136	0.311*	0.141	0.076	0.021
SPLS	0.137	0.571*	0.185	0.398	0.324	0.040	0.242*	0.039	0.144	0.104
SUNW	0.825*	0.441	0.512	0.392	0.207	0.192*	0.035	0.048	0.018	0.013
WCOM	0.916*	0.202	0.241	0.024	0.084	0.550*	0.027	0.033	0.005	0.013
XLNX	0.196	0.236	0.134	0.493*	0.234	0.107	0.135	0.058	0.325*	0.136
YHOO	0.892*	0.477	0.104	0.045	0.020	0.459*	0.084	0.005	0.008	0.002
Mean	0.527	0.578	0.362	0.234	0.172	0.163	0.174	0.063	0.053	0.033
Std. dev.	0.285	0.235	0.158	0.176	0.153	0.131	0.134	0.052	0.074	0.041
Std. error of mean	0.052	0.043	0.029	0.032	0.028	0.024	0.024	0.009	0.014	0.007

Table VI
Weighted Price Contributions

The table presents the proportion of the daily change in bid quotes accounted for by various Nasdaq quote participants. An asterisk identifies the biggest weighted price contribution among the participating groups.

Symbol	July 1998					November 1999				
	Instinet	Island	Wholesaler	Wire House	Inst. Broker	Instinet	Island	Wholesaler	Wire House	Inst. Broker
AMAT	0.3308	0.3613*	0.1754	0.0290	0.1037	0.4177*	0.4038	0.0513	−0.0178	0.1450
AMGN	0.1611	0.2580	0.2831*	0.2439	0.0540	0.5057*	0.3224	0.0047	−0.0349	0.2021
AMTD	0.2946	0.4795*	0.0434	0.0914	0.0914	0.5911*	0.1860	0.1091	0.0840	0.0300
AMZN	0.1639	0.2943	0.0319	−0.0901	0.6003*	0.3496	0.6155*	−0.0091	0.0716	−0.0276
ATHM	0.1072	0.7656*	0.1098	0.0346	−0.0170	0.1140	0.4528*	0.0733	0.3099	0.0502
CIEN	0.7712*	0.1433	0.0404	−0.0345	0.0796	0.2802*	0.2217	0.1928	0.0981	0.2073
CMGI	0.3802*	0.1508	0.2191	0.1482	0.1018	0.5075*	0.1818	0.2315	0.0580	0.0213
COMS	0.0487	0.0923	0.0702	0.0345	0.7544*	0.4832*	0.0708	0.4352	−0.0012	0.0120
CORL	0.2958*	0.2932	0.1981	0.0844	0.1286	0.0405	0.5245*	0.3534	0.0565	0.0253
CPWR	0.7810*	0.1470	0.0442	0.0309	−0.0029	0.4703*	0.3273	0.0012	0.0069	0.1945
CSCO	0.3553*	0.2652	0.0985	0.2854	−0.0043	0.3462*	0.1969	0.0947	0.0385	0.3238
DELL	0.3964*	0.3575	0.0991	0.0823	0.0648	0.0355	0.4637*	0.4200	0.0221	0.0589
EGRP	0.4768*	0.1825	0.3286	−0.0322	0.0444	0.2921*	0.2340	0.1493	0.0411	0.2836
GBLX	0.2200	0.2605	0.2766*	0.1822	0.0609	0.3918	0.0872	0.4473*	0.0182	0.0556
IFMX	0.7014*	0.1757	0.0776	0.0023	0.0430	0.0401	0.0524	0.0404	0.8093*	0.0579
INTC	0.4802	0.0126	0.0077	0.0116	0.4881*	0.0732	0.7666*	0.0814	0.0666	0.0123
MSFT	0.1064	0.3551*	0.3139	0.1304	0.0944	0.0526	0.2354	0.1837	0.1076	0.4207*
NETA	0.3438	0.3872*	0.1320	0.1059	0.0313	0.7253*	−0.0457	0.0236	0.3033	−0.0064
NITE	0.6914*	0.1172	0.0391	0.0743	0.0782	0.3675	0.1596	0.3746*	0.0824	0.0161
NOVL	0.3844*	0.1726	0.3306	0.1010	0.0114	0.3801	0.4107*	0.1795	0.0153	0.0145
NXTL	0.2075	0.1542	0.6029*	0.0269	0.0087	0.2142	0.0628	0.6390*	0.0005	0.0838
ORCL	0.3086	0.4078*	0.1076	−0.0201	0.1962	0.6632*	0.1246	0.0908	−0.0028	0.1242
PSFT	0.4162*	0.3063	0.0799	0.1702	0.0275	0.4502	0.4516*	0.0656	0.0075	0.0252
QCOM	0.5018*	0.2268	−0.0535	0.3233	0.0017	0.4132	0.4383*	0.1075	0.0080	0.0331
QWST	0.7139*	0.1745	−0.0991	0.1793	0.0315	0.0313	0.0347	0.9598*	−0.0349	0.0092
SPLS	0.6901*	0.1918	0.0188	0.0371	0.0624	0.3011	0.3457*	0.1500	0.0892	0.1142
SUNW	0.3325	0.4511*	0.0528	0.0965	0.0671	0.2864	0.0454	0.7656*	−0.0694	−0.0280
WCOM	0.3750*	0.3709	0.1459	0.0333	0.0750	0.4349*	0.1021	0.0708	0.0403	0.3519
XLNX	0.1132	0.2432	0.5178*	0.0940	0.0320	0.0657	0.2312	0.4187*	0.1476	0.1370
YHOO	0.2506	0.5440*	0.1356	0.0183	0.0516	0.8149*	0.1118	0.0707	−0.0113	0.0139
Mean	0.3800	0.2780	0.1476	0.0825	0.1120	0.3380	0.2605	0.2259	0.0770	0.0987
Std. dev.	0.2101	0.1540	0.1565	0.0948	0.1793	0.2154	0.1940	0.2396	0.1618	0.1188
Std. error of mean	0.0384	0.0281	0.0286	0.0173	0.0327	0.0393	0.0354	0.0437	0.0295	0.0217

ship across intraday time periods.[23] For this purpose, the modified WPC is computed as

$$MWPC_k^{i,j} = \sum_{t=1}^{T} \left(\frac{|\Delta p_t^{i,j}|}{\sum_{t=1}^{T} |\Delta p_t^{i,j}|} \right) \left(\frac{\Delta p_{k,t}^{i,j}}{\Delta p_t^{i,j}} \right), \tag{13}$$

where $p_{k,t}^{i,j}$ is the quote at period k on day t by Nasdaq participant j in stock i. The second factor in parentheses on the right side of (13) measures the fraction of the open-to-close quote change on each day t that is accounted for by the quote change during period k. This fraction is weighted by the contribution of the absolute quote change during day t to the cumulative absolute quote change over the entire sample period. Measure (13) is calculated not only for each stock but also for each Nasdaq quote participant. Although not as direct a measure of price leadership as (12), it allows comparison of the cumulative percentage of the daily quote change that is realized at various times during the trading period.

Table VII reports the MWPC (13) averaged over all stocks or $WPC_k^j = 1/30 \sum_{i=1}^{30} WPC_k^{i,j}$. Although the weighted price contribution is estimated for every minute, only the results on the half-hour are reported. Table VII shows that Instinet and Island are price leaders among the Nasdaq quote participants. During the earlier sample period, Instinet quotes have a higher percentage of the daily quote changes than Island in half the time slots, and, during November 1999, Island is ahead of Instinet from the start of trading at 9:30 a.m. until half an hour before closing. Among the market makers, quotes from wholesalers tend to account for more of the daily quote changes on the hour than the wire houses and the institutional brokers. Comparing the latter two Nasdaq participants, there is no clear pattern of price leadership. These results are also comparable to those observed with information shares and WPC.

There is another approach in the literature that addresses the issue of which market moves prices first when an asset is traded on multiple markets. Stoll and Whaley (1990) and Easley, O'Hara, and Srinivas (1998) offer examples of this work. With this approach, temporal precedence is interpreted as Granger causality: Prices in market A Granger cause prices in market B, if lagged A prices predict movements in B prices, after accounting for lagged B prices. This analysis is typically performed using price returns rather than price levels. However, the lead-lag representation for Granger causality in returns does not exist if price levels have unit roots as illustrated in Table II. Thus, this section uses the WPC measure to determine price leadership.

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[23] The information shares also examine the complete time series of quotes from the five participants whereas the WPC in (12) is based on the inside quotes during the day.

Table VII
Modified Weighted Price Contributions

The table presents the cumulative mean weighted bid quote contributions by Nasdaq quote participants over 30 stocks on the half hour.

Time	July 1998					November 1999				
	Instinet	Island	Wholesaler	Wire House	Inst. Broker	Instinet	Island	Wholesaler	Wire House	Inst. Broker
10:00	0.257	0.234	0.249	0.211	0.192	0.326	0.343	0.290	0.292	0.304
10:30	0.365	0.348	0.341	0.311	0.327	0.420	0.449	0.422	0.393	0.436
11:00	0.446	0.427	0.424	0.396	0.393	0.475	0.507	0.479	0.488	0.481
11:30	0.473	0.459	0.468	0.442	0.443	0.513	0.543	0.511	0.502	0.486
12:00	0.504	0.532	0.522	0.498	0.482	0.554	0.574	0.561	0.539	0.528
12:30	0.574	0.584	0.575	0.542	0.549	0.589	0.607	0.578	0.562	0.576
13:00	0.580	0.614	0.608	0.574	0.589	0.631	0.655	0.639	0.626	0.626
13:30	0.598	0.617	0.645	0.590	0.613	0.685	0.695	0.675	0.677	0.675
14:00	0.647	0.646	0.647	0.620	0.633	0.730	0.744	0.711	0.701	0.698
14:30	0.683	0.723	0.712	0.684	0.691	0.771	0.779	0.758	0.748	0.762
15:00	0.743	0.766	0.771	0.739	0.771	0.804	0.827	0.794	0.794	0.778
15:30	0.817	0.810	0.832	0.803	0.814	0.891	0.889	0.873	0.872	0.878
16:00	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

A. Best Price

Another aspect of price quality is best price. The highest bid and the lowest ask constitute the NBBO and create the inside spread. How do Instinet and Island compare to Nasdaq market makers and to one another with regard to the percentage of quotes at the inside?

Bid-ask quotes play a central role in studies of dealer competition and trading costs, and this literature has grown rapidly in recent years. Christie and Schultz's (1994) conclusion that Nasdaq dealers tacitly collude to maintain wide spreads by avoiding odd-eighth quotes motivated numerous academic studies.[24] Their analysis also prompted lawsuits and government investigations. Studies of the impact of the OHR find that the rules had a profound effect on trading costs. Barclay et al. (1999) report that following the rule changes, bid-ask spreads declined approximately 30 percent. Simaan, Weaver, and Whitcomb (1998) examine the quotation behavior of ECNs and Nasdaq market makers. They find that following the tick size reduction from eighths to sixteenths on June 2, 1997, Nasdaq market makers still appear to be avoiding odd ticks (odd sixteenths), but that limit orders from the ECNs do not appear to have such biases.

Being a price leader is not necessarily associated with the frequency with which best prices are posted. The information share and the WPC measure the participant's contribution to timely movements of permanent prices, presumably movements toward its unobservable true fundamental value. As such, it is possible for a dealer who often posts the best prices to have minimal contribution to price discovery, if the dealer's prices reflect temporary effects. The separation of price leadership and frequency at best price is exacerbated by the institutional practices of preferencing, internalization, and payment for order flow.

Table VIII, Panels A and B, report the results for the analysis of the percentage of quotes that are at the inside, categorized by stock and by participant, for July 1998 and November 1999, respectively. The evidence is presented for the percentage of quotes at the inside bid, at the inside ask, and for simultaneous inside bid and ask. All three measures lead to similar inferences. The two ECNs, Instinet and Island, are the two top participants with the highest percentages at the inside. Instinet has more quotes at the inside than Island during July 1998, but Island appears to have narrowed the gap during November 1999. As for market makers, wire houses have more quotes at the inside than wholesalers during July 1998, but the ranking reverses during November 1999. These results are a reflection of differences between ECNs and Nasdaq market makers with regard to how quotes are set as discussed in Section I. Recall that the limit order book structure of ECNs ensures that quotes from ECNs are more like effective spreads than quoted spreads and reflect the information in recent trades.

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[24] For example, the theoretical works include Dutta and Madhavan (1997), Kandel and Marx (1999), and Lamoureux and Schnitzlein (1997). For examples of empirical work, see the July 1997 issue of the *Journal of Financial Economics*.

Table VIII

Quotes at the Inside: July 1998 and November 1999 Samples

Panel A of the table presents the percentage of quotes by Nasdaq quote participants that are at the inside bid, at the inside ask, and at the inside bid and ask simultaneously for July 1998. Panel B presents the same information for November 1999.

Symbol	Percentage at the Inside Bid					Percentage at the Inside Ask					Percentage at the Inside Bid and Ask				
	Instinet	Island	Wholesaler	Wire Hse.	Inst. Broker	Instinet	Island	Wholesaler	Wire Hse.	Inst. Broker	Instinet	Island	Wholesaler	Wire Hse.	Inst. Broker
						Panel A: July 1998 Sample									
AAPL	54	35	32	24	34	52	39	38	24	28	26	13	10	4.3	5.5
AFCI	60	20	29	24	22	51	23	27	21	27	31	6.1	7.3	3.6	3
AMAT	62	53	38	34	35	62	59	36	33	27	36	28	11	6.3	5.8
AMGN	45	25	10	30	41	49	33	18	34	33	20	8.2	1.1	9	14
AMZN	29	72	12	4.5	3.7	29	76	11	4.4	2.8	7.3	53	0.72	0.17	0.06
ASND	51	42	17	23	38	54	46	24	26	32	26	18	2.3	4.8	9.6
COMS	59	58	35	44	38	64	57	27	36	32	36	30	7.7	16	8
CSCO	54	59	23	28	31	49	61	17	28	35	25	33	3.4	6	9.9
DELL	49	66	20	22	23	45	69	20	20	23	21	41	2.6	3.2	4
EGGS	46	63	44	9.7	9.6	38	64	47	8.6	14	16	40	19	0.49	1.1
ERICY	75	32	24	33	11	79	40	20	24	11	58	11	3.1	5	0.47
HBOC	53	39	28	31	31	57	45	18	27	32	28	16	3.8	8.1	7.4
INTC	58	56	27	30	40	60	62	47	32	27	32	31	10	8.1	9
LCOS	42	57	23	6.8	3.7	38	65	17	5.5	4.5	15	37	3.1	0.12	0.16
MSFT	64	53	20	27	25	64	59	20	27	21	39	28	2.9	5.2	3.7
NOVL	69	30	45	41	39	79	36	50	54	33	53	9.1	19	17	7
NSCP	43	56	34	25	22	41	62	33	21	18	17	33	9.3	4.4	3.1
NXTL	59	26	22	22	38	57	29	28	24	29	32	6.8	4.4	4.4	8.1
ORCL	75	51	34	35	44	79	59	52	41	34	57	27	14	10	10
PMTC	71	39	36	37	42	70	43	21	45	31	49	15	6	14	8.6
PSFT	48	41	33	26	28	45	42	26	27	27	21	16	7.3	5.1	4.5
QWST	61	23	15	33	29	58	27	19	41	32	35	6.9	2.2	11	7.1
SPLS	75	18	13	32	25	82	22	14	22	22	60	3.3	1.5	4.3	1.7
SUNW	61	35	21	33	29	60	43	28	38	22	34	14	3.8	10	4.2
TCOMA	53	23	15	47	33	56	34	28	48	32	29	5.8	2.4	22	6.1
TLAB	47	34	16	27	21	53	46	10	22	22	23	15	1.1	4.5	3.1
WAMU	51	40	13	40	27	63	39	15	34	15	33	11	1.3	16	2.4
WCOM	75	45	40	44	36	76	50	29	37	35	55	19	8.4	17	8.5
XCIT	35	61	29	2.9	3.3	32	69	21	3.9	4.3	10	41	5.6	0.01	0.09
YHOO	34	65	15	3.6	7.5	34	68	12	4	7.6	11	43	1.2	0.01	0.34
Mean	55	44	25	27	27	56	49	26	27	24	31	22	6	7	5

AMAT	58	46	32	9.7	30	64	51	26	13	27	31	19	6.3	0.85	5.6
AMGN	55	42	29	29	29	59	42	36	20	23	28	11	11	4.6	4.1
AMTD	49	65	57	22	16	51	67	57	17	8.1	20	41	32	3.2	0.43
AMZN	55	62	38	11	22	56	62	33	13	23	22	31	12	1	3.8
ATHM	59	58	46	29	18	57	62	46	23	17	28	30	19	5.2	2.5
CIEN	42	52	29	14	28	40	54	33	14	25	15	22	6.6	2.4	4.9
CMGI	51	43	38	9.4	8.6	46	42	40	9.1	11	18	16	13	0.54	0.56
COMS	71	53	36	26	36	71	62	43	35	28	47	28	14	9.6	8.1
CORL	53	46	56	15	9	39	54	54	17	9.9	20	24	29	1.8	0.39
CPWR	52	40	29	44	32	54	49	31	33	26	26	13	6.7	13	5.2
CSCO	71	65	44	36	34	71	63	36	31	34	45	35	16	12	11
DELL	80	72	59	46	56	78	77	60	38	50	59	52	32	17	27
EGRP	48	63	55	20	25	56	67	60	20	15	24	36	32	3.8	1.9
GBLX	58	43	60	47	31	65	54	47	37	29	32	17	26	17	5.7
IFMX	51	43	44	24	42	45	52	55	29	26	19	20	24	5.8	8.1
INTC	69	66	53	38	37	71	65	52	33	35	43	36	26	11	11
MSFT	73	66	39	39	45	75	66	46	38	40	50	37	17	16	16
NETA	62	50	42	21	31	56	61	45	24	33	32	24	18	4.8	7
NITE	49	59	51	15	14	47	61	54	17	11	19	30	25	2.4	0.79
NOVL	75	58	48	26	31	72	65	46	27	26	52	31	20	4	5.9
NXTL	58	25	37	12	28	58	32	29	17	27	31	8.1	8.5	1.6	6
ORCL	59	56	49	33	46	63	67	50	30	37	30	31	22	8.9	15
PSFT	56	54	47	32	32	55	62	43	27	28	28	29	18	7.7	6.2
QCOM	52	39	30	9.9	9.7	48	44	24	10	7.5	18	13	5.7	0.89	0.57
QWST	68	56	45	45	35	76	62	40	34	31	49	28	14	16	8
SPLS	58	54	50	44	42	69	59	33	27	34	37	26	14	10	12
SUNW	59	47	36	22	33	64	46	32	22	35	31	18	9.2	4.1	9.7
WCOM	73	50	37	27	33	68	52	33	21	28	46	19	9.9	4.4	7.1
XLNX	53	25	32	26	25	52	32	23	20	27	23	8	6.5	5	4.4
YHOO	61	33	22	6.6	15	54	42	20	5.8	19	27	13	3.6	0.29	1.9
Mean	59	51	42	26	29	59	56	41	23	26	32	25	17	6	7

B. Market Liquidity

This section explores the environment within which price discovery occurs. Specifically, it considers the relation between market liquidity and price leadership by Nasdaq quote participants. The use of WPC (12) provides a single measure of price leadership that can be used in cross-sectional analyses for this purpose.

The differences in institutional arrangements between ECNs and Nasdaq market makers have implications for the relation between price leadership and market liquidity. First, consider the price discovery environment for ECNs. Informed traders, who are key to the price discovery process, may be attracted to ECNs because they can trade anonymously. However, anonymity alone is insufficient since informed traders need somebody to trade with. As Admati and Pfleiderer (1988) pointed out, informed traders prefer to trade during times when liquidity traders are in the market.

Liquidity traders may also be attracted to ECNs because of the possibility of lower trading costs.[25] The trading structure of the ECNs ensures that their spreads are more like effective spreads than quoted spreads and are therefore lower. This is borne out in Table I, in which Instinet and Island have the lowest spreads. The two ECNs with the biggest volume may be especially attractive to liquidity traders, because volume increases the probability that an order will cross with a counter party. With the implementation of the OHR, liquidity traders have the further assurance that their orders will be submitted to the Nasdaq quote system in the event that their orders cannot be matched. For example, buy-side institutions, such as Fidelity, typically use Instinet. Under the requirements of the OHR, Instinet will submit their orders to Nasdaq if they do not receive a quick fill on Instinet.

For informed traders, the probability of receiving the best price may be of less importance than the ability to trade in size. Indeed, informed traders may prefer to trade less frequently at the inside, in order to protect their anonymity. This is because of the presence of third party vendors who add bells and whistles to the Nasdaq Level II screen. Their software helps identify those trading at the inside. For example, Tools-of-the-Trade indicates the number of times a market participant is the only one posting the best bid or offer.[26] This results in game playing, whereby informed traders avoid appearing at the inside. Nonetheless, informed traders prefer to trade in an environment that draws in uninformed traders. Therefore, prices may become increasingly more informative as ECN quotes are more frequently at the inside.

Summarizing, the more liquid an ECN is, the more informative its prices may be, because uninformed traders are attracted by liquidity, and informed traders like to trade where the uninformed congregate. This has implica-

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[25] This would be the case for limit orders but not for market orders. ECNs also generally impose a fee for order submission, whereas a participant may receive payment for order flow through preferencing arrangements with market makers.

[26] This information is referred to as "# Best" or "Hammer." The participant that appears most frequently at the inside is called an "Axe" or a leader, and day traders' decisions are often based on the behavior of the Axe.

Table IX

Trading Volume

The table presents the means and medians of share volume statistics by Nasdaq quote participants.

Group	Mean Share Volume	Median Share Volume	Mean Percentage of Total Volume	Median Percentage of Total Volume
		Panel A: July 1998		
Instinet	6,023,216	4,216,901	0.036	0.031
Island	2,854,767	1,593,153	0.018	0.013
Wholesaler	29,475,424	21,026,483	0.185	0.163
Wire house	30,815,095	26,025,077	0.204	0.211
Inst. Broker	45,255,723	38,432,580	0.299	0.324
		Panel B: November 1999		
Instinet	9,025,410	7,216,000	0.041	0.041
Island	13,003,759	11,451,390	0.066	0.046
Wholesaler	43,623,693	34,830,690	0.217	0.172
Wire house	37,736,288	23,337,194	0.168	0.173
Inst. Broker	60,909,009	41,093,036	0.263	0.292

tions for the cross-sectional variation in the ECNs' contribution to price discovery. Specifically, the fact that an ECN quote moves first could be a manifestation of informed traders trading through an ECN. If so, an ECN's WPC in a stock would be positively correlated with market liquidity as proxied by share volume and the percentage of quotes that are at the inside.

Second, consider the environment for the Nasdaq market makers. In sharp contrast to ECN quotes, the market maker quotes may not fully reflect the information that is being generated through trading activity at market makers. A market maker may provide price improvement and may not change its quotes following an execution. Preferencing arrangements may further confound the relations noted for ECNs. These arrangements are typically restricted to retail orders with little information content, weakening the relation between trading volume and price discovery. Preferenced orders may confound the relation between being at the inside and WPC. Preferenced orders are executed at the inside quotes irrespective of whether the dealer who is paying for the order flow is quoting at the inside. It may also be the case that insiders avoid trading with market makers because there is no guarantee of anonymity. Thus, the associations noted for ECNs are likely to be much weaker for Nasdaq market makers even if informed traders prefer to trade with market makers.

Table IX presents the mean and median share volumes and percentage of total share volumes by Nasdaq quote participants. Consistent with the discussion in Section I, the table reveals that ECNs are the most active of all the groups in submitting quotes, but the quote activity does not translate into corresponding trades. Instinet and Island have the smallest percentage of the share volume. In July 1998, the two ECNs only account for about five percent of the total share volume. Their percentage shares had doubled by

Table X

Information Share, Share Volume, and Quotes at the Inside

The table presents regressions of bid upper bound information shares on share volume and the percentage of inside bid quotes by Nasdaq quote participants.

	July 1998			November 1999		
Variable	Parameter Estimate	Standard Error	Pr > |t|	Parameter Estimate	Standard Error	Pr > |t|
Instinet						
Intercept	0.583	0.373	0.130	0.306	0.341	0.377
Share vol.	−6.651	4.252	0.130	8.352	4.342	0.065
Inside bid	0.55E-03	4.72E-03	0.908	−5.44E-03	5.16E-03	0.301
$\bar{R}^2$	0.07			0.08		
Island						
Intercept	0.280	0.097	0.008	0.014	0.216	0.951
Share vol.	9.847	2.904	0.002	1.868	1.030	0.081
Inside bid	−4.83E-03	2.78E-03	0.094	1.07E-03	3.86E-03	0.784
$\bar{R}^2$	0.27			0.04		
Wholesaler						
Intercept	0.12E-03	0.113	0.999	0.059	0.206	0.778
Share vol.	0.310	0.407	0.453	0.026	0.661	0.970
Inside bid	4.84E-03	4.03E-03	0.240	3.02E-03	5.49E-03	0.587
$\bar{R}^2$	0.03			−0.06		
Wire house						
Intercept	0.061	0.055	0.284	0.114	0.124	0.368
Share vol.	−0.412	0.515	0.430	0.034	0.895	0.970
Inside bid	4.20E-03	3.77E-03	0.275	−0.95E-03	3.77E-03	0.803
$\bar{R}^2$	−0.02			−0.07		
Inst. broker						
Intercept	0.029	0.088	0.745	−0.062	0.102	0.549
Share vol.	−0.181	0.354	0.613	0.341	0.462	0.467
Inside bid	4.93E-03	3.38E-03	0.156	3.45E-03	4.10E-03	0.408
$\bar{R}^2$	0.02			0.06		

November 1999. This increase is due almost entirely to the growth in Island's market share with little change in Instinet's share.

Table X reports the cross-sectional results of regressing WPCs on share volume and frequency of being at the inside bid. The results are presented for each Nasdaq quote participant. For both ECNs, the coefficients for being at the inside are insignificant. This suggests that being a price leader is not associated with posting the best quotes. For Island, the coefficients on share volume are materially positive for both sample periods. For Instinet, the volume coefficient is significant only for the more recent period and is insignificant for the earlier sample. Therefore, the rapid-fire trades of day traders appear to be more strongly associated with the timely submissions of informative quotes than those of institutional traders and market makers who use Instinet. The results for market makers are as expected with all the coefficients being insignificant. Similar results are obtained with upper and lower bound information shares.[27]

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[27] These results are not reported in the paper.

V. Conclusions

This paper examines the quality of quotes submitted by electronic communication networks (ECNs) and Nasdaq market makers. The analysis is based on data for the most actively traded Nasdaq stocks during July 1998 and November 1999. The results show that quoted spreads on Instinet and Island are less than half the width of the quoted spreads posted by market makers in 1998 and less than a third by 1999. Knowing the quality of the quote is as important as the size of the spread. Since competition among market participants is important, knowing which venue provides timely and informative quotes is important. More specifically, the findings on quote quality are:

1. Price integration. Quotes submitted by all Nasdaq participants, including ECNs, contain information. Moreover, quotes on the same stock are not independent of one another. Individually, they are nonstationary, but they are linked to one another by stationary long-run equilibrium conditions. The number of equilibrium relations suggests that they are based on common information. This suggests that despite the predominance of volatile Internet stocks in the samples and despite the prevalence of preferencing, internalization, and payment for order flow, the addition of new trading venues has not adversely affected the information quality of bid-ask quotes.

2. Price leadership. The two most liquid ECNs, Instinet and Island, contribute to price discovery and are price leaders. An examination of price contribution shows that, on average, informative quotes from Instinet are the first to be posted on the Nasdaq quote montage and those from Island are second. This suggests that the ECNs' market structure is conducive to the timely dissemination of an asset's intrinsic value. The evidence also indicates that the ECN quotes do not free-ride off Nasdaq market maker quotes.

3. Best price. Among the Nasdaq quote participants, Instinet and Island are at the inside most frequently. Preferencing arrangements among Nasdaq market makers may have caused their quotes to differ from actual trade prices. The ranking among the market makers appears to be less stable, with wholesalers and wire houses trading leadership in the two time-period samples.

4. Price leadership and market liquidity. Market makers' contribution to price innovation is not systematically associated with measures of market liquidity. This result is consistent with the presence of institutional preferencing arrangements that confound the linkage between market liquidity and price discovery. On the other hand, there is some evidence that Instinet's and Island's price contributions are positively associated with trading volume. This could be evidence of informed traders trading on ECNs when liquidity is sufficient.

Therefore, ECN quotes contribute substantially to quote quality on the Nasdaq quote montage. ECN quotes are informative, and relative to market maker quotes, they are posted rapidly and often at the inside.

There is widespread concern about the deleterious effects of market fragmentation resulting from the proliferation of alternative trading venues. The results of this paper suggest that this concern may have been misplaced, and that, in fact, the emergence of ECNs has had the opposite effect of enhancing quote quality. Further, since ECNs reveal more of the limit order book, the evidence also suggests that the greater pretrade transparency provided by an open book adds to quote quality. Thus, the additional competition provided by ECNs, the structural diversity that they offer, and the presence of regulation aimed to foster competition appear to have combined to generate a positive effect on quote quality.

Appendix A

Stock Ticker Symbols Sorted by Share Volume

July 1998		November 1999	
Ticker	Company Name	Ticker	Company Name
INTC	Intel Corp.	MSFT	Microsoft Corporation
DELL	Dell Computer Corporation	DELL	Dell Computer Corporation
MSFT	Microsoft Corp.	CSCO	Cisco Systems, Inc.
WCOM	MCI WorldCom Inc.	INTC	Intel Corporation
HBOC	HBO Corporation	ORCL	Oracle Corporation
CSCO	Cisco Systems Inc.	AMZN	Amazon.com, Inc.
NSCP	Netscape Communications Corp	SUNW	Sun Microsystems, Inc.
EGGS	Egghead.com	COMS	3Com Corporation
ORCL	Oracle Corporation	GBLX	Global Crossing Ltd.
AMAT	Applied Materials Inc.	WCOM	WorldCom, Inc.
PMTC	Parametric Technology Corp.	SPLS	Staples, Inc.
COMS	3Com Corporation	ATHM	At Home Corporation
ASND	Ascend Communication Inc.	EGRP	E*TRADE Group, Inc.
SUNW	Sun Microsystems Inc.	CORL	Corel Corporation
YHOO	Yahoo! Inc.	QCOM	QUALCOMM Incorporated
TCOMA	Tele-Commntsn Inc S-A TCI	QWST	Qwest Communications Inter.
ERICY	Ericsson L.M. Tel ADR-B	AMAT	Applied Materials, Inc.
AMZN	Amazon.com	NOVL	Novell, Inc.
PSFT	PeopleSoft Inc.	NITE	Knight Trading Group Inc.
XCIT	Excite Inc.	AMTD	AmeriTrade Holding Corp.
AAPL	Apple Computer Inc.	CIEN	CIENA Corporation
AFCI	Adv. Fibre Communications, Inc	AMGN	Amgen Inc.
LCOS	Lycos Inc.	IFMX	Informix Corporation
QWST	Qwest Communications Intl Inc.	NXTL	Nextel Communications Inc.
TLAB	Tellabs Inc.	YHOO	Yahoo! Inc.
WAMU	Washington Mutual Inc.	NETA	Network Associates, Inc.
NOVL	Novell Inc.	PSFT	PeopleSoft, Inc.
NXTL	Nextel Communications CL-A	CPWR	Compuware Corporation
SPLS	Staples Inc.	XLNX	Xilinx, Inc.
AMGN	Amgen, Inc.	CMGI	CMGI, Inc.

Appendix B

ECNs and Market Makers

ID	Name	July 1998	Nov. 1999
Electronic communication networks			
ARCA	Archipelago		X
ATTN	Attain	X	X
BRUT	Brass Utility	X	X
BTRD	B-Trade Services	X	X
INCA	Instinet	X	X
ISLD	Island	X	X
MKXT	Marketxt		X
NTRD	Pim Global Equities	X	X
REDI	REDI	X	X
STRK	Strike Technologies	X	X
TNTO	Terra Nova Trading	X	
Wholesalers			
FLTT	Fleet Trading		X
HRZG	Herzog, Heine, Geduld	X	X
MASH	Mayer & Schweitzer	X	X
NAWE	Nash Weiss	X	
NITE	Knight/Trimark Securities	X	X
SHWD	Sherwood Securities	X	X
SLKC	Spear Leeds & Kellogg Capital		X
TSCO	Troster Singer	X	
USCT	US Clearing Corporation		X
Wire houses			
DEAN	Dean Witter Reynolds	X	X
MLCO	Merrill Lynch, Pierce, Fenner & Smith	X	X
PRUS	Prudential Securities	X	X
PWJC	Painewebber	X	X
SBSH	Salomon Smith Barney	X	X
Institutional brokers			
BEST	Bear Stearns	X	X
BTAB	BT Alex. Brown	X	X
DBKS	Deutsche Bank Securities		X
DLJP	Donaldson, Lufkin & Jenrette	X	X
FBCO	Credit Suisse First Boston		X
GSCO	Goldman Sachs	X	X
HMQT	Hambrecht & Quist	X	X
JPMS	J. P. Morgan Securities		X
LEHM	Lehman Brothers	X	X
MONT	Banc Of America Securities	X	X
MSCO	Morgan Stanley	X	X
RSSF	Robertson Stephens		X
WARR	UBS Warburg		X

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