CIRANO

Centre interuniversitaire de recherche en analyse des organisations

Série Scientifique

Scientific Series

98s-14

Why Is the Bid Price Greater than the Ask? Price Discovery during the Nasdaq Pre-Opening

Charles Cao, Eric Ghysels, Frank Hatheway

Montréal
Mai 1998

CIRANO

Le CIRANO est une corporation privée à but non lucratif constituée en vertu de la Loi des compagnies du Québec. Le financement de son infrastructure et de ses activités de recherche provient des cotisations de ses organisations-membres, d'une subvention d'infrastructure du ministère de l'Industrie, du Commerce, de la Science et de la Technologie, de même que des subventions et mandats obtenus par ses équipes de recherche. La *Série Scientifique* est la réalisation d'une des missions que s'est données le CIRANO, soit de développer l'analyse scientifique des organisations et des comportements stratégiques.

CIRANO is a private non-profit organization incorporated under the Québec Companies Act. Its infrastructure and research activities are funded through fees paid by member organizations, an infrastructure grant from the Ministère de l'Industrie, du Commerce, de la Science et de la Technologie, and grants and research mandates obtained by its research teams. The Scientific Series *fulfils one of the missions of CIRANO: to develop the scientific analysis of organizations and strategic behaviour.*

Les organisations-partenaires / The Partner Organizations

- École des Hautes Études Commerciales
- École Polytechnique
- McGill University
- Université de Montréal
- Université du Québec à Montréal
- Université Laval
- MEQ
- MICST
- Avenor
- Banque Nationale du Canada
- Bell Québec
- Caisse de dépôt et placement du Québec
- Fédération des caisses populaires Desjardins de Montréal et de l'Ouest-du-Québec
- Hydro-Québec
- Industrie Canada
- Microcell Labs inc.
- Raymond, Chabot, Martin, Paré
- Scetauroute
- Société d'électrolyse et de chimie Alcan Ltée
- Téléglobe Canada
- Ville de Montréal

ISSN 1198-8177

Why Is the Bid Price Greater than the Ask? Price Discovery during the Nasdaq Pre-Opening*

Charles Cao[†], *Eric Ghysels*[‡], *Frank Hatheway*[§]

Résumé / Abstract

Chaque matin avant l'ouverture du Nasdaq il y a une session durant laquelle les faiseurs de marché font des cotations sans exécutions d'ordres. Malgré le fait qu'il n'y a pas de transactions pendant cette période, il s'y produit une activité importante de soumission et de révision des cotations. Nous étudions l'information révélée par les cotations de prix d'achat et de vente. Notre banque de données contient l'identification des participants, ce qui nous permet de tester plusieurs hypothèses sur la dynamique de la formation du prix d'ouverture. Nous trouvons notamment que certains faiseurs de marché prennent un role de leaders.

One fundamental issue in the study of market microstructures is that of price discovery. While most existing studies focus on the trading period, little is known whether and how much the non-trading period contributes to the price discovery. This paper offers a new perspective on the price discovery process by studying market makers' posting and revising of non-binding prices on Nasdaq during the one-and-half hours pre-opening period. We examine a unique data set containing all the market maker quotes and identifications collected for 50 of the most active Nasdaq stocks. Our empirical investigation shows there is strong evidence that non-binding prices contain information, and there is significant price discovery during the pre-opening period. In the absence of trades, Nasdaq dealers use locked market notes (e.g., the situation where the best bid price among all market makers is greater than the best ask) as an important device to indicate to other market makers which direction the price should move and what the opening price should be. Furthermore, we find evidence that there exists a leadership pattern among market makers, particularly for the most active stocks.

Mots Clés : Prix d'achat et de vente, pré-ouverture, Nasdaq

---

* Corresponding Author: Eric Ghysels, CIRANO, 2020 University Street, 25th floor, Montréal, Qc, Canada H3A 2A5 Tel: (514) 985-4000 Fax: (514) 985-4039 e-mail: ghyselse@cirano.umontreal.ca
We wish to thank Harold Mulherin and seminar participants at the Securities and Exchange Commission and the Pennsylvania State University for helpful comments. We also thank Bridge Information Systems for providing access to the Nasdaq data. Mike Chernov provided invaluable research assistance.

† Pennsylvania State University

‡ Pennsylvania State University and CIRANO

§ Pennsylvania State University

Keywords : Bid and ask prices, locked market quotes, pre-opening period, price discovery, Nasdaq market makers

JEL : G10, G12, G13

Introduction

One of the fundamental issues in the study of market microstructures is that of price discovery which is the incorporation of new information into the security price. Numerous theoretical studies have developed structural models which provide important insights into the learning process faced by market makers.[1] These studies consider an asymmetric information setting, where buyers and sellers are better informed than market makers. The informational impact of a trade is perceived as the market makers' estimate of the private information of a transaction. Market makers learn about the fundamental value of the underlying asset from the sequence and timing of trades which reveal the motivation of traders and their private information. Viewed from this perspective, the trading process contains the information that subsequently appears in prices. On the empirical front, there are extensive studies which analyze price and trade data and their information content, with a focus on price-discovery during trading periods.[2]

This paper offers a new perspective on the price discovery process, the price discovery during *pre-trading periods*, by studying market makers' activity on Nasdaq prior to the market opening. We examine a unique data set collected during the pre-opening period for 50 of the most active Nasdaq firms from October 1, 1995 to September 31, 1996. The data set contains all the *market maker quotes and identifications.* The availability of the market maker identifications makes it possible to examine many issues hitherto unaddressed in the literature.

Despite the potential importance of pre-opening activity for price discovery, the research on this topic is only emerging. Biais, Hillion and Spatt (1996) were the first to conduct a comprehensive study of pre-opening activity using data from the Paris Bourse. They test alternative hypotheses regarding whether pre-opening prices reflect pure noise, rational learning or noisy learning and found that the informational content of the pre-opening prices increases steadily as the opening

[1]Copeland and Galai (1983), Glosten and Milgrom (1985), Kyle (1985), Easley and O'Hara (1987) are only a few of the many prominent papers on the subject. For a unified exposition and examination of the major models and theories in market microstructures see O'Hara (1995).

[2]See for instance, Glosten and Harris (1988), Hasbrouck (1988), Harris (1990), Hasbrouck (1991), Easley, Kiefer, O'Hara and Paperman (1996), Madhavan, Richardson and Roomans (1997). For major U.S. equity markets, the trading period is from 9:30 a.m. to 4:00 a.m. Although off-hours trading is possible (e.g., Crossing Sections I and II on the NYSE, and InstiNet on Nasdaq), its volume is negligible. For example, the NYSE average volume was 412 million shares, while the Crossing Sections I and II averaged 2.5 million shares per day in 1996, according to the NYSE Fact Book (1996).

of the market becomes more imminent. Madhavan and Panchapagesan (1997) investigate the price discovery process at the New York Stock Exchange (NYSE) open. They show, both theoretically and empirically, that a specialist who observes the evolution and components of the limit order book in the pre-opening period obtains valuable information and he can facilitate price discovery at the open.[3] The nature of our data set and the institutional settings of Nasdaq allow us to go much deeper into many of the issues raised in this literature. In particular, from the perspective of theoretical developments about price discovery, many game theorists study games of coordination and pre-play without firm commitments. However, the empirical evidence is sparse. The phenomenon of pre-opening activity on Nasdaq provides an interesting case for studying the nature of the communication game in the absence of firm commitments.

Nasdaq market makers may start to enter bid-ask quotes shortly after 8:00 a.m. They are able to revise their quotes before the opening of Nasdaq at 9:30 a.m. Hence, they are not obligated to honor any quotes during this pre-opening period unless these prices prevail until the time the market opens. During this pre-opening period there is an inter-dealer market where *real* trades may take place. Therefore, one may wonder whether the non-binding quotes have any value. Contrary to what one might expect, trading volume on the inter-dealer market, *InstiNet*, is negligible during the pre-opening while quote activity is very intense, with many Nasdaq market makers frequently posting and revising their bid and ask prices. Take the Intel Corporation as an example. During our sample period, the number of pre-opening quotes averaged 118 per day, with an average of 42 individual market makers participating. Why do we observe this puzzling phenomenon that market makers prefer to quote repeatedly without any commitment rather than actively trade on the inter-dealer market? Does this suggest that there is a communication value to the non-binding quotes and that price discovery takes place? If this is the case, how does the price discovery mechanism work without active trading? The answers to these questions have several components.

First, Nasdaq price quotes are submitted by market makers who have an affirmative obligation to make a two-sided market in the stock during regular trading hours.[4] On both the NYSE and the Paris Bourse, all orders from the public and from dealers are intermingled and those submitting orders to the exchange are not obligated to submit orders

[3] We should also note the recent interest in the informational content of non-binding quotes in the foreign exchange market, see for instance Evans (1997).

[4] Chan, Christie and Schultz (1995) provide a detailed analysis of the price discovery process during Nasdaq trading hours and elaborate on its institutional aspects.

on both sides of the market. We argue that the incentives for price discovery among Nasdaq market makers is different from that of investors. Namely, we explain why Nasdaq dealers have incentives to identify themselves in a communication mechanism and share their information before trading starts.

Second, there is strong evidence that pre-opening non-binding price quotes contain information, and there is significant price discovery during the pre-opening period. In our sample we find that 17% of the daily price change is attributable to the pre-opening period. These findings are consistent with those obtained by Biais, Hillion and Spatt (1996) for the Paris Bourse. In fact, if anything the presence of price discovery during the pre-opening appears stronger on the Nasdaq compared to the Paris Bourse.

Third, Nasdaq features a *market quote* mechanism which is a combination of the highest bid and lowest ask across all market makers.[5] We discover that the market often involves *locked* market quotes during the pre-opening. Such market quotes correspond to the situation where the best bid is equal or higher than the best ask price. Pre-opening prices have their unique characteristics: about 35% of them are locked market quotes. In contrast, locked market quotes occur only 0.3% of the time during regular trading hours.[6]

Fourth, we need to explain why market makers choose to use the mechanism of posting non-binding quotes despite the possibility of trading on the inter-dealer market. The latter involves *anonymous* trading, however, while the posting of quotes during the Nasdaq pre-opening reveals market maker ID's (that is Nasdaq market makers have level 2 access which displays the market maker ID's).[7] With many market makers participating in the pre-opening and hundreds of quotes flashing across screens there must be a way to communicate a desire to change the market price quotes. Like someone standing on a box to address a noisy and unorganized crowd one may conjecture that there is a Nasdaq equivalent to standing on a box. Nasdaq market makers use locked market quotes as an important device to inform other market makers which direction the price should move and what the opening price should be. We find that the majority of price discovery takes place precisely during

[5]Throughout this paper, we use the terminology market quote and best bid-ask prices interchangeably. For any stock at any time, the market quotes are defined as the pair of the lowest ask price and the highest bid price among all market makers who quote on the stock.

[6]In principle, market locks are not "allowed" during trading hours according to Nasdaq regulations.

[7]On the Paris Bourse market maker ID's are not revealed during the pre-opening (nor during regular trading) unlike the Nasdaq.

locked market conditions. We find that this locked market condition is the mechanism par excellence to signal price changes and is the core of price discovery during the pre-opening on Nasdaq.

The game theory literature has coined the term *cheap talk* to designate situations like the pre-opening where Nasdaq market makers communicate without commitment (see Farrell and Rabin (1996) for a recent survey). One may wonder whether there exist leadership patterns among market makers. In particular, whether any particular market maker or small group of market makers take a leading role in sending credible signals to others when they possess valuable information. We find evidence of leadership in creating locked market conditions. First, initiations of locks for certain market makers appear to be disproportional to their typical quote behavior during the pre-opening. Moreover, there is a small group of market makers responsible for the majority of the price contribution from locked markets. The top three market makers account for 49% of the price contribution from locked markets while they only represent 9% of the quote frequency during the pre-opening. Furthermore, for active stocks locked market returns associated with the top three market makers are better predictors of the close-to-open return than locked market returns associated with the remaining market makers.

The paper is organized as follows. Section 1 describes the institutional environment of the Nasdaq pre-opening. Section 2 describes the pre-opening data. Section 3 provides evidence of price discovery during the pre-opening. In Section 4, we examine the dynamics of quotes during the pre-opening and compare it to the regular trading quote pattern. Section 5 addresses the leadership hypothesis. Concluding remarks are offered in Section 6.

1 The Pre-Opening Session on Nasdaq

The Nasdaq Stock Market is an electronic securities market comprised of competing market makers whose trading is supported by a communications network that includes quote dissemination, trade reporting and order execution systems. Trading in individual stocks is characterized by a multiple dealer market where participants are required to display their individual bid and ask prices on the system. The reported market quotes (e.g., the best bid-ask prices) consist of the highest bid and lowest ask prices posted by the market makers. The Nasdaq reporting systems updates the market quote whenever a dealer updates his prices and either exceeds the highest bid or under-cuts the lowest ask and therefore affects the existing best bid-ask prices.

Although the trading system opens at 9:30 a.m., the quotation reporting system of Nasdaq opens much earlier. The first quotation of the day typically is around 8:15 a.m., with the earliest occurrences of quotes at 8:00 a.m. During the one and half hour pre-opening period (from 8:00 to 9:30 a.m.), market makers are able to transmit their bid-ask prices, display arriving customer orders, observe other dealers' prices, identify the dealers present, and most importantly revise their prices. One important difference between the pre-opening prices and prices quoted during trading hours is that pre-opening prices are a non-binding commitment. In contrast, dealers are obligated to honor their prices for the minimum quantity of 1000 shares during trading hours. Dealers have the ability to execute trades during the pre-opening on the inter-dealer Electronic Crossing Network (ECN) markets, however, trading activity is negligible.[8]

The Nasdaq system contains no formal order matching procedure for the opening of trading. At 9:30 a.m., Nasdaq market makers may begin entering trades into the system. Individual market makers are expected to enter transactions in chronological sequence within 90 seconds of execution. These conditions prevail throughout the trading day. In contrast, market makers are under no obligation to quote during the pre-opening period. This raises the question why they would quote at all. To address this, we need to consider the institutional issues of the best bid-ask price, the customary practice for quoting volume, Nasdaq rules on best execution, the stability of the population of active market makers in a given stock over time, and the role of preferencing.[9]

In principle, any informed market maker with short-lived private information regarding order flow or prospects for the company's stock could choose not to reveal his information prior to the market opening and exploit the value of the information when trading starts. However, under Nasdaq rules the counter-party dealer is only obligated to trade his posted volume or the Nasdaq minimum (1000 shares for our stocks)

[8]There are a number of ECNs, the most active of which is *InstiNet*. Using the Trade and Quote (TAQ) database to extract ECN trades before 9:30 a.m., the pre-opening volume is about 0.5% of the volume traded between 9:30 a.m. and 4:00 p.m. To identify such trades we used Rule 6620 trades. Rule 6620 requires that all trades, including InstiNet trades during the pre-opening by Nasdaq member firms be reported.

[9]Preferencing refers to the practice of directing an order to any market maker who has agreed in advance to execute orders at the best quoted price, regardless of the prices actually quoted by the market maker to whom the order is directed. As a result, market makers who offer the best price do not necessarily attract more order flow. According to Godek (1996), virtually all Nasdaq market makers are preference traders. Also see Battalio, Greene and Jennings (1995).

at that market maker's posted price. In practice, Nasdaq dealers routinely posted the minimum volume during our sample period. So an informed dealer may be limited in his ability to purchase (or sell) a large number of shares. On the other hand, the informed dealer also has the obligation to act as a market maker and quote a two sided market. Furthermore, a market maker receiving an order to trade must execute that trade consistent with Nasdaq rules on best execution, typically at the prevailing best bid-ask spread. If the informed dealer receives a customer order on the same side of the market, he must either execute that order against his own account or allow the order to trade ahead of him against the uninformed dealer. The problem of exploiting private information is compounded if the informed market maker has a preferencing contract and is obligated to trade the customer order at the prevailing best bid-ask spread against his own account. A final point is that stability of the registered market maker community in a stock makes the pre-opening a repeated game where reputation may limit the ability of informed dealers to take advantage of their information by trading against their fellow market makers. A market maker who exploits his information at the expense of other dealers may find them unwilling to trade with him in the future. In conclusion, an informed market maker may be unable to trade on his information and is at risk to have to trade shares against public orders that are on the same side of the market as the informed market maker. Informed market makers also recognize that other market makers may be in a similar position either on the same day or any other.

Taken together, these institutional factors limit the ability of market makers to act as informed traders and exploit their private information as in Kyle (1985). Furthermore, non-market makers can exploit private information against the market maker. Therefore, there are incentives for market makers to participate in a communiction game with other dealers so that the opening bid and ask prices reflect all available information. As described by Farrell (1995), a central insight from the theory of communication games is that a receiver of a signal changes his actions in a way that is both to his benefit and to that of the sender. Since dealers mutually benefit by an opening that reflects all available information, one would expect that the market will open at or near the equilibrium price, if a communiction game takes place during the pre-opening and functions properly.

To better understand the role played by the pre-opening we need to further elaborate on one last attribute of the Nasdaq national market. Nasdaq rule 4613 prohibits market makers entering or maintaining quotes during normal business hours that cause a locked or crossed market without first making a reasonable effort to avoid locking or crossing the market.[10] However, this rule is not in effect during the pre-opening.

2 Description of the Data

Two intra-day data sets are used to conduct our empirical analysis. The primary one is the Nasdaq pre-opening data set. The source of the data is the Bridge Information Services. The data was down-loaded by saving screens of real-time quotes for the pre-opening period from 8:00 to 9:30 a.m.[11] The sample period extends from October 1, 1995 through September 30, 1996. The pre-opening data set contains (1) individual market maker quotes and the identity of the originating market maker who enters the quotes, and (2) the market quotes (i.e., the best bid-ask prices), which is updated when the best individual market maker quotes (either the bid, the ask, or both) change. Both quotes are time stamped to the minute and are recorded in chronological sequence within a minute. The individual market maker quotes provide valuable information that allows us to infer which market maker contributes to the change in the market quotes.

The second data set consists of all trades and quotes for our sample stocks that exist on the TAQ database. Several standard filters were used to screen the data. First, trades and quotes flagged as errors, non-standard delivery trades, and non-firm quotations were excluded. Second, we excluded all quotes originating in markets other than Nasdaq because regional quotes tend to closely follow the quotes posted by market makers on the primary market. Finally, quotes with obvious recording errors were discarded. In the TAQ database, the market quotes are time-stamped to the nearest second and updated when the best individual market maker quotes change. While the market quotes are available for both pre-opening and trading periods from the TAQ database, the individual market maker quotes are not available.

Our sample consists of 50 of the most active Nasdaq stocks, as measured by 1994 share volume. These stocks are also among the largest on Nasdaq as there is a high correlation between trading activity and market capitalization. Hence, our analysis includes all the major Nasdaq

[10] A crossed market is a market where the best bid price equals the best asked price. A locked market is one where the best bid price exceeds the best ask price. For simplicity, this paper refers to both locked and crossed markets as locked markets.

[11] Since the focus of the paper is the price discovery during the pre-opening period, we did not down-load individual market maker quotes entered into the system during trading hours.

stocks such as Apple, Microsoft, Intel, Cisco Systems, Biogen and several others. As five stocks switched to other markets or were otherwise de-listed from Nasdaq during the sample period, additional stocks were added in order of 1994's share volume to maintain a total sample size of 50. Three stocks with less than 60 trading days available are excluded. Thus, the final sample includes 52 stocks which are listed in Table 1. The table also shows that most stocks have about 252 trading days during the sample period. The average market value of the stock is $6,574 million.[12]

Table 2 presents characteristics of the sample stocks during pre-opening and during trading hours. For the pre-opening period, the stock with the most market makers (84 market makers) is Novell, while the one with the least is Willamette Industries (21 market makers). On average, 22 market makers participate in the pre-opening communication for a stock. The daily average number of pre-opening market maker quotes is 47. The number of market quotes per hour during the pre-opening averages 3.3. The average number of market quotes per hour is 11.0 during the trading hours, which is about three times as much as that during the pre-opening period. For the trading period, the average number of trades is 1294 trades per day, and the daily average share (dollar) volume is 1.88 million shares (82 million dollars).

The stocks appearing in Table 2 are partitioned into four quartiles according to their trading frequency, which is measured by the daily average number of trades. Quartile 1 consists of the least active stocks with less than 416 trades per day, while quartile 4 contains the most active stocks with more than 1,712 trades per day. We note from Table 2 that there is a strong monotonically increasing pattern between trading frequency and the daily averages for number of market makers (13, 18, 24 and 32), number of pre-opening market maker quotes (20, 33, 52 and 84) , and number of market quotes per hour during the pre-opening (2.0, 2.4, 3.8, and 4.9) and during trading hours (2.9, 7.3, 13.2, 20.6).

3 Characteristics of Nasdaq Pre-Opening Prices

This section provides a first look at the characteristics of Nasdaq pre-opening quotes. In the first subsection we describe in detail the peculiar phenomenon of locked market quotes. Next we examine how overnight

[12]The Center for Research in Security Prices (CRSP) data set is used to obtain market capitalization of sample stocks. Five securities in our sample are either foreign stocks or ADR's, and the market value of these firms was unavailable from CRSP.

returns are related to price quote activity during the pre-opening. The final subsection investigates the price contribution of the pre-opening to the daily price changes. The statistical analysis is confined to the price quote data and does not yet investigate the market maker identifications. Restricting our attention here only on the quotes during pre-opening is done to reject the prior that the pre-opening is purely a noisy warming up session. Evidence against this prior should be strong enough to be transparent through summary statistics involving price quotes only. In the next section we will examine the pre-opening individual market maker quotes and demonstrate the role of leadership among market makers in the price discovery process.

3.1 Locked Market Quotes

In the absence of trading, we adopt a prior from the prevailing literature and do not expect that prices during the pre-opening mimic the behavior during regular trading as private information will not be revealed. It may be further argued that pre-opening sessions are pure noise because all the posted quotes are void of any commitment. In this section, we first establish empirical regularities of the market quotes during the pre-opening, and identify important features of the pre-opening prices which are different from those during the trading hours. We then find evidence that pre-opening quotes contain information even though they are non-binding commitments.

Since the locked market quotes and locked sequences are important characteristics of pre-opening prices, and are therefore the focus of our empirical investigation, we provide first their formal definitions:

- **Locked market quote:** is defined as a market quote where the best bid is higher than or equal to the best ask. The market quote is the best bid-ask prices among all dealers. We will frequently refer to locked market quotes simply as locks for brevity.

- **Locked sequence:** is defined as a continuous series of locked market quotes. A locked sequence begins with the last unlocked market quote prior to the sequence and ends with the first unlocked market quote after the sequence. Whenever a lock is widened it is considered as the start of a new lock sequence.

Table 3 presents summary statistics of market quotes during the pre-opening and trading hours. As shown in Panel A, which is organized by time of the day, a large fraction of the market quotes (34.9%) is locked during the pre-opening. In the first five minutes following the market opens, the frequency of the locked market quotes drops to 4.2%, and then drops to virtually zero during the rest of the trading day. On average, the frequency of the locked market quotes during trading hours is only 0.3%, which is negligible. In addition to the difference in the frequency of locks, there is also a significant difference in the size of locks between pre-opening and trading hours. During the pre-opening, the average magnitude of locks is \$0.48. The size of locks is generally below \$0.10 during morning trading hours, and below \$0.03 in the afternoon. The average duration of locked market sequences suggests that most of the locked market sequences initiated during the pre-opening are unlocked by the end of the first five minutes of the trading session. After this, a lock is usually unlocked quickly. These results indicate that pre-opening quotes are fundamentally different from those of trading hours in that the best (individual market maker) bid price often exceeds the best (individual market maker) ask price. Locking the market *during trading hours*, even during the time when the market is extremely volatile, is discouraged by Nasdaq, and the locked market quotes during trading hours are often considered not to be sustainable.[13]

Why do Nasdaq dealers lock the market so frequently during the pre-opening? Are these locks associated with the overnight information flow and therefore contain information? Before answering these questions formally it will be useful to present some illustrative plots of locked market conditions during the pre-opening.

Figures 1 and 2 represent two examples chosen to highlight salient features of the incidence of locks during the pre-opening. Most stocks in our sample exhibit a mixture of these features including (1) the pre-opening prices converge to the opening price gradually, with a single market maker dominating a change in the stock price, and (2) the pre-opening prices converge to the opening prices, but with overshooting at the beginning of the pre-opening.

In Figure 1, we display the bid-ask and the midpoint of individual market maker quotes as well as the best bid-ask quotes during the pre-opening for Microsoft (MSFT) on December 8, 1995. On the previous trading day, December 7, Microsoft had closed at $\$90\frac{5}{8}$ - $\$90\frac{3}{4}$. On the 8th, the stock would rise to $\$94\frac{1}{8}$ - $\$94\frac{5}{8}$. At 8:22 a.m., the Nasdaq computers recorded the initial best bid-ask quote of the day, repeating the previous day's close quote of $\$90\frac{5}{8}$ - $\$90\frac{3}{4}$. Seventeen minutes later, Morgan Stanley & Co. posted the first market maker quote of the day,

[13] During trading hours, the market makers who lock the market often get phone calls from Nasdaq officials to resolve the lock quickly. Under rule 4613, the market makers are also obligated to trade at their locked prices and consequently risk monetary loss should they lock a market.

locking the market and raising the best bid $\$\frac{1}{4}$ to $\$90\frac{7}{8}$. Within the next minute, Bear, Stearns & Co. raised the best bid another $\$\frac{1}{8}$. Eight minutes later Weeden & Co. raised the best bid by $\$\frac{1}{8}$ to $\$91\frac{1}{8}$, and Morgan Stanley & Co. raised the bid by $\$\frac{3}{8}$. Microsoft, with a market capitalization of $51 billion, was up $\$\frac{7}{8}$ 31 minutes after the Nasdaq system came on. At this point 7 different market makers had entered their quotes into the system. In the 37 minutes left in the pre-opening, the best bid would rise four more times in establishing the opening bid of $\$92\frac{1}{2}$. Overall, Morgan Stanley would increase the best bid quote 3 times and account for $\$\frac{7}{8}$ of the $\$1\frac{7}{8}$ increase during the pre-opening. The opening best bid-ask quote of $\$92\frac{1}{2}$ - $\$92\frac{5}{8}$ appears to have been a reasonable estimate of the equilibrium price as the 11 a.m. trade prices were in the range $\$92\frac{3}{4}$ - $\$93\frac{1}{4}$. Through a series of quote changes, Nasdaq market makers had established a new equilibrium price with which to start the trading day. This plot is selected as a typical example of a single market maker dominating a change in the price level of a stock with a series of quotes that alter the best bid-ask spread. Morgan Stanley is identified as the dominating market maker who initiated and reinforced the lock.

Figure 2 presents the pre-opening quote behavior of Chiron Corp. (CHIR) on August 1, 1996. On the previous trading day, the stock closed at $\$21\frac{7}{8}$ - $22. At 8:24 a.m., Hambrecht and Quist initiated the first lock of the day and lowered the best ask price by $2. Subsequent quotes by other market makers reversed some of the $2 price decline and the stock opened down $\$1\frac{1}{4}$. This example shows that the movement of the best bid-ask quote during the pre-opening is not a steady convergence to the opening price as was the case for Microsoft on December 8, 1995. For Chiron, the direction of the overnight price change is consistent with the assessment of Hambrecht and Quist who initiated the lock. However, their prediction of the magnitude of the price change is larger than that of other market makers. The market makers' later quotes reflected a less pessimistic outlook for the stock and that assessment was transmitted to the market. This example demonstrates that locked market quotes contain valuable information about the subsequent opening price, and that they signal other market makers what the opening price should be. Yet, these signals are not perfect and contain noise.

To appreciate the information content of the pre-opening prices and to understand how Nasdaq market makers use these prices to reveal and share information, we examine the association between the pre-opening locked market quotes and two measures of overnight information flow. We use the absolute value of price changes as a measure of information flow following Bessembinder, Chan and Sequin (1996). In Panel B the overnight information flow is measured as the absolute value of the close-to-open price change which is denoted by ($|\Delta P^{ov}|$). Arguably this measure may be biased towards finding some spurious association between pre-opening quote activity and $|\Delta P^{ov}|$ since the last pre-opening quote should straddle the opening price. To avoid potential endogeneity problems, we replace the absolute value of close-to-open price change by the absolute value of close-to-close price change ($|\Delta P^{cc}|$), and repeat the above exercise. These results are reported in Panel C of Table 3.

Panel B of Table 3 presents summary statistics of locked market quotes during the pre-opening, with the results being partitioned by $|\Delta P^{ov}|$. Clearly, the frequency of the locked market quotes monotonically increase with the absolute value of the overnight return. For example, when $|\Delta P^{ov}| \in \$0\text{–}\frac{1}{8}$, the frequency of locks is 8.2%, whereas for $|\Delta P^{ov}| \in \$2\text{–}5$ range the frequency of locks increases substantially to 81.8%. The average size of locks (bid price less the ask price) also increases monotonically with the absolute value of overnight price changes. When $|\Delta P^{ov}|$ is small, the magnitude of locks is only \$0.15. However, when $|\Delta P^{ov}|$ is large (say, between \$2 and \$5), the size of corresponding locks is also large (\$1.38). Finally, the duration of locks, as measured by minutes or number of market quotes, show similar patterns: the larger the absolute value of the overnight price change, the longer the duration of locks. Given that the absolute value of overnight price changes is often used as proxy for overnight information flows, or overnight volatility of the price change, the reported evidence suggests that locked market quotes are informative and bear a relation with the accumulated overnight information flow. The results in Panel C are consistent with the findings in the Panel B. Again, the frequency of locked market quotes, the size of locks and their durations all increase monotonically with the absolute value of the close-to-close price change. For example, the size of the lock is \$\$0.20 when $|\Delta P^{cc}| \in \$0 - \frac{1}{8}$. It increases to \$0.70 when the overnight return is between \$2 and \$5. These results, together with those in Panel B, suggest that locked market quotes occurring during the pre-opening are associated with the overnight information flow and are informative.

We conclude this section with Panel D of Table 3. It reports summary statistics by trading frequency. The 52 sample stocks are partitioned into four equal-size subsamples according to daily average number of trades. It is noted that the frequency of locks during the pre-opening increases while the duration of locks decreases with trading frequency. For the least active stocks, the frequency of locked market quotes is 20.2%, while the average duration is 29.8 minutes. For the most active stocks, the frequency of locks increases to 52.5%, but the average duration decreases to 14.2 minutes. We expect that active stocks feature more often overnight information arrival, which often may lead to a greater dispersion of opinion about the fundamental value of the stock among individual market makers. Hence, one would expect that, active stocks have more market locks during the pre-opening. On the other hand, for the active stocks, more market makers participate in the pre-opening. This might explain why the information uncertainty about active stocks is resolved more quickly, and why the average duration of market locks is shorter for active stocks.

3.2 Regression Analysis of Market Locks

To further our understanding of locked market quotes during the pre-opening, we rely on regression models to study the association between the size of locks (or the duration) and the proxies of the overnight information arrival. A first set of three regressions involves $|\Delta P^{ov}|$. Specifically, we estimate the following three regressions:

$$\begin{aligned}
|\Delta P_t^{ov}| &= \alpha + \beta LockSize_t + \eta_t, \qquad (1)\\
|\Delta P_t^{ov}| &= \alpha + \beta LockTime_t + \eta_t, \qquad (2)\\
|\Delta P_t^{ov}| &= \alpha + \beta LockQuote_t + \eta_t, \qquad (3)
\end{aligned}$$

where $|\Delta P^{ov}|$ is the absolute value of the overnight (close-to-open) price change, $LockSize$ is the size (bid price less the ask price) of the locked market quote, expressed in cents, $LockTime$ is the duration of the locked market sequence in minutes, and $LockQuote$ is the duration of the locked market sequence in market quotes. The regressions are based on pooled data involving all the stocks together.[14]

The first three columns of Table 4 display the results for the three regression models (1) through (3). The results show that $|\Delta P^{ov}|$ is significantly and positively related to the size of the locks as well as their duration. Based on the coefficient estimate of 0.88, the absolute value of the overnight price change will be 11 cents larger when the lock size increases by $\$\frac{1}{8}$. Moreover, the regression results also suggest that the absolute value of the overnight price change will increase by about 10.2 cents when the duration of a lock increases by 10 minutes. One noticeable result is that, although both the size of locks and their duration are significantly related to $|\Delta P^{ov}|$, the explanatory power provided by the size of locks is much larger. The adjusted R^2s are 0.13 and 0.03, respectively, when the size and the duration are used as independent variables.

[14]For each stock on a given day, observations are stacked together when there are multiple locks.

Using the alternative definition of lock duration in terms of number of market quotes leads to similar results. We also consider the absolute value of the close-to-close price change ($|\Delta P^{cc}|$) as the dependent variable in the regression. The results are reported in the next panel of three columns in Table 4. Clearly, these regressions are qualitatively similar to those based on $|\Delta P^{ov}|$, with the estimated coefficient β slightly smaller.

The last two regression models examine the relationship between the size and duration of locks:

$$
\begin{aligned}
LockTime_t &= \alpha + \beta LockSize_t + \eta_t, && (4)\\
LockQuote_t &= \alpha + \beta LockSize_t + \eta_t. && (5)
\end{aligned}
$$

The null hypothesis is that $LockSize$ has no relationship with the length of the lock. If locks are not informative, we should expect that the magnitude of the lock and the duration are unrelated. If β is significantly different from zero and of positive sign then large size locks during the pre-opening take a longer time to unlock. In terms of economic interpretation such an empirical result would suggest that more information uncertainty and more dispersion of opinion about the opening price among market makers as reflected by larger $LockSize$ results in longer coordination spells. The results appearing in the last two columns of Table 4 show that the estimated β coefficients are positive and significant, regardless of whether the duration of the lock is measured in minutes or in number of market quotes. The coefficient of β is 12.02 when $LockTime$ is regressed on $LockSize$. Therefore, the duration of a lock is about 1.5 minutes longer for an $\$\frac{1}{8}$ increase in the size of the lock. The results based on $LockTime$ are slightly stronger in terms of adjusted R^2 than those of $LockQuote$.

3.3 The Contribution of the Pre-Opening to the Daily Price Change

Having demonstrated that pre-opening prices and locked market quotes reflect overnight information, we now address two related questions: how large is the contribution of the pre-opening period towards daily stock price changes, and how large is the contribution of locked periods? Substantial price contributions from the pre-opening and from periods when the markets are locked would indicate that the pre-opening and locked markets are an important component of the price discovery process. To answer these questions, we consider two alternative approaches to quantify the contribution of each time period.

For any given day, we partition the pre-opening and trading hours into four sub-periods. Let i denote a particular period, and $i \in$ (pre-lock, lock, post-lock, trading period). The first three sub-periods cover the pre-opening period, which is from 8:00 to 9:30 a.m. The *pre-lock* period is from 8:00 a.m. until the quote prior to the start of the first locked market sequence. The *lock* period spans from the quote prior to the occurrence of a locked market sequence until the first subsequent non-locked market quote or until 9:30 a.m. The *post-lock* period starts when the last locked market is unlocked until 9:30 a.m., plus the time period in-between any two locked periods (if there are multiple lock periods). If there are no locks, the entire pre-opening is defined to be part of the *pre-lock* period. The *trading* period is from 9:30 a.m. until 4:00 p.m.

The measures of price contribution we use are inspired by the analysis of Barclay and Warner (1993). The first measure uses the absolute value of the cumulative daily price change as the weight. Specifically, for each stock and for a given period $i \in$ (pre-lock, lock, post-lock, trading period), we calculate the fraction of the price change over period i relative to close-to-close price change on each day. Next, we weight each day's contribution of period i based on that day's contribution to the cumulative absolute price change over the entire sample period. The weighted price contribution (WPC) of period i to daily price change is determined as:

$$WPC_i = \sum_{t=1}^{T} \left(\frac{|\Delta P_t|}{\sum_{t=1}^{T} |\Delta P_t|} \right) \times \left(\frac{\Delta P_{i,t}}{\Delta P_t} \right) \tag{6}$$

where $\Delta P_{i,t}$ is the total price change for period i on day t and ΔP_t is the price change for day t (e.g., from day $t-1$ close to day t close). The first term in parentheses is the weighting factor for each day, while the second term in parentheses is the relative contribution of the price change for period i on day t to the price change on day t. As noted by Barclay and Warner (1993), this measure serves the purpose of reducing the heteroskedasticity in the observations since the relative rather than absolute price contributions of each day t are used.[15]

Table 5 presents the cross-sectional average of the contribution of each time period to the daily price change. The results are reported for each sub-period for the full sample and for each of the trade frequency

[15]To justify the weighting scheme, consider the situation where the price change during the pre-opening is +7/8 and the price change during the trading hours is -3/4. Hence, the daily price change is 1/8. Without weighting, the percentage of pre-opening contribution is 700%. The weighting scheme down-weights observations when the absolute value of daily price change is small. It is also worth observing that the measure avoids the pitfalls of zero price change.

quartiles. On average, 16.5% of the daily price change is attributable to the pre-opening period, and the remaining 83.5% to the trading period. Within the pre-opening period, the contribution of the pre-lock, lock, and post-lock periods are 5.9%, 10.1%, and 0.5%, respectively. Therefore, 61.2% of the pre-opening price change occurred during market locks. It suggests that locking the market is an important part of the price discovery process, and that locked market quotes contain information about future price changes. The results for each trading frequency quartile reveal that the contribution of the lock period increases with the trading frequency. For the least active stocks, for example, the locked period and pre-opening period accounted for 7.7% and 16.9% of the daily price change. While for the most active stocks, these fractions are 14.8% and 20.4%, respectively. Therefore, the contribution of locked market quotes to either daily price change or the price change during the pre-opening period is much larger for active stocks than for inactive stocks. These results are consistent with our earlier findings that pre-opening prices are informative about the future prices, and that locking the market quotes is an important mechanism to discover the equilibrium opening price.

Although the above measure of the contribution of each time period towards the daily price change is informative, it does not take into account the fact that the pre-opening period is much shorter than the trading period (one and half hours versus six and half hours), and that locked periods are much shorter than the pre-opening period. Viewed from this perspective, both the contribution of the pre-opening period to daily price change and the contribution of the lock period to the price change during the pre-opening are, to a certain degree, under-estimated. To take the time length of each sub-period into account, we re-scale the weighted contribution of the pre-opening period by 1.25 hours and of the trading period by 6.5 hours. Moreover, within the pre-opening period, we modify the measure given in (6) by including the time length of each period in the weight. Using the time weighted price change during the trading period as a benchmark, the relative time weighted price contribution (RTWPC) for each sub-period $i \in$ (pre-open, pre-lock, lock, or post-lock) is determined as:

$$RTWPC_i = \frac{WPC_i / \sum_{t=1}^{T} \text{Time}_{i,t}}{WPC_{trading} / \sum_{t=1}^{T} \text{Time}_{trading,t}}. \tag{7}$$

With this refinement, the results will show the contribution of each period towards daily price change per unit of time relative to that of the trading period. The results presented in Table 5 show that the price contribution per unit time during the pre-opening is slightly larger than that during the trading period, namely the ratio is 1.1. In comparison to the contribution of trading periods, the contribution of the locked periods is larger by a factor of 3.5 (or 350%), and the contribution of post-lock periods is larger by a factor of 1.6 (160%). In contrast, the contribution of pre-lock period is only 60% of that of the trading period. These results demonstrate that the pre-opening period, especially the locks, contribute significantly to the daily price change, even though there is no trading during the pre-opening.

3.4 A First Look at Individual Stocks and Market Makers

The regression results reported in this section so far pertained to all stocks together. We find that locked market quotes are related to the overnight information flow. We explore this further now with individual market maker data. Table 6 reports, for each stock, the number of locked market quotes, the frequency of locks relative to total number of market quotes, the number of locked sequences during the entire sample period, and the identity (ID) of the market maker responsible for the largest contribution to the price change during locked sequences.[16] All statistics are calculated using information exclusively from the pre-opening period. The results are reported according to trading frequency quartiles. It is seen that each of the variables monotonically increases with the trading frequency. Starting with the number of locked market quotes we observe in Table 6 that in the least active quartile, the number of locks ranges from 8 to 75 (with RTRSY being the only exception). In contrast, the number of locks varies from 152 to 1308 for stocks in the most active quartile. The median number of locks for each quartile are 33, 106, 267 and 703, respectively. In relative terms, the average frequency of the locked market quotes are 11.2%, 14.3%, 31.1% and 49.9%, respectively for each quartile. In addition, the average number of locked sequences increases from 59 for least active stocks (quartile 1) to 410 for most active stocks (quartile 4). These results further demonstrate that locks primarily occur for actively traded stocks.

The last column of Table 6 reports the identity of the market maker who is responsible for the largest price contribution during locked sequences for a given stock. Interestingly, among more than 200 Nasdaq dealers, a few of them stand out as the leading market maker. For example, among the 52 sample stocks, Bear, Stearns (with market maker ID

[16] Details about the calculations of price contributions for individual market makers will be discussed in section 5.

BEST) is the number one leading market maker for 7 stocks, and Morgan Stanley (with market maker ID MSCO) is the number one leading market maker for another 7 stocks. These results raise the question whether there is a leadership pattern among individual market makers who make the market in the same stocks, an issue raised by Chan, Christie and Schultz (1995). We will discuss this issue in Section 5. Before we investigate leadership behavior we examine the temporal dynamics of quote behavior during the pre-opening.

4 Quote Behavior with and without Trading

We have examined the characteristics of pre-opening prices and shown that they do contain information about the opening prices and future prices. This section turns to the analysis of the temporal dynamics of market quotes with and without trading. The interest here is to see what *differences* exist in the interactions between quote arrivals and market volatility in market mechanisms with and without binding quotes. In the first subsection we study the contemporaneous relationship between innovations in volatility and quote arrivals. The second subsection explores Granger causality between innovations in volatility and quote arrivals.

4.1 The Contemporaneous Relationship between Innovations in Volatility and Quote Arrivals

The tests used in this subsection require the construction of return series. Each day, for both the pre-opening and trading periods, returns are constructed on a 15-minute interval basis using the market quotes outstanding at the end of each interval.[17] Every interval is classified as either a *no trade and no lock* or a *no trade and lock* interval during the pre-opening period from 8:00 to 9:30 a.m. A *no trade and lock* interval is one during which a locked market quote occurred or that contains part of a lock market sequence. During trading hours, all intervals are classified as *trade* intervals. For each stock, 15-minute return observations are stacked together to obtain a time series of returns over the entire sample period. The volatility of the return during the 15-minute interval is defined as the absolute value of the 15-minute return, and the quote arrivals as the number of market quotes during the interval.

[17] We also performed the analysis based on the 5-minute interval, and found the results are similar. The results are available upon request.

To obtain the innovation in volatility, we pre-whiten the volatility time series using an AR(5) process augmented with three daily lags.[18] With a similar filter, we obtain the time series of the innovations in quote arrivals. It is important to note that the pre-whitening is done over the entire sample covering the observations of the pre-opening as well as the regular trading session.

The purpose of our tests is to see whether the binding nature of the quote has any impact on the relationship between return volatility and quote arrival. The return series during the pre-opening are based on non-binding quotes whereas those during regular trading hours are based on binding quotes. Before examining the contemporaneous relationship between volatility and quote arrivals during the different market regimes, we report some summary statistics in Panel A of Table 7. The means of both series are zero by construction since the pre-whitening removes the overall mean. The standard deviation of quote arrival is larger than the standard deviation of volatility (in parentheses), 0.422 and 1.790, respectively. When we partition the results using the classification of the 15-minute interval, the means of the innovation in volatility are -0.039, 0.343 and -0.004 for each of the three distinct classifications. Hence, the innovation in volatility is much larger during *a no trade and lock period* than during *a no trade and no lock period* or *a trade period*. Similar conclusions can be drawn from the innovations in quote arrival: there is a much larger innovation in the quote arrival during *a no trade and lock period* than during other times. These figures tell us that locked market quotes display an unusual surprise in volatility effect and atypical quote arrivals.[19] To gauge the contemporaneous relationship between innovations in volatility and quote arrivals, we consider the regression model:

$$\begin{aligned} \epsilon_t^V &= \alpha^{NT,NL}\, I_t^{NT,NL} + \beta^{NT,NL}\, I_t^{NT,NL}\, \epsilon_t^Q + \alpha^{NT,L}\, I_t^{NT,L} \\ &\quad + \beta^{NT,L}\, I_t^{NT,L}\, \epsilon_t^Q + \alpha^T\, I_t^T + \beta^T\, I_t^T\, \epsilon_t^Q + \eta_t, \end{aligned} \tag{8}$$

where ϵ^V is the innovation in volatility, ϵ^Q is the innovation in quote arrivals, $I^{NT,NL}$ is a dummy variable for *no trade and no lock*, $I^{NT,L}$ is a dummy variable for *no trade and lock*, and I^T is a dummy variable for *trade*.[20] We estimate the regression model for each stock in the sample

[18]The appropriate choice of AR lags is based on a model selection procedure using significant t-statistics as a guidance for lag selection.

[19]Recall that the dependent variable is pre-whitened over the complete sample across all three market regimes and therefore is mean zero by construction. Since the trading period covers the majority of sample data it is not surprising that the trade subsample mean is close to zero as well.

[20]To facilitate interpretation, we us superscripts for each coefficient to indicate the

and obtain robust standard errors using the Newey-West method. The cross-sectional average and standard error (in parentheses) of coefficient estimates, and number of significant coefficients at the 5% level among 52 stocks are reported in Panel B of Table 7. Of the three level effects $\alpha^{NT,NL}$, $\alpha^{NT,L}$, and α^{T}, the dummy variable of the *no trade and lock* period has the largest impact on ϵ_t^V. The level effect of the *trade* period is small and negligible.[21]

Of greater interest are the slope coefficients $\beta^{NT,NL}, \beta^{NT,L}$ and β^{T}. The point estimates suggest that, for each unit increase in the innovation in quote arrival, the increase in the innovation in volatility will be 0.048 ($\beta^{NT,NL}$), 0.096 ($\beta^{NT,L}$) and 0.201 (β^{T}), and the number of significant coefficients at 5% (among 52 stocks) are 51, 42 and 52, respectively. The first hypothesis of interest is whether the pre-opening period (or the lock period) does not contribute to the innovation in volatility. Under this null hypothesis, the coefficients $\alpha^{NT,NL}, \beta^{NT,NL}, \alpha^{NT,L}, \beta^{NT,L}$, $\beta^{NT,NL}$ and $\beta^{NT,L}$ are expected to be zero. The results show that this hypothesis is strongly rejected. This evidence is consistent with results reported in the previous section that non-binding pre-opening prices contain information. The second hypothesis concerns whether the flow of quotes has a greater impact during locks compared to the rest of the pre-opening. This hypothesis can be formulated as $H_0 : \beta^{NT,NL} = \beta^{NT,L}$ and $H_a : \beta^{NT,NL} < \beta^{NT,L}$. In the lower part of Panel B it is reported that the number of rejections is 40. Hence, the volatility response to quote flow is higher during the pre-opening when the market is locked. The final hypothesis tests for differential sensitivity of the innovation in volatility with respect to the innovation in quote arrival between a *no trade and lock* interval and a *trade* interval: $H_0 : \beta^{NT,L} = \beta^{T}$ versus $H_a : \beta^{NT,L} < \beta^{T}$. The null hypothesis is rejected for 42 of the 52 firms in our sample. Hence, it is clear that the innovations in quote arrival during a trading interval has a much larger impact on volatility compared to locked market regimes in the pre-opening. The conclusions we ought to draw for the moment is that the pre-opening is neither real trading, nor pure noise. So, what are the dynamics at play?

---

nature of the time interval.

[21]Though not reported in Table 7 we tested $H_0 : \alpha^{NT,NL} = \alpha^{NT,L}$ and $H_a : \alpha^{NT,NL} < \alpha^{NT,L}$, and found that the number of rejections is 40 among 52 firms. Likewise, we tested $H_0 : \alpha^{NT,L} = \alpha^{T}$ and $H_a : \alpha^{NT,L} < \alpha^{T}$, and found that the number of rejections is 45 among 52 firms.

4.2 Tests of Granger Causality between Volatility and Order Flow

The preceding subsection has investigated the contemporaneous relationship between the innovation in volatility and quote arrivals during three distinct time periods. In this subsection, we examine the dynamic interaction between the two series via time series methods. The usual approach is to look at impulse response functions of Vector Autoregressive representations or techniques closely related to that. Impulse response analysis and Granger (1969) causality tests are related but serve different purposes as discussed by Sims (1980). We focus here on formal tests of Granger causality to compare the different market regimes. Specifically, we test for Granger causality between the innovations in volatility and quote arrival and vice versa. In particular we will study: the Granger causality from quote arrival to volatility, and the Granger causality from volatility to quote arrivals.

The idea of Granger causality is to see whether past quote arrivals can improve univariate predictions of price volatility where univariate predictions only use the own past of a series. If there is predictive power in past quotes then it is said that quotes Granger cause current volatility. The converse can also be true and can be tested by running a regression of past volatility onto current quote arrivals. If we find Granger causality only in one direction, then we call this uni-directional Granger causality. As we are interested in conducting Granger causality tests in each of the three market regimes, we use the following regression equations to conduct the tests:

$$\begin{aligned}\epsilon_t^V \;=\;& \alpha^{NT,NL}\, I_t^{NT,NL} + \beta^{NT,NL}\, I_t^{NT,NL}\, \epsilon_{t-1}^Q + \alpha^{NT,L}\, I_t^{NT,L} \\ &+\beta^{NT,L}\, I_t^{NT,L}\, \epsilon_{t-1}^Q + \alpha^T\, I_t^T + \beta^T\, I_t^T\, \epsilon_{t-1}^Q + \gamma^{NT,NL}\, I_t^{NT,NL}\, \epsilon_{t-1}^V \\ &+\gamma^{NT,L}\, I_t^{NT,L}\, \epsilon_{t-1}^V + \gamma^T\, I_t^T\, \epsilon_{t-1}^V + \eta_t, \qquad (9)\end{aligned}$$

and

$$\begin{aligned}\epsilon_t^Q \;=\;& \alpha^{NT,NL}\, I_t^{NT,NL} + \beta^{NT,NL}\, I_t^{NT,NL}\, \epsilon_{t-1}^V + \alpha^{NT,L}\, I_t^{NT,L} \\ &+\beta^{NT,L}\, I_t^{NT,L}\, \epsilon_{t-1}^V + \alpha^T\, I_t^T + \beta^T\, I_t^T\, \epsilon_{t-1}^V + \gamma^{NT,NL}\, I_t^{NT,NL}\, \epsilon_{t-1}^Q \\ &+\gamma^{NT,L}\, I_t^{NT,L}\, \epsilon_{t-1}^Q + \gamma^T\, I_t^T\, \epsilon_{t-1}^Q + \eta_t, \qquad (10)\end{aligned}$$

where we use the same notation as in the previous subsection.

Recall that we perform Granger causality tests on pre-whitened series, that is series fitted first with a univariate time series model. However, the pre-whitening pertains to the entire sample across the three market regimes. We know from the Panel A of Table 7 that there are differences across the three regimes. Therefore we need to include lagged dependent variables associated with each market regime despite the pre-whitening. The coefficients which are the most important in these regressions are $\beta^{NT,NL}$, $\beta^{NT,L}$ and β^{T}. Again, we estimate the regression model and use corrected standard errors and variance-covariance matrix for hypothesis testing.

Let us first consider Granger causality from quotes to volatility in Panel A of Table 8. The null of the joint test $H_0 : \beta^{NT,NL} = \beta^{NT,L} = \beta^{T} = 0$ is rejected for 19 stocks among 52. The significance of individual coefficients shows similar features. Hence, regardless of trading or pre-opening market conditions, there appears to be some information in the previous 15 minute quote arrivals that predict surprises in volatility. The results indicate a negative relationship between quote arrivals and future volatility regardless of the regime. It is interesting to note that $\beta^{NT,NL}$ and β^{T} are both roughly equal whereas $\beta^{NT,L}$ is more than three times larger. Hence, quote arrivals during locks have a much larger impact on subsequent price volatility.

Panel B of Table 8 shows very strong evidence that past innovations in volatility Granger causes innovations in quote arrivals. The null $H_0 : \beta^{NT,NL} = \beta^{NT,L} = \beta^{T} = 0$ is overwhelmingly rejected. Most importantly, it is clear that the rejection comes from the trading period as $\beta^{NT,NL}$, and to a lesser extent $\beta^{NT,L}$, are barely significant. Moreover, we observe that β^{T} is not only highly significant but also positive while $\beta^{NT,L}$ is negative and implies a steep slope in comparison to β^{T}. This finding shows significant differences in quote/volatility dynamics between a trading period and a locked period. This difference should be attributed to Nasdaq rule 4613 against locked markets during trading. When a volatility shock occurs during a trading period, market makers must not change their price in a way that would lock the markets. Consequently, the best bid-ask quote must be walked up or down through successive rounds of quotes as market makers adjust to the new information. There will be a series of new market quotes reflecting $\$\frac{1}{16}$ to $\frac{1}{8}$ changes in the best bid-ask spread following the shock. As the market quotes adjust at the pace of the slowest market maker, the impact of the volatility shock affects quote arrivals positively in the subsequent interval because of the slow adjustment pace. In contrast, during the pre-opening period market locks are a fast price adjustment which explains the immediate slowdown in quote arrivals subsequent to volatility. These results emphasize the very distinct quote/volatility dynamics associated with market locks during the pre-opening.

5 Is there Leadership among Market Makers?

It is clear that while price quotes during the pre-opening have an informational content they respond and affect quote behavior differently compared to the regular trading hours on the Nasdaq. So, what is the logic behind the quote dynamics? We found that during the pre-opening, Nasdaq market makers often use a distinct mechanism (i.e., to lock the market quotes) to indicate to others what the opening prices should be and which direction the price should move. Since many market makers participate in the pre-opening and hundreds of quotes flash across screens we know that market locks are a way to signal a willingness to change the price quotes. Therefore, one may wonder whether any particular market maker or small group of market makers take a leading role in sending credible signals to others when they possess valuable information. Finding such a leadership pattern would strongly reinforce the fact that a coordination game takes place during the pre-opening. In this section, we address two related questions. First, who are the market makers who lock the market most frequently? Second, are there leaders among market makers in a given stock. In other words, does each market maker contribute equally to the price discovery during the pre-opening? Answers to these questions will provide additional insight into the price discovery process during the pre-opening.

5.1 Does Each Market Maker Contribute Equally to the Lock?

Multiple locked market quotes can occur during the pre-opening on a given day. However, some locked market quotes are triggered by new information, and some locks are simply part of the processes of unlocking the market during a locked market sequence. We start by identifying market makers who *initiate* the locked sequence as these quotes provide new information. To determine the distribution of locked sequence initiation for each sample stock, we calculate the frequency of locked sequences attributed to each market maker, and then, test for the uniform distribution of locked sequences across all market makers.

The three market makers responsible for initiating the greatest fraction of the locked sequences for each stock initiate an aggregate of about 40% of the total locked sequences during the pre-opening. In contrast, they contribute an aggregate of approximately 9% of the pre-opening quotes. Using a χ^2 test, we find the null hypothesis that each market maker initiates the lock sequences with equal probability is strongly rejected. We also strongly reject the null that the distribution of initiation of locked sequences is the same as the distribution of market maker quotes.[22] Overall, these results suggest that there exist different patterns of behavior in terms of lock initiation across market makers.

The rejections of the distributional tests are so strong as to warrant further analysis. In order to uncover potential leadership among market makers, it is important to identify market makers who make significant contribution to the price change during lock periods, as their quotes provide new information to the market. To gauge the contribution of each market maker during locks, we use a measure similar to the weighted price contribution in equation (6). Specifically, for a given stock, the weighted price contribution during locks (WPCL) by market maker k is defined as:

$$WPCL_k = \sum_{t=1}^{T} \left(\frac{|\sum_{j=1}^{N_t} \Delta P_{j,t}|}{\sum_{t=1}^{T} |\sum_{j=1}^{N_t} \Delta P_{j,t}|} \right) \times \left(\frac{\sum_{j=1}^{N_t} \Delta P_{j,t} I_{j,k}}{\sum_{j=1}^{N_t} \Delta P_{j,t}} \right) \quad (11)$$

where $\Delta P_{j,t}$ is the price change during jth lock on day t, N_t is the number of locks on day t, and $I_{j,k}$ is a dummy variable with value 1 if the jth lock is initiated by market maker k and with value 0 otherwise. The first term in parentheses is the weighting factor for each day. Each day's weight is determined by that day's contribution to the cumulative absolute daily price change across all locks over the entire sample period. The second term in parentheses is the contribution of the price change during locks initiated by market maker k on day t relative to total price change across all locks on day t.

For each stock, Table 9 presents the Nasdaq market maker ID for the three market makers who contribute the most to the price change during locks (The full name of these market makers will appear in Table 10 shortly). We define these three market makers as leading market makers.[23] The results are sorted and reported according to trading frequency quartiles. The top three market makers are credited with a significant proportion of the price contribution. For example, the cross-sectional average of the price contribution of the number one, two and three leading market makers during locks are 24.3%, 14.0% and 10.6%, respectively, and their contribution constitutes 49.0% of the total price change in aggregate during locks.

[22]We relied both on χ^2 goodness-of-fit tests as well as sign tests to compare the distribution of quotes and locked sequences across market makers.

[23]Alternative definitions of leading market makers were also considered. Using a relative measure, for example, defining leaders as those market makers who contribute 50% of the price change during locks, yielded similar results.

Table 9 also presents the locked-sequence frequency and the quote frequency for each leading market maker identified with the measure of the price contribution. On average, 13.7% of the locked sequences are initiated by the number one market maker, 11.3% by the number two market maker, and 9.7% by the number three market maker. In aggregate, the leading market makers initiate about 35% of the total locked sequences during the pre-opening. In contrast, the number one, two and three market makers contribute 3.0%, 3.0% and 3.0% of pre-opening quotes, respectively. Therefore, the difference in the contribution to the price discovery is apparent among the leading market makers, although they quote prices with similar frequency.

If the pre-opening is used by market makers to exchange information regarding the opening price then the leading market makers should be those who are expected to possess significant private information about the security or order flow. To investigate this possibility we present the ID of the leading market maker, its full name, and its occurrence as the number one, two and three market maker for our sample stocks in Table 10. The results indicate that major brokerage firms often act as leading market makers. For instance, Morgan Stanley & Co. (or Bear, Stearns & Co.) is identified as the number one, two and three leading market maker for 7, 6, and 5 stocks (or for 7, 5, and 5 stocks). The four large brokerage firms, Morgan Stanley & Co., Bear, Stearns & Co., Goldman Sachs & Co. and Merrill Lynch Inc. are identified as the leading number one market maker for 20 stocks, among the 52 sample stocks. The same four brokerage firms are also the second leading market maker in 19 stocks and they are ranked third for 16 stocks. Overall, these results suggest that there exists leading market makers who contribute more to the price discovery during the pre-opening than many other market makers.

5.2 Regression Analysis of Overnight Return

Having demonstrated the presence of leadership among market makers, we now turn to the analysis of the relationship between the overnight return and the return during locked market sequences to further test the role of leading market makers. Two specifications are considered. First, we examine the association between the overnight return and the return of the locked period on days when there is at least one locked sequence.[24] Second, we identify whether a locked sequence is associated with a leader (i.e., one of the top three market makers who contribute the

[24]In this exercise, days on which there are no locked sequences, which account for about 30% of the total observations, are dropped from the analysis.

most to the price change during locks) or with a non-leader, and separate the lock-period return associated with leaders from those associated with non-leaders. The estimated models are:

$$R_t^{ov} = \alpha + \beta_1 R_t^{Lock} + \eta_t, \tag{12}$$

$$\begin{aligned} R_t^{ov} &= \alpha + \beta_2 R_t^{Lock,Non-Leaders} + \beta_3 R_t^{Lock,Leaders} \\ &\quad + \beta_4 R_t^{PostLock} + \eta_t, \end{aligned} \tag{13}$$

where R^{ov} is the overnight return, R^{Lock} is the compounded return for all locks occurring during the pre-opening, $R^{Lock,Non-Leaders}$ is the compounded return for all pre-opening locks that are associated with non-leading market makers, $R^{Lock,Leaders}$ is the compounded return for all pre-opening locks that are associated with leading market makers, and $R^{PostLock}$ is the compounded return from the end of the last lock until the open, and between any two consecutive locks if more than one lock occurs. Under the null hypothesis that locks are uninformative, β_1 in equation (12) should be zero, $H_0 : \beta_1 = 0$. Furthermore, there are three hypotheses to be tested using equation (13). The first hypothesis is that only locks initiated by leaders are informative (i.e., $H_0 : \beta_2 = 0$). Another interesting hypothesis is that there is no leader effect and locks have the same explanatory power regardless of who initiates them: $H_0 : \beta_2 = \beta_3$ versus $H_a : \beta_2 < \beta_3$. The third hypothesis concerns the explanatory power of the post-lock return. If locks are the only informative feature of the pre-opening then β_4 is expected to be zero, i.e. $H_0 : \beta_4 = 0$.

The test result, as reported in Table 11, is based on observations pooled both over time and cross-sectionally for the entire sample and for each trade-frequency quartile. For the full sample, the estimated coefficient of β_1 in equation (12) is 0.64 and significant at 5%, and the adjusted R^2 is 0.50. Thus, 50% of the overnight return is explained by the return over locked periods, which is consistent with the result in Table 5. For equation (13), the coefficient estimates of β_2 and β_3 are 0.67 and 0.78, and both are significant at the 5% level. The null hypothesis that only leaders matter (i.e., $H_0 : \beta_2 = 0$) is strongly rejected, suggesting that both leaders and non-leaders contribute to the overnight return. The second null hypothesis that the leader effect is the same as the non-leader effect is strongly rejected at the 5% level, and the result leads to the conclusion that the leader effect, β_3, is larger than the non-leader effect, β_2. For the final hypothesis concerning the explanatory power of the post-lock return, the point estimate of β_4 is 1.47 and the null hypothesis is rejected at 5%. Although the post-lock return has additional explanatory power, it increases the adjusted R^2 from 50% to 60%, its marginal contribution is smaller in comparison to the return over locked periods.

The results for trading frequency quartiles exhibit several patterns. The coefficient estimate of β_2 decreases, while β_3 is relative stable with respect to trading frequency. It is noted that the leader effect is significantly larger than the non-leader effect for stocks in the most active quartile. For stocks in trade-frequency quartiles 1, 2 and 3, the leader and non-leader effects are statistically similar. The results of larger leader effect for the entire sample mainly come from the most actively traded stocks, which accounted for about 50% (1726 observations) of the total observations (3543 observations).

In summary, the regression analysis reveals that returns over locked periods explain a significantly large portion (50% – 60%) of overnight returns. In addition, locked sequences associated with leading market makers have a larger impact on the overnight return than those associated with non-leading market makers.

6 Conclusion

We have studied the price discovery process on Nasdaq during the one-and-half hours prior to the opening of trading. The Nasdaq pre-opening has several characteristics: (1) many Nasdaq market makers participate in the pre-opening communication game and actively quote prices, (2) the pre-opening prices are non-binding commitments which can be revised, and (3) the identity of participating market makers is known to others. Hence, the pre-opening period provides an ideal setting to investigate (1) whether there is price discovery in the absence of trading and binding commitments, (2) whether the price discovery during the pre-opening is a significant part of the daily price change, and (3) whether the Nasdaq structure facilitates market makers' signal to each other to share information and resolve the information uncertainty without actual trading.

While it is a common belief that non-binding commitments do not contain any information and do not contribute to price discovery, this article shows that there is price discovery in the absence of firm commitments and trading on Nasdaq. The contribution of the pre-opening period to the daily price change averaged 17% for our sample stocks. On a relative unit of time basis, the contribution of the pre-opening is as large as that of the trading period. Moreover, our empirical evidence indicates that Nasdaq dealers use locked market quotes as an unique mechanism to indicate to others what the equilibrium opening prices should be conditional on the overnight information. Finally, we show that among more than 200 Nasdaq market makers, only a small fraction of them is responsible for about 50% of the price changes during locks and for about 35% of the locks, and the evidence suggests that there are leading market makers among dealers who trade the same stock.

This paper, along with recent studies by Biais, Hillion and Spatt (1996) and Madhavan and Panchapagesan (1997), enriches our understanding of the informational role of pre-opening prices. It suggests several avenues for future research. Indeed, while the microstructure literature now has a multitude of theoretical models for price discovery during trading, there is at this stage no equivalent model for the pre-opening coordination games, with the exception of the auction model in Madhavan and Panchapagesan (1997). So far we have established that the quote dynamics reveal information, but a structural interpretation of the process remains a challenge. Moreover, we now have evidence for three different opening mechanisms, namely Paris, NYSE and Nasdaq. Both the latter and the former are screen-driven markets and therefore more directly comparable. While there are many similarities between the two there are some subtle and very important differences. Which mechanism is the most transparent and efficient in reaching consensus about the opening price? There is no clear answer to this question at this point. Nor is there a clear indication about how both compare to a single batch auction. Finally, while market makers may come to a consensus price, it remains unclear whether such a price is incentive compatible with regard to profit taking schemes in the early stages of the trading process.

References

Barclay, Michael and Jerold Warner, 1993, Stealth Trading and Volatility: Which Trades Move Prices? *Journal of Financial Economics* 34, 281-305.

Battalio, Robert, Jason Greene, and Robert Jennings, 1997, Do Competing Specialists and Preferencing Dealers Affect Market Quality? An Empirical Analysis, *Review of Financial Studies* 10, 969-995.

Bessembinder, Hendrik, Kalok Chan and Paul Seguin, 1996, An Empirical Examination of Information, Differences of Opinion, and Trading Activity, *Journal of Financial Economics* 40, 105-134.

Biais, Bruno, Pierre Hillion, and Chester Spatt, 1996, Price Discovery and Learning During the Pre-opening on the Paris Bourse. Working paper, Toulouse University, INSEAD and Carnegie Mellon University.

Chan, K. C., William Christie, and Paul Schultz, 1995, Market Structure and the Intraday Pattern of Bid-Ask Spreads for NASDAQ Securities, *Journal of Business* 68, 35-60.

Copeland, Thomas, and Dan Galai, 1983, Information Effects and the Bid-ask Spread, *Journal of Finance* 38, 1457-1469.

Easley, David, Nicholas Kiefer, Maureen O'Hara and Joseph Paperman, 1996, Liquidity, Information and Infrequently Traded Stocks, *Journal of Finance* 51, 1405-1436.

Easley, David, and Maureen O'Hara, 1987, Price, Trade Size, and Information in Securities Markets, *Journal of Financial Economics* 19, 69-90.

Evans, Martin, 1997, The Microstructure of Foreign Exchange Dynamics, Working Paper Georgetown University.

Farrell, Joseph, 1995, Talk is Cheap, *American Economic Review* 85, 186-190.

Farrell, Joseph and Matthew Rabin, 1996, Cheap Talk, *Journal of Economic Perspectives* 10, 103-118.

Glosten, Lawrence and Lawrence Harris, 1988, Estimating the Components of the Bid/ask Spread, *Journal of Financial Economics* 21, 123-142.

Glosten, Lawrence and Paul Milgrom, 1985, Bid, Ask and Transaction Prices in a Specialist Market with Heterogeneously Informed Traders, *Journal of Financial Economics* 13, 71-100.

Godek, Paul, 1996, Why Nasdaq Market Makers Avoid Odd-Eighth Quotes, *Journal of Financial Economics* 41, 465-474.

Granger, Clive, 1969, Testing for Causality and Feedback, *Econometrica* 37, 424-438.

Harris, Lawrence, 1990, Estimation of Stock Price Variance and Serial Covariance from Discrete Observations, *Journal of Financial and Quantitative Analysis* 25, 291-306.

Hasbrouck, Joel, 1988, Trades, Quotes, Inventories, and Information, *Journal of Financial Economics* 22, 229-252.

Hasbrouck, Joel, 1991, Measuring the Information Content of Stock Trades, *Journal of Finance* 46, 179-207.

Kyle, Albert, 1985, Continuous Auctions and Insider Trading, *Econometrica* 53, 1315-1336.

Madhavan, Ananth, and Venkatesh Panchapagesan, 1997, Price Discovery and Exchange Openings, Working paper, University of Southern California.

Madhavan, Ananth, Matthew Richardson and Mark Roomans, 1997, Why Do Security Prices Change? A Transaction-level Analysis of NYSE Stocks, *Review of Financial Studies* 10, 1035-1064.

O'Hara, Maureen, 1995, Market Microstructure Theory (Blackwell Publisher, Cambridge, Massachusetts).

Sims, Christopher, 1980, Macroeconomics and Reality, *Econometrica* 48, 1-48.

Table 1: Ticker Symbols of 50 of the Most Active Nasdaq Stocks

For 50 of the most active Nasdaq stocks (as measured by 1994 share volume), reported below are the stock's ticker symbol, the company name, the number of trading days in the sample where there exist pre-opening prices between 8:00 and 9:30 a.m. in the Bridge data set, and the market value of the stock at the end of 1995. The sample period extends from October 1, 1995 through September 30, 1996. As five stocks are delisted from Nasdaq during the sample period, additional stocks are added in order of 1994's share volume to maintain a total sample size of 50. Three stocks with less than 60 trading days available are dropped from the final sample.

	Ticker	Company Name	No. of Days	Market Value ($ mil.)		Ticker	Company Name	No. of Days	Market Value ($ mil.)
1	AAPL	Apple Computer, Inc.	251	3924	27	ERTS	Electronic Arts, Inc.	252	1369
2	ADBE	Adobe Systems Incorporated	251	3957	28	FITB	Fifth Third Bancorp	248	4901
3	ADPT	Adaptec, Inc.	252	2155	29	GATE	Gateway 2000, Inc.	252	1778
4	AKLM	Acclaim Entertainment, Inc.	252	617	30	GNPT	GP Financial Corp.	152	1454
5	ALTR	Altera Corporation	252	2164	31	IDTI	Integrated Device Technology, Inc.	251	994
6	AMAT	Applied Materials, Inc.	252	7059	32	IFMX	Informix Corporation	252	4036
7	AMGN	Amgen Inc.	252	15794	33	INTC	Intel Corporation	252	46603
8	APCC	American Power Conversion Corp.	251	885	34	MCIC	MCI Communications Corporation	252	14238
9	ASTA	AST Research, Inc.	251	380	35	MEOHF	Methanex Corporation	250	NA
10	ATML	Atmel Corporation	252	2173	36	MSFT	Microsoft Corporation	252	51772
11	BGEN	Biogen, Inc.	251	2181	37	NOBE	Nordstrom, Inc.	252	3293
12	BMCS	BMC Software, Inc.	251	2164	38	NOVL	Novell, Inc.	252	5275
13	BNET	Bay Networks, Inc.	122	7129	39	ORCL	Oracle Systems Corporation	252	18446
14	BOAT	Boatmen's Bancshares, Inc.	206	5272	40	PCCW	Price/Costco, Inc.	252	2978
15	CALL	NEXTEL Communications, Inc.	252	2578	41	PMTC	Parametric Technology	252	4161
16	CHIR	Chiron Corporation	251	4592	42	PRGO	Perrigo Company	252	904
17	CMCSK	Comcast Corporation	251	3493	43	PYXS	Pyxis Corporation	168	532
18	CNTO	Centocor, Inc.	251	1802	44	QNTM	Quantum Corporation	252	852
19	COMS	3Com Corporation	252	7667	45	RTRSY	Reuters Holdings PLC	252	NA
20	COTTF	Cott Corporation	252	NA	46	SAFC	SAFECO Corporation	252	4346
21	CREAF	Creative Technology Ltd.	251	NA	47	SUNW	Sun Microsystems, Inc.	252	8298
22	CRUS	Cirrus Logic, Inc.	251	1247	48	SYBS	Sybase, Inc.	252	2597
23	CSCO	Cisco Systems, Inc.	252	20624	49	TCOMA	Tele-Communications, Inc.	252	11360
24	DELL	Dell Computer Corporation	251	3169	50	TLAB	Tellabs, Inc.	88	3276
25	DIGI	DSC Communications Corporation	252	4252	51	USHC	U.S. Healthcare, Inc.	220	7139
26	ERICY	LM Ericsson Telephone Company	252	NA	52	WMTT	Willamette Industries, Inc.	130	3109

NA: The market value is not available from the CRSP database because the stock is a foreign stock or an ADR.

Table 2: Characteristics of 50 of the Most Active Nasdaq Stocks During the Pre-opening and Trading Hours

For each stock, the reported numbers are (1) daily average number of trades, (2) total number of dealers who post bid-ask prices during the pre-opening, (3) daily average number of dealers during the pre-opening, (4) daily average number of dealer quotes during the pre-opening, (5) daily average share volume, (6) daily average dollar volume, (7) daily average number of market quotes (i.e., best bid-ask prices) per hour during the pre-opening and (8) daily average number of market quotes per hour during trading hours. The sample period extends from October 1, 1995 through September 30, 1996. The number of dealers, pre-opening dealer quotes, and pre-opening market quotes are from the Bridge data set. The number of trades, share volume, and dollar volume are from the TAQ database. The sample stocks are partitioned into four quartiles and sorted according to daily average number of trades.

Trading Frequency Quartile	Ticker	Daily No. of Trades	Total No. of Dealers	Avg. No. of Dealers	Daily Dealer Pre-open Quotes	Daily Share Volume (1000)	Daily Dollar Volume ($ mil.)	No. of Market Quotes per Hour (Pre-open)	No. of Market Quotes per Hour (Post-open)
Quartile 1 (Least Active)	MEOHF	86	44	7	8	214	1	1.9	1.1
	RTRSY	124	33	23	52	299	18	5.5	4.0
	FITB	147	28	10	15	192	11	1.8	2.6
	GNPT	167	31	11	17	497	13	1.5	2.2
	COTTF	171	53	8	11	296	2	1.4	2.0
	PRGO	182	37	9	10	325	3	1.1	1.4
	WMTT	193	21	9	13	222	13	2.0	4.2
	SAFC	198	29	10	16	320	12	2.0	4.0
	ASTA	212	49	13	18	308	2	1.4	1.7
	CREAF	224	37	9	13	321	2	1.6	2.0
	BOAT	369	41	17	24	577	25	1.9	4.1
	CMCSK	405	49	20	30	1404	25	1.8	2.7
	NOBE	416	44	18	30	636	27	2.2	6.1
Quartile 2	PYXS	421	37	11	16	772	14	1.8	3.5
	PCCW	425	57	18	25	1044	19	1.4	2.4
	AKLM	431	51	20	35	676	10	2.0	4.2
	BMCS	527	30	16	33	880	48	3.0	9.1
	QNTM	598	47	20	36	1184	22	2.1	4.0
	PMTC	608	33	17	36	1026	52	3.6	12.2
	CHIR	627	37	17	39	644	50	3.7	13.0
	APCC	702	56	18	28	923	10	2.1	4.4
	TCOMA	762	63	23	34	2804	51	1.7	3.2
	ERTS	763	42	21	40	1168	35	2.8	12.0
	CNTO	780	48	21	44	1121	32	2.9	12.1
	BGEN	820	34	17	34	975	60	2.7	11.0
	CALL	826	62	21	32	1293	22	1.9	4.2

Table 2: Characteristics of 50 of the Most Active Nasdaq Stocks During the Pre-opening and Trading Hours (continued)

Trading Frequency Quartile	Ticker	Daily No. of Trades	Total No. of Dealers	Avg. No. of Dealers	Daily Dealer Pre-open Quotes	Daily Share Volume (1000)	Daily Dollar Volume ($ mil.)	No. of Market Quotes per Hour (Pre-open)	No. of Market Quotes per Hour (Post-open)
	ADPT	915	27	17	44	1279	59	4.4	19.0
	SYBS	1025	46	24	46	1501	42	2.7	8.5
	TLAB	1027	33	19	39	1183	73	4.0	17.2
	GATE	1034	38	23	52	1319	42	3.8	13.8
	ADBE	1060	38	23	55	1585	68	4.3	16.1
	MCIC	1150	65	27	40	2945	79	1.6	4.6
Quartile 3	USHC	1237	45	19	32	2051	97	2.2	7.3
	ERICY	1389	56	35	69	2677	57	4.2	3.8
	IDTI	1417	52	23	50	1897	33	3.3	6.5
	IFMX	1477	55	30	64	2638	69	3.6	11.2
	ALTR	1480	30	16	55	2043	107	6.0	34.8
	ATML	1574	36	19	53	2356	68	4.8	15.8
	DIGI	1712	57	31	78	2620	89	4.4	13.5
	CRUS	1720	43	22	55	2005	58	4.1	13.0
	AMGN	1739	43	24	49	2233	123	3.3	14.0
	AAPL	1911	51	35	77	2057	62	3.7	7.9
	NOVL	1985	84	32	52	3416	49	1.9	3.1
	DELL	2046	50	25	70	2752	138	5.3	24.5
	COMS	2376	48	31	82	3507	158	4.8	22.5
Quartile 4 (Most Active)	BNET	2668	40	25	78	3827	186	5.4	29.2
	ORCL	2858	59	37	95	4241	175	4.7	15.8
	AMAT	2924	51	34	96	4001	167	5.7	19.0
	MSFT	3983	45	34	92	4641	479	5.6	30.2
	SUNW	4224	49	32	107	4620	261	7.0	37.8
	CSCO	4501	66	39	122	6205	376	6.2	30.2
	INTC	6693	54	42	118	8385	554	6.0	20.0

Table 3: Characteristics of Locked Market Quotes During the Pre-opening and Trading Hours

Reported below are the number of locked market quotes, the frequency of locks, the average size (in dollars), and the average duration (in minutes and in number of market quotes) of locked market quotes for sample stocks. A lock is defined as a market quote where the bid price is greater than or equal to the ask price. The frequency of locks is the total number of locked market quotes divided by the total number of market quotes. The size of the lock is the bid minus the ask. The duration of the lock in minutes (or in market quotes) is calculated from the time when the lock is initiated to the termination of the lock. Panels A, B, C and D present summary statistics by time of the day, the absolute value of the overnight (close-to-open) price change, the absolute value of the close-to-close price change, and daily average number of trades, respectively. The sample period extends from October 1, 1995 through September 30, 1996.

Panel A: Characteristics of Locked Market Quotes by Time of the Day

	Time of Day	No. of Locks	Frequency of Locks (%)	Average Size ($)	Average Duration (minutes)	Average Duration (quotes)
Pre-opening	8:00 – 9:30 a.m.	17449	34.9	0.48	16.0	2.7
Trading Period	9:30 – 9:35 p.m.	1062	4.2	0.11	25.4	5.7
	9:35 – 10:30 a.m.	730	0.4	0.08	2.7	1.8
	10:30 – 12:00 a.m.	411	0.2	0.08	3.4	1.3
	12:00 – 13:30 p.m.	230	0.2	0.03	0.1	1.1
	13:30 – 14:30 p.m.	198	0.1	0.02	0.1	1.1
	14:30 – 16:00 p.m.	252	0.2	0.02	0.1	1.1

Panel B: Characteristics of Locked Market Quotes During the Pre-opening Period (Sorted by Absolute Value of the Overnight Price Change)

Abs. Value of Overnight Price Change ($\lvert\Delta P^{ov}\rvert$)	No. of Locks	Frequency of Locks (%)	Average Size ($)	Average Duration (minutes)	Average Duration (quotes)
$\$0 - \frac{1}{8}$	1117	8.2	0.15	18.4	1.4
$\$\frac{1}{8} - \frac{1}{4}$	1498	18.9	0.09	14.6	1.6
$\$\frac{1}{4} - \frac{1}{2}$	3682	33.1	0.15	11.5	1.9
$\$\frac{1}{2} - 1$	5305	53.6	0.30	14.0	3.4
$1 – 2	3664	72.3	0.61	24.6	6.0
$2 – 5	1902	81.8	1.38	39.2	10.4
> $5	281	82.8	4.09	41.6	9.9

Table 3: Characteristics of Locked Market Quotes During the Pre-opening and Trading Hours (continued)

Panel C: Characteristics of Locked Market Quotes During the Pre-opening Period (Sorted by Absolute Value of the Close-to-Close Price Change)

Abs. Value of Close-to-close Price Change ($\lvert\Delta P^{cc}\rvert$)	No. of Locks	Frequency of Locks (%)	Average Size ($)	Average Duration (minutes)	Average Duration (quotes)
$\$0 - \frac{1}{8}$	1621	20.2	0.20	16.8	2.1
$\$\frac{1}{8} - \frac{1}{4}$	1132	23.4	0.20	15.0	2.0
$\$\frac{1}{4} - \frac{1}{2}$	2181	31.6	0.27	15.7	2.3
$\$\frac{1}{2} - 1$	3366	33.0	0.32	15.3	2.4
$1 – 2	4495	43.0	0.47	15.6	3.0
$2 – 5	4006	51.8	0.70	16.6	3.9
$> \$5$	648	66.6	2.08	25.1	6.2

Panel D: Characteristics of Locked Market Quotes During the Pre-opening Period (Sorted by Trading Frequency)

Daily Avg. No. of Trades	No. of Locks	Frequency of Locks (%)	Average Size ($)	Average Duration (minutes)	Average Duration (quotes)
≤ 416	1492	20.2	0.54	29.8	3.5
416 – 826	1379	14.3	0.50	12.6	2.0
826 – 1712	4776	33.3	0.42	16.3	2.6
1712 – 6693	9802	52.5	0.51	14.2	2.8

Table 4: Regression Analysis of Absolute Value of Price Change and Lock Duration

The regression results below are based on the following equations:

$$
\begin{aligned}
|\Delta P_t^{ov}| &= \alpha + \beta LockSize_t + \eta_t, \\
|\Delta P_t^{ov}| &= \alpha + \beta LockTime_t + \eta_t, \\
|\Delta P_t^{ov}| &= \alpha + \beta LockQuote_t + \eta_t, \\
\\
|\Delta P_t^{cc}| &= \alpha + \beta LockSize_t + \eta_t, \\
|\Delta P_t^{cc}| &= \alpha + \beta LockTime_t + \eta_t, \\
|\Delta P_t^{cc}| &= \alpha + \beta LockQuote_t + \eta_t, \\
\\
LockTime_t &= \alpha + \beta LockSize_t + \eta_t, \quad \text{and} \\
LockQuote_t &= \alpha + \beta LockSize_t + \eta_t,
\end{aligned}
$$

where $|\Delta P^{ov}|$ is the absolute value of the overnight (close-to-open) price change, $|\Delta P^{cc}|$ is the absolute value of the close-to-close price change, $LockSize$ is the size (i.e., bid price less the ask price) of the locked market quote, defined as a market quote where the bid price is greater than or equal to the ask price, expressed in cents. $LockTime$ is the duration of the locked market quote in minutes, i.e., the elapsed time from the occurrence of a locked market quote to the first subsequent non-locked market quote. $LockQuote$ is the duration of the lock in market quotes, which is the total number of locked market quotes observed from the occurrence of a locked market to the first subsequent non-locked market quote.

	Dependent Variable							
Coefficient	$\|\Delta P^{ov}\|$	$\|\Delta P^{ov}\|$	$\|\Delta P^{ov}\|$	$\|\Delta P^{cc}\|$	$\|\Delta P^{cc}\|$	$\|\Delta P^{cc}\|$	LockTime	LockQuote
Constant	75.36*	33.20*	49.05*	131.91*	94.79*	112.20*	17.70*	8.07*
LockSize	0.88*			0.72*			12.02*	2.68*
LockTime		1.02*			0.68*			
LockQuote			11.82*			10.37*		
$Adj.R^2$	0.13	0.03	0.02	0.07	0.02	0.01	0.08	0.02

* Indicates significance at the 5% level.

Table 5: Contributions of Pre-opening and Trading Periods to Daily Price Change

The reported statistics are fractions of the daily stock price change attributable to the (1) pre-opening period, (2) pre-lock period, (3) lock period, (4) post-lock period, and (5) trading period. The pre-opening period is from 8:00 to 9:30 a.m., the pre-lock period is from 8:00 a.m. to the time of the first locked market quote, and the lock period spans from the occurrence of a locked market quote until the first subsequent non-locked market quote. The post-lock period is from when the last locked market is unlocked until the first market quote after 9:30 a.m., plus the time period in-between any two lock periods (if there are multiple locks), and trading period is from the first market quote after 9:29 a.m. to 4:00 p.m. The sample period extends from October 1, 1995 through September 30, 1996. For each stock and for a given period i, where $i \in$ (pre-open, pre-lock, lock, post-lock, or trading period), each day's price change is weighted based on its contribution to the cumulative absolute price change over the sample period. Specifically, the weighted price contribution (WPC) and the relative time weighted price contribution (RTWPC) for period i is determined as

$$WPC_i = \sum_{t=1}^{T} \left(\frac{|\Delta P_t|}{\sum_{t=1}^{T} |\Delta P_t|} \right) \times \left(\frac{\Delta P_{i,t}}{\Delta P_t} \right)$$

$$RTWPC_i = \frac{WPC_i / \sum_{t=1}^{T} \text{Time}_{i,t}}{WPC_{trading} / \sum_{t=1}^{T} \text{Time}_{trading,t}}$$

where $\Delta P_{i,t}$ is the total price change for period i on day t and ΔP_t is the total price change on day t. The first term in parentheses is the weighting factor for each day. The second term in parentheses is the relative contribution of the price change of period i on day t to the daily price change.

Weighted Price Contribution

Sample	WPC (%) (Pre-open)	Pre-Open: WPC (%) (Pre-lock)	Pre-Open: WPC (%) (Lock)	Pre-Open: WPC (%) (Post-lock)	WPC (%) (Trading)
Full sample	16.5	5.9	10.1	0.5	83.5
Quartile 1	16.9	8.6	7.7	0.6	83.1
Quartile 2	13.1	6.7	5.8	0.6	86.9
Quartile 3	15.5	2.9	12.1	0.5	84.5
Quartile 4	20.4	5.2	14.8	0.4	79.6

Relative Time Weighted Price Contribution

Sample	RTWPC (Pre-open)	Pre-Open: RTWPC (Pre-lock)	Pre-Open: RTWPC (Lock)	Pre-Open: RTWPC (Post-lock)	RTWPC (Trading)
Full sample	1.1	0.6	4.5	2.6	1
Quartile 1	1.3	0.6	7.8	4.9	1
Quartile 2	0.8	0.4	4.7	2.9	1
Quartile 3	1.1	0.2	3.1	1.8	1
Quartile 4	1.4	0.7	2.6	1.1	1

Table 6: Summary Statistics of Locked Market Quotes During the Pre-opening

For each sample stock, reported below are (1) the ticker symbol, (2) the number of locked market quotes, (3) the frequency of locked market quotes (i.e., the total number of locked market quotes divided by the total number of market quotes), (4) the number of locked market sequences, and (5) the identity (ID) of the market maker who has the greatest weighted price contribution during locks. All statistics are reported for the pre-opening period. A lock is defined as a market quote where the bid price is greater than or equal to the ask price, and the market quote is the best bid-ask prices. A locked market sequence is defined as a continuous series of locked market quotes. The sample stocks are partitioned into four quartiles and sorted according to daily average number of trades.

Trading Frequency Quartile	Ticker	No. of Locked Market Quotes	% of Locked Market Quotes	No. of Locked Seq.	#1 Market Maker ID	Trading Frequency Quartile	Ticker	No. of Locked Market Quotes	% of Locked Market Quotes	No. of Locked Seq.	#1 Market Maker ID
	MEOHF	15	3.7	8	MLSI		ADPT	203	14.8	130	MSCO
	RTRSY	1077	61.8	517	HRZG		SYBS	236	27.8	148	CANT
	FITB	27	4.9	11	GSCO		TLAB	85	20.4	55	ABSB
	GNPT	22	7.7	11	FBRC		GATE	207	17.7	146	NITE
	COTTF	37	8.3	20	DLJP		ADBE	267	20.4	156	MONT
	PRGO	15	4.2	9	BEST		MCIC	115	22.4	82	MSCO
Quartile 1	WMTT	8	2.5	6	PRUS	**Quartile 3**	USHC	145	24.8	79	MONT
(Least	SAFC	33	5.3	17	LEHM		ERICY	1034	79.1	575	HRZG
Active)	ASTA	38	8.4	24	SHWD		IDTI	395	38.8	261	PERT
	CREAF	40	8.0	25	SHWD		IFMX	358	31.9	212	SNDV
	BOAT	32	6.7	22	FBCO		ALTR	606	33.5	355	NEED
	CMCSK	75	13.8	53	GSCO		ATML	492	33.0	274	OLDE
	NOBE	75	10.8	46	MSCO		DIGI	634	46.4	333	GSCO
	PYXS	39	11.9	19	DLJP		CRUS	526	42.0	303	NITE
	PCCW	34	7.5	28	GSCO		AMGN	316	31.1	177	MSCO
	AKLM	99	15.4	58	JEFF		AAPL	525	46.1	273	BEST
	BMCS	106	11.5	71	MSCO		NOVL	152	25.7	107	ROSS
	QNTM	117	16.7	70	BEST		DELL	703	42.5	400	PERT
	PMTC	125	11.3	85	SHWD		COMS	700	47.3	395	MSCO
Quartile 2	CHIR	122	10.7	80	BEST	**Quartile 4**	BNET	494	57.3	217	SBSH
	APCC	92	14.1	61	MADF	**(Most**	ORCL	720	49.1	446	MSCO
	TCOMA	105	19.9	65	GSCO	**Active)**	AMAT	1006	57.4	541	BEST
	ERTS	182	20.9	98	SHWD		MSFT	967	58.9	494	BEST
	CNTO	176	19.4	94	BEST		SUNW	1308	60.4	687	HRZG
	BGEN	108	13.2	74	MLCO		CSCO	1141	61.1	611	ABSB
	CALL	77	13.2	56	SBSH		INTC	1264	69.1	681	NAWE

Table 7: Regression Analysis of Innovation in Volatility

Reported below are the mean and the standard deviation (in parentheses) of innovation in volatility and quote arrival (Panel A), and the regression results (Panel B) based on the equation:

$$\epsilon_t^V \;=\; \alpha^{NT,NL}\, I_t^{NT,NL} + \beta^{NT,NL}\, I_t^{NT,NL}\, \epsilon_t^Q + \alpha^{NT,L}\, I_t^{NT,L} + \beta^{NT,L}\, I_t^{NT,L}\, \epsilon_t^Q + \alpha^T\, I_t^T + \beta^T\, I_t^T\, \epsilon_t^Q + \eta_t.$$

The return series is constructed for each 15-minute interval using the market quotes from 8:00 a.m. to 4:00 p.m. Each 15-minute interval is classified as (1) a no trade and no lock, or (2) a no trade and lock interval during the pre-opening period from 8:00 to 9:30 a.m. During trading hours (9:30 a.m. to 4:00 p.m.), all 15-minute intervals are classified as trade intervals. The volatility is defined as the absolute value of the 15-minute return, and the quote arrival as the number of market quotes occurring during the 15-minute interval. In the regression model, ϵ^V is the innovation in volatility, ϵ^Q is the innovation in quote arrival, $I^{NT,NL}$ is a dummy variable for no trade and no lock, $I^{NT,L}$ is a dummy variable for no trade and lock, and I^T is a dummy variable for trade. ϵ^V (or ϵ^Q) is obtained by whitening the volatility (or the quote arrival) time series using an AR(5) process augmented with three daily lags. For each stock in the sample, we estimate the regression model and adjust the standard error using the Newey-West (1987) method. The cross-sectional average and standard error of coefficient estimates are reported. The sample period extends from October 1, 1995 through September 30, 1996.

Panel A: Summary Statistics of Innovation in Volatility and Quote Arrival

	No Trade, No Lock	No Trade, Lock	Trade	All
Innovation in Volatility	-0.039 (0.271)	0.343 (1.196)	-0.004 (0.392)	0.000 (0.422)
Innovation in Quote Arrival	-0.229 (2.567)	1.220 (3.640)	-0.001 (1.520)	0.000 (1.790)

Panel B: Coefficient Estimates and Hypotheses Testing

	$\alpha^{NT,NL}$	$\beta^{NT,NL}$	$\alpha^{NT,L}$	$\beta^{NT,L}$	α^T	β^T
Average Coefficient (St. Error)	-0.028 (0.004)	0.048 (0.004)	0.320 (0.030)	0.096 (0.010)	-0.003 (0.001)	0.201 (0.012)
No. of Significant Coefficients at 5%	43	51	42	42	14	52
Hypothesis	$H_0: \beta^{NT,NL} = \beta^{NT,L}$ $H_a: \beta^{NT,NL} < \beta^{NT,L}$			$H_0: \beta^{NT,L} = \beta^T$ $H_a: \beta^{NT,L} < \beta^T$		
No. of Rejections at 5% Among 52	40			42		

Table 8: Tests of Granger Causality Between Innovations in Volatility and Innovations in Quote Arrival

Reported below are results of Granger causality tests based on the following equations:

$$\begin{aligned}
\text{Model 1:}\quad \epsilon_t^V &= \alpha^{NT,NL} I_t^{NT,NL} + \beta^{NT,NL} I_t^{NT,NL} \epsilon_{t-1}^Q + \alpha^{NT,L} I_t^{NT,L} + \beta^{NT,L} I_t^{NT,L} \epsilon_{t-1}^Q + \alpha^T I_t^T + \beta^T I_t^T \epsilon_{t-1}^Q \\
&\quad + \gamma^{NT,NL} I_t^{NT,NL} \epsilon_{t-1}^V + \gamma^{NT,L} I_t^{NT,L} \epsilon_{t-1}^V + \gamma^T I_t^T \epsilon_{t-1}^V + \eta_t, \\
\text{Model 2:}\quad \epsilon_t^Q &= \alpha^{NT,NL} I_t^{NT,NL} + \beta^{NT,NL} I_t^{NT,NL} \epsilon_{t-1}^V + \alpha^{NT,L} I_t^{NT,L} + \beta^{NT,L} I_t^{NT,L} \epsilon_{t-1}^V + \alpha^T I_t^T + \beta^T I_t^T \epsilon_{t-1}^V \\
&\quad + \gamma^{NT,NL} I_t^{NT,NL} \epsilon_{t-1}^Q + \gamma^{NT,L} I_t^{NT,L} \epsilon_{t-1}^Q + \gamma^T I_t^T \epsilon_{t-1}^Q + \eta_t.
\end{aligned}$$

The return series is constructed for each 15-minute interval using the market quotes from 8:00 a.m. to 4:00 p.m. Each 15-minute interval is classified as (1) a no trade and no lock, or (2) a no trade and lock interval during the pre-opening period from 8:00 to 9:30 a.m. During trading hours (9:30 a.m. to 4:00 p.m.), all 15-minute intervals are classified as trade intervals. The volatility is defined as the absolute value of the 15-minute return, and the quote arrival as the number of market quotes occurring during the 15-minute interval. ϵ^V is the innovation in volatility, ϵ^Q is the innovation in quote arrival, $I^{NT,NL}$ is a dummy variable for no trade and no lock, $I^{NT,L}$ is a dummy variable for no trade and lock, and I^T is a dummy variable for trade. ϵ^V (or ϵ^Q) is obtained by whitening the volatility (or the quote arrival) time series using an AR(5) process augmented with three daily lags. For each of 52 stocks in the sample, we estimate the model and adjust the standard error using the Newey-West (1987) method. The cross-sectional average and standard error of coefficient estimates, the number of significant coefficients and the number of significant χ^2-statistics among 52 are reported. The sample period extends from October 1, 1995 through September 30, 1996.

Panel A: Test of Granger Causality from Innovations in Quote Arrival to Innovations in Volatility

Model 1	$\alpha^{NT,NL}$	$\beta^{NT,NL}$	$\alpha^{NT,L}$	$\beta^{NT,L}$	α^T	β^T	$\gamma^{NT,NL}$	$\gamma^{NT,L}$	γ^T	$H_0: \beta^{NT,NL} = \beta^{NT,L} = \beta^T = 0$
Average Coefficient	-0.044	-0.003	0.606	-0.017	-0.004	-0.005	0.059	0.075	-0.007	
(St. Error)	(0.005)	(0.001)	(0.056)	(0.020)	(0.001)	(0.001)	(0.018)	(0.018)	(0.005)	
No. of Sig. Coef. at 5%	42	13	49	10	9	12	12	16	5	
No. of Rejections at 5%										19

Panel B: Test of Granger Causality from Innovations in Volatility to Innovations in Quote Arrival

Model 2	$\alpha^{NT,NL}$	$\beta^{NT,NL}$	$\alpha^{NT,L}$	$\beta^{NT,L}$	α^T	β^T	$\gamma^{NT,NL}$	$\gamma^{NT,L}$	γ^T	$H_0: \beta^{NT,NL} = \beta^{NT,L} = \beta^T = 0$
Average Coefficient	-0.304	0.620	3.819	-0.720	-0.003	0.291	-0.166	-0.144	-0.011	
St. Error	(0.026)	(0.154)	(0.376)	(1.080)	(0.000)	(0.027)	(0.007)	(0.054)	(0.004)	
No. of Sig. Coef. at 5%	34	5	49	13	0	42	48	26	8	
No. of Rejections at 5%										41

Table 9: Leaders in Market Locks for 50 of the Most Active Nasdaq Stocks During the Pre-opening

For each stock, reported below are the ticker symbol, the identities (ID) of the #1, #2 and #3 leading market makers who have the greatest weighted price contribution during locks, the corresponding price contribution (price cont.) during locks, the locked sequence frequencies (lock seq.) and the quote frequencies. The sample period extends from October 1, 1995 through September 30, 1996. The sample stocks are partitioned into four quartiles and sorted according to daily average number of trades.

		#1 Market Maker				#2 Market Maker				#3 Market Maker				Total (#1–3)		
	Ticker	Market Maker ID	% of Price Cont.	% of Lock Seq.	% of Quote	Market Maker ID	% of Price Cont.	% of Lock Seq.	% of Quote	Market Maker ID	% of Price Cont.	% of Lock Seq.	% of Quote	% of Price Cont.	% of Lock Seq.	% of Quote
Quartile 1 (Least Active)	MEOHF	MLSI	23.6	25.0	1.9	WEED	23.5	12.5	1.9	BEST	17.6	12.5	1.6	64.7	50.0	5.4
	RTRSY	HRZG	18.6	14.7	3.5	TSCO	14.9	10.6	5.1	BEST	10.0	5.2	2.8	43.5	30.5	11.4
	FITB	GSCO	28.1	18.2	1.8	NITE	24.5	9.1	5.4	MDLD	14.0	18.2	3.3	66.6	45.5	10.5
	GNPT	FBRC	36.6	18.2	2.8	BEST	24.4	9.1	2.9	NITE	19.5	27.3	4.1	80.5	54.6	9.8
	COTTF	DLJP	17.3	25.0	1.6	MLCO	17.2	5.0	2.0	MSCO	13.8	15.0	2.6	48.3	45.0	6.2
	PRGO	BEST	36.7	11.1	2.5	MSCO	20.0	22.2	3.6	GVRC	13.3	11.1	2.0	70.0	44.4	8.1
	WMTT	PRUS	38.4	33.3	4.3	GSCO	15.4	16.7	4.2	SALB	15.4	16.7	5.5	69.2	66.7	14.0
	SAFC	LEHM	40.0	17.6	2.9	MSCO	17.8	23.5	4.9	JEFF	13.3	6.0	4.4	71.1	47.1	12.2
	ASTA	SHWD	29.1	25.0	1.9	MASH	16.7	16.7	2.4	MLCO	12.5	12.5	3.9	58.3	54.2	8.2
	CREAF	SHWD	27.7	16.0	3.9	MSCO	20.1	24.0	4.0	NITE	15.2	8.0	3.9	63.0	48.0	11.8
	BOAT	FBCO	80.5	4.5	2.8	MDLD	5.1	4.5	1.6	MASH	4.7	4.5	2.1	90.3	13.5	6.5
	CMCSK	GSCO	22.6	18.9	2.1	MSCO	15.1	17.2	2.3	BEST	13.2	13.2	2.8	50.9	49.3	7.2
	NOBE	MSCO	20.8	13.0	3.0	MONT	16.4	13.0	3.6	UBSS	12.0	6.5	1.7	49.2	32.5	8.3
Quartile 2	PYXS	DLJP	40.0	10.5	3.6	MONT	20.9	15.8	3.2	MLCO	20.0	15.8	3.0	80.9	42.1	9.8
	PCCW	GSCO	21.1	18.0	1.9	HRZG	20.6	14.3	2.5	PWJC	16.6	10.7	2.1	58.3	43.0	6.5
	AKLM	JEFF	8.6	1.7	1.4	PIPR	8.5	5.2	1.8	SHWD	8.5	15.5	2.9	25.6	22.4	6.1
	BMCS	MSCO	27.7	25.4	4.1	MLCO	8.6	10.0	3.9	DLJP	8.0	7.0	3.7	44.3	42.4	11.7
	QNTM	BEST	28.6	4.3	2.1	CANT	14.6	7.1	2.7	NITE	9.0	12.9	3.2	52.2	24.3	8.0
	PMTC	SHWD	24.2	17.6	4.5	MLCO	13.8	9.4	5.3	MASH	12.6	18.8	4.2	50.6	45.8	14.0
	CHIR	BEST	21.4	10.0	4.8	HMQT	17.1	6.3	4.0	MSCO	16.5	16.3	3.5	55.0	32.6	12.3
	APCC	MADF	25.2	1.6	2.2	ROSS	21.9	18.0	3.9	MASH	15.1	34.4	3.5	62.2	54.0	9.6
	TCOMA	GSCO	18.3	15.4	2.1	BEST	17.0	10.8	2.4	MSCA	13.0	15.4	3.8	48.3	41.6	8.3
	ERTS	SHWD	22.2	18.4	4.5	NITE	14.2	2.0	3.5	PIPR	11.8	8.2	2.0	48.2	28.6	10.0
	CNTO	BEST	27.6	15.0	2.8	TSCO	17.9	12.8	4.2	MLCO	9.2	5.3	3.0	54.7	33.1	10.0
	BGEN	MLCO	38.1	31.1	4.0	BEST	9.8	12.2	3.1	MSCO	6.7	8.1	4.1	54.6	51.4	11.2
	CALL	SBSH	27.1	37.5	2.1	GSCO	12.5	3.6	1.8	MLCO	10.4	8.9	4.3	50.0	50.0	8.2

Table 9: Leaders in Market Locks for 50 of the Most Active Nasdaq Stocks During the Pre-opening (continued)

		#1 Market Maker				#2 Market Maker				#3 Market Maker				Total (#1–3)		
	Ticker	Market Maker ID	% of Price Cont.	% of Lock Seq.	% of Quote	Market Maker ID	% of Price Cont.	% of Lock Seq.	% of Quote	Market Maker ID	% of Price Cont.	% of Lock Seq.	% of Quote	% of Price Cont.	% of Lock Seq.	% of Quote
Quartile 3	ADPT	MSCO	25.9	15.4	5.2	BEST	16.1	14.6	5.0	FBCO	11.6	13.8	4.2	53.6	43.8	14.4
	SYBS	CANT	20.9	2.0	2.9	GSCO	10.0	12.2	2.1	TSCO	8.7	2.0	3.3	39.6	16.2	8.3
	TLAB	ABSB	26.2	20.0	4.8	GSCO	13.2	2.0	3.1	TSCO	12.3	20.0	4.0	51.7	42.0	11.9
	GATE	NITE	15.7	21.2	3.8	PWJC	9.3	5.5	2.8	SBNY	8.7	3.4	3.1	33.7	30.1	9.7
	ADBE	MONT	37.5	5.8	4.4	WSLS	8.2	6.4	3.4	GSCO	4.6	7.1	3.0	50.3	19.3	10.8
	MCIC	MSCO	19.0	15.9	2.1	SBSH	15.0	7.3	1.0	CANT	9.0	5.0	2.2	43.0	28.2	5.3
	USHC	MONT	37.9	5.1	2.2	BEST	9.3	14.0	2.7	NITE	8.0	13.9	2.3	55.2	33.0	7.2
	ERICY	HRZG	25.2	14.4	3.0	TSCO	9.1	6.3	3.2	AASI	8.9	8.5	3.0	43.2	29.2	9.2
	IDTI	PERT	16.0	12.6	2.1	OLDE	12.0	13.8	3.1	PRUS	9.5	3.1	2.4	37.5	29.5	7.6
	IFMX	SNDV	19.1	3.3	2.0	MSCO	12.7	8.0	2.5	CANT	7.3	7.1	2.7	39.1	18.4	7.2
	ALTR	NEED	31.3	20.8	4.7	MONT	10.2	7.3	4.7	SBSH	6.3	8.2	5.7	47.8	36.3	15.1
	ATML	OLDE	18.2	13.1	4.0	SBSH	12.7	15.3	4.7	PRUS	10.1	5.8	4.0	41.0	34.2	12.7
	DIGI	GSCO	14.3	16.2	2.2	ABSB	12.8	10.2	2.5	PWJC	10.8	0.9	3.1	37.9	27.3	7.8
Quartile 4 (Most Active	CRUS	NITE	18.1	4.3	3.8	GSCO	16.5	11.0	2.8	NEED	9.5	10.6	4.1	44.1	25.9	10.7
	AMGN	MSCO	14.1	8.5	3.2	GSCO	13.7	6.2	2.6	BEST	12.9	11.3	3.7	40.7	26.0	9.5
	AAPL	BEST	29.8	8.8	2.6	MASH	24.5	29.3	2.6	FBCO	7.9	3.0	1.7	62.2	41.1	6.9
	NOVL	ROSS	6.3	5.6	0.7	GSCO	5.3	2.8	1.1	DEAN	4.4	4.7	1.1	16.0	13.1	2.9
	DELL	PERT	9.8	10.5	1.8	SHWD	9.7	12.8	3.3	DMGL	8.3	3.0	0.9	27.8	26.3	6.0
	COMS	MSCO	7.8	6.6	2.8	MONT	6.5	8.9	3.0	ADAM	6.3	1.8	2.3	20.6	17.3	8.1
	BNET	SBSH	14.5	6.0	3.2	MASH	10.7	17.1	2.7	NEED	9.8	2.3	1.8	35.0	25.4	7.7
	ORCL	MSCO	13.1	8.5	2.7	MLCO	10.8	12.6	2.3	BEST	8.6	8.3	2.1	32.5	29.4	7.1
	AMAT	BEST	20.8	9.1	3.1	MSCO	12.5	13.0	3.3	NEED	8.7	6.5	2.5	42.0	28.6	8.9
	MSFT	BEST	26.6	14.4	2.9	WEED	9.0	9.3	3.1	LEHM	8.8	4.5	2.4	44.4	28.2	8.4
	SUNW	HRZG	14.9	7.9	4.3	GSCO	8.0	7.1	2.5	MSCO	6.0	3.8	3.0	28.9	18.8	9.8
	CSCO	ABSB	13.1	3.1	1.9	TSCO	9.2	12.3	2.5	MSCO	8.1	6.4	3.0	30.4	21.8	7.4
	INTC	NAWE	17.2	8.2	3.5	NITE	8.6	11.3	2.1	GSCO	8.0	5.6	1.9	33.8	25.1	7.5

Table 10: The Identity of the Top Three Leading Market Makers During the Pre-opening for 50 of the Most Active Nasdaq Stocks

For each stock, reported below are (1) the identities (IDs) of the top three Nasdaq market makers who have the greatest weighted price contribution during locks, (2) the name of the market maker, and (3) the count that each market maker ranks as the #1, #2, or #3 based on the weighted price contribution during locks across all the sample stocks. The sample period extends from October 1, 1995 through September 30, 1996.

Market Maker ID	Name of Market Maker	Ranking #1	#2	#3	Total
MSCO	Morgan Stanley & Co., Inc.	7	6	5	18
BEST	Bear, Stearns & Co., Inc.	7	5	5	17
GSCO	Goldman Sachs & Co.	5	8	2	15
MLCO	Merrill Lynch Inc.	1	4	4	9
NITE	Knight Securities L.P.	2	3	4	9
TSCO	Troster Singer Corp.	-	4	2	6
MONT	Montgomery Securities	2	4	-	6
SHWD	Sherwood Securities Corp.	4	1	1	6
MASH	Mayer & Schweitzer, Inc.	-	3	3	6
SBSH	Smith Barney Inc.	2	2	1	5
CANT	Cantor Fitzgerald & Co.	1	1	2	4
HRZG	Herzog, Heine, Geduld, Inc.	3	1	-	4
NEED	Needham & Company, Inc.	1	-	3	4
ABSB	Alex Brown and Sons Inc.	2	1	-	3
DLJP	Donaldson, Lufkin, Jenrette Securities Corp.	2	-	1	3
FBCO	Credit Suisse First Boston Corp.	1	-	2	3
PRUS	Prudential Securities Inc.	1	-	2	3
PWJC	PaineWebber Inc.	-	1	2	3
JEFF	Jeffries & Co., Inc.	1	-	1	2
LEHM	Lehman Brothers Inc.	1	-	1	2
MDLD	McDonald & Company Securities, Inc.	-	1	1	2
OLDE	Olde Discount Corp.	1	1	-	2
PERT	Pershing Trading Company, L.P.	2	-	-	2
PIPR	Piper Jaffray Inc.	-	1	1	2
ROSS	Ross Securities	1	1	-	2
WEED	Weeden & Co L.P.	-	2	-	2
AASI	ABN Amro Securities Corp.	-	-	1	1
ADAM	Adams, Harkness & Hill, Inc.	-	-	1	1
DEAN	Dean Witter Reynolds Inc.	-	-	1	1
DMGL	Deutsche Morgan Grenfell Inc.	-	-	1	1
FBRC	Friedman, Billings, Ramsey & Co., Inc.	1	-	-	1
GVRC	G.V.R. Company	-	-	1	1
HMQT	Hambrecht & Quist	-	1	-	1
MADF	Madoff	1	-	-	1
MLSI	Major League Securities	1	-	-	1
MSCA	Marcus Schloss & Co., Inc.	-	-	1	1
NAWE	Nash, Weiss & Co.	1	-	-	1
SALB	Salomon Brother Inc.	-	-	1	1
SBNY	Sands Brothers & Co., Ltd.	-	-	1	1
SNDV	Soundview Financial Group, Inc.	1	-	-	1
UBSS	UBS Securities L.L.C.	-	-	1	1
WSLS	Wessels, Arnold and Henderson & Co.	-	1	-	1
Total		52	52	52	156

Table 11: Regression Analysis of Overnight Returns

The regression results below are based on following equations:

$$\text{Model 1:} \quad R_t^{ov} = \alpha + \beta_1 R_t^{Lock} + \epsilon_t,$$
$$\text{Model 2:} \quad R_t^{ov} = \alpha + \beta_2 R_t^{Lock,Non-Leaders} + \beta_3 R_t^{Lock,Leaders} + \beta_4 R_t^{PostLock} + \epsilon_t,$$

where R^{ov} is the overnight return calculated from the current day's opening price and previous day's closing price, R^{Lock} is the compound return for all locks occurring during the pre-opening, $R^{Lock,Non-Leaders}$ is the compound return for all pre-opening locks that are initiated by non-leading maker makers, $R^{Lock,Leaders}$ is the compound return for all pre-opening locks that are initiated by leading market makers, and $R^{PostLock}$ is the compound return from the end of the last lock until the open, and between any two consecutive locks if more than one lock occurs. For each stock, leading market makers are defined as the set of three market makers who have the greatest weighted price contribution during locks. The results are reported for the aggregated samples.

	Model 1						**Model 2**								
Sample	Nobs	$\alpha \times 100$	β_1	adj. R^2	p-value $H_0: \beta_1 = 0$ $H_a: \beta_1 \neq 0$	p-value $\beta_1 = 1$ $\beta_1 \neq 1$	Nobs	$\alpha \times 100$	β_2	β_3	β_4	adj. R^2	p-value $H_0: \beta_2 = 0$ $H_a: \beta_2 \neq 0$	p-value $\beta_2 = \beta_3$ $\beta_2 < \beta_3$	p-value $\beta_4 = 0$ $\beta_4 \neq 0$
Full sample	3543	0.15*	0.64*	0.50	<0.01	<0.01	3237	0.13*	0.67*	0.78*	1.47*	0.60	<0.01	<0.01	<0.01
Quartile 1	319	0.01	0.85*	0.79	<0.01	<0.01	312	0.04	0.76*	0.77*	1.35*	0.76	<0.01	0.82	<0.01
Quartile 2	406	0.12	0.71*	0.67	<0.01	<0.01	385	0.12	0.79*	0.85*	1.20*	0.78	<0.01	0.24	<0.01
Quartile 3	1086	0.18*	0.63*	0.48	<0.01	<0.01	959	0.13*	0.74*	0.79*	1.40*	0.67	<0.01	0.21	<0.01
Quartile 4	1732	0.17*	0.58*	0.41	<0.01	<0.01	1581	0.14*	0.59*	0.74*	1.77*	0.47	<0.01	<0.01	<0.01

* indicates significance at the 5 percent level.

Figure 1: Individual Market Maker Quotes and Market Quotes During the Pre-opening for Microsoft Corp.

Figure 1 displays the bid-ask and midpoints of individual market maker quotes and the contemporaneous best bid and ask quotes for Microsoft (MSFT) during the pre-opening period of December 8, 1995. The initial dealer locked quote was recorded by Morgan Stanley. The figure shows how changes in the quotes of one market maker can dominate the pre-opening. Morgan Stanley's quotes will increase the best bid three times and cause $7/8 of the $1 7/8 price change which occured on the pre-opening.

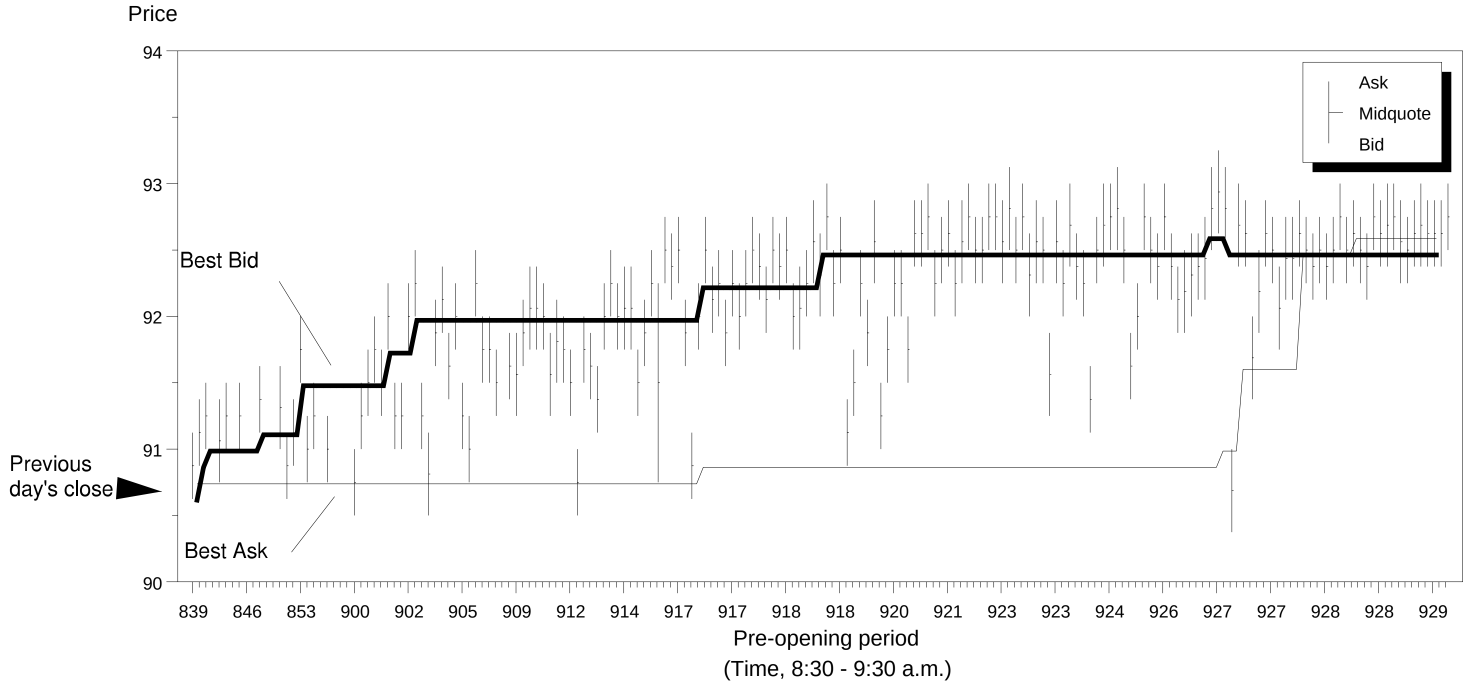
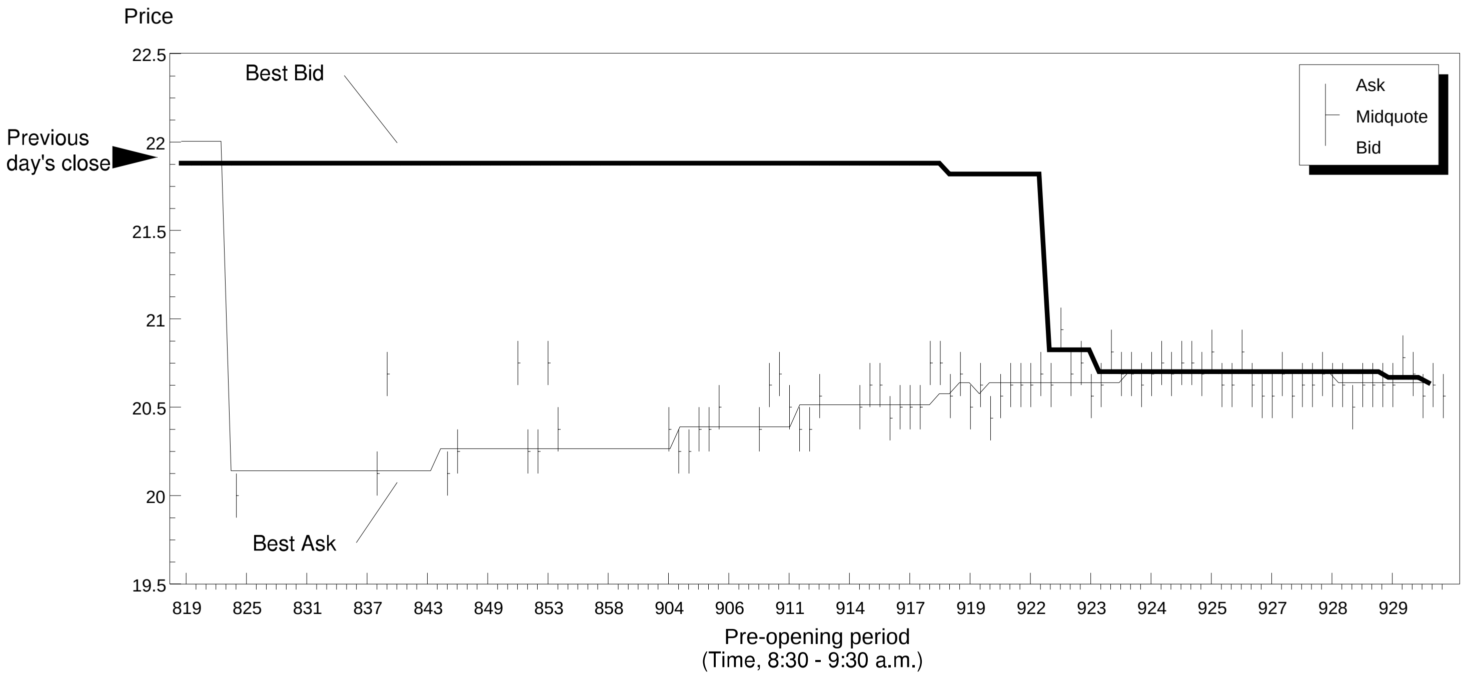


Figure 2: Individual Market Maker Quotes and Market Quotes
During the Pre-opening for Chiron Corp.

Figure 2 displays the bid-ask and midpoints of individual market maker quotes and the contemporaneous best bid and ask quotes for Chiron (CHIR) during the pre-opening period of August 1, 1996. The initial dealer locked quote was recorded by Hambrecht & Quist. The figure shows that the first locked quote contains valuable information about the opening price. The first quote can also be a noisy signal and subject to subsequent revision.



Liste des publications au CIRANO *

Cahiers CIRANO / *CIRANO Papers* (ISSN 1198-8169)

96c-1 Peut-on créer des emplois en réglementant le temps de travail ? / Robert Lacroix

95c-2 Anomalies de marché et sélection des titres au Canada / Richard Guay, Jean-François L'Her et Jean-Marc Suret

95c-1 La réglementation incitative / Marcel Boyer

94c-3 L'importance relative des gouvernements : causes, conséquences et organisations alternative / Claude Montmarquette

94c-2 Commercial Bankruptcy and Financial Reorganization in Canada / Jocelyn Martel

94c-1 Faire ou faire faire : La perspective de l'économie des organisations / Michel Patry

Série Scientifique / *Scientific Series* (ISSN 1198-8177)

98s-13 "Informal Thinkering": How Is It Important? / Pierre J. Tremblay

98s-12 Organize to Generate Innovation: Tools to Measure Technical Change, Productivity and Change-Generating Efforts / Pierre J. Tremblay

98s-11 Worksharing in Québec : Five Case Studies / Michael Huberman et Paul Lanoie

98s-10 Predictors of Hierarchical Success for Male and Female Canadian Managers / Denis Chênevert et Michel Tremblay

98s-09 Managerial Career Success in Canadian Organizations: Is Gender a Determinant? / Denis Chênevert et Michel Tremblay

98s-08 Job Characteristics and the Form of Compensation / W. Bentley MacLeod et Daniel Parent

98s-07 Technological Capability and Productivity Growth: An Industrialized / Industrializing Country Comparison / Pierre J. Tremblay

98s-06 L'évolution du taux d'activité des femmes au Canada, 1976-1994 : Une analyse de cohortes / Paul Beaudry et Thomas Lemieux

98s-05 Dix exemples de rentabilité financière liés à une saine gestion environnementale / Paul Lanoie et Georges A. Tanguay

98s-04 Effects of Workers' Compensation: A Survey / Bernard Fortin et Paul Lanoie

98s-03 Dépendance à l'égard de l'aide sociale et réforme de la sécurité du revenu / Bernard Fortin

98s-02 Risk Aversion, Intertemporal Substitution, and Option Pricing / René Garcia et Éric Renault

98s-01 Learning-by-Doing and Strategic Trade Policy / Hassan Benchekroun, Ngo Van Long et Huilan Tian

97s-42 Sector-Specific On-the-Job Training: Evidence from U.S. Data / Lars Vilhuber

97s-41 Competition and Access in Electricity Markets: ECPR, Global Price Cap, and Auctions / Marcel Boyer et Jacques Robert

97s-40 Strategic Adoption of a New Technology under Uncertain Implementation / Marcel Boyer

---

* Vous pouvez consulter la liste complète des publications du CIRANO et les publications elles-mêmes sur notre site World Wide Web à l'adresse suivante :
http://www.cirano.umontreal.ca/publication/page1.html