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The Quality of Price Formation at Market Openings and Closings: Evidence from the Nasdaq Stock Market*

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Abstract:
We assess the quality of opening and closing prices for Nasdaq stocks by examining the effect that opening and closing call auctions (introduced in 2004) have had on price formation. Our use of measurement intervals of one minute or less sharpens the picture of intra-day volatility accentuations: they are concentrated within the first two minutes after the open and the last minute prior to the close, with the overall pattern being stapleshaped rather than U-shaped. We find that Nasdaq's calls have reduced this volatility, reorganized order flow, and lowered volatility persistence. Opening and closing prices had previously contained appreciable transitory components which have been dampened by Nasdaq's market structure innovation.

JEL Classification: G14, D44

Keywords: Opening Price, Closing Price, Price Discovery, Intra-Day Volatility, Market Microstructure, Equity Markets, Call Market, Nasdaq.

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The Quality of Price Formation at Market Openings and Closings: Evidence from the Nasdaq Stock Market

1. Introduction

The quality of price formation at equity market openings and closings is of major importance to market participants, listed companies, regulators, academic researchers, and securities exchange operators because of the various uses to which they are put. Following the arrival of overnight news, opening prices are the first reflections of the mood of the market at the start of a new trading day. Closing prices are used for a variety of legal valuation purposes, for marking-to-market, for converting mutual fund inflows (withdrawals) into fund holdings (cash), and for derivative settlements (e.g., options for individual shares and ETF options expire using closing prices).[1] Further, closing prices provide important performance benchmarks for institutional traders, and are commonly used for academic research on stock returns.

The importance that the financial community places on having appropriately set opening and closing prices, and the difficulty of achieving them, are evidenced by the pressures that led Nasdaq to introduce a major structural change in its marketplace: in 2004 it instituted two call auctions that it refers to as the "Opening Cross" and the "Closing Cross." Along with assessing the quality of opening and closing prices, we consider the effect that these auctions have had as price-setting devices at these two critically important moments of the trading day.

Our assessment of the quality of opening and closing prices focuses primarily on their transitory components. A price change is "transitory" if it occurs due to microstructure factors such as bid-ask spreads, market impact, price discreteness, and non-instantaneous price discovery. In contrast, a price change is "permanent" if it is attributable to a change in the underlying efficient price. Fully efficient prices are not empirically observable, but it is well known that transitory effects can contribute significantly to price volatility in short measurement intervals. As such, the magnitude of transitory volatility can be controlled by superior market structure design and,

[1] Some derivative contracts (e.g., the S&P 500 financial futures contract) settle based on the opening price instead of the closing price.

accordingly, we can draw inferences on price efficiency by examining the impact of a market structure change on price volatility The approach is complementary to Hasbrouck (1993) who has presented an econometric procedure for decomposing the permanent and transitory components of price changes.

We are able to implement our methodology because of Nasdaq's very significant market structure change. Our analysis sheds light on both the magnitude of opening and closing transitory volatility, and on the efficacy of a call auction as a price-setting mechanism. As we discuss in Section 3, prior research on call auctions has yielded divergent conclusions about a call's effect on market quality.[2] Accordingly, along with obtaining further insight into the importance of transitory factors at market openings and closings, we seek additional understanding of the efficiency properties of call auction trading.

With the exception of Kandel, Rindi, and Bosetti (2008), who used one-minute measurement intervals, prior research has assessed volatility over intervals that, because of their length (commonly 15 or 30 minutes), makes it difficult to discern whether accentuated volatility is attributable to matters pertaining to the opening and closing per se, or to some other attribute of the continuous market. For this reason, we analyze the ultra-short measurement intervals (i.e., one-minute and ten-seconds) that immediately follow market openings and which immediately precede market closings. These ultra-brief intervals are characterized by large trading volume and high volatility. Targeting these intervals directly gives us a sharper assessment of opening and closing pricing efficiency.

Using these ultra-fine measurement intervals, we find that, prior to the Nasdaq market structure innovation, opening and closing prices reflected substantial volatility that could be attributable to microstructure factors. We also observe that opening and closing volatility decreased appreciably after Nasdaq instituted its two calls. These results indicate that: 1) opening and closing prices previously had contained sizable transitory components, and 2) Nasdaq's market structure innovation has improved the

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[2] For example, findings by Hillion and Souminen (2000), Smith (2007), Kandel, Rindi, and Bosetti (2008), among others, suggest that a call's introduction can improve market quality by reducing intra-day volatility. However, Ellul, Shin, and Tonks (2005), and Chakraborty, Pagano, and Schwartz (2008) identify potential coordination and communication problems associated with call auctions which can lead to poorer market quality.

quality of opening and closing prices. In addition, we find that the U-shaped intra-day volatility pattern typically observed in half-hour data is largely driven by the first two minutes after the open and the final minute prior to the close. Thus, the intra-day volatility pattern more closely resembles a "staple" rather than a U-shape.[3]

We sought confirmation that the two Nasdaq calls enhanced market quality by assessing comparable volatility changes for a matched sample of New York Stock Exchange stocks. The NYSE stocks showed no consistent pattern of volatility reductions. This contrast between the two securities markets suggests that the volatility reductions for the Nasdaq stocks were not attributable to other exogenous factors that could have systematically changed volatility levels across stocks.

Our empirical analysis covers two months (February 2004 and February 2005) that bracket the introduction of both the opening and the closing Nasdaq calls. Our main findings are:

1) The three most volatile minutes in a trading day are the two minutes following the open and the final minute preceding the close.
2) Nasdaq's opening and closing calls have significantly reduced volatility in the neighborhood of the open and the close.
3) The auctions concentrated the opening volatility closer to the first minute, while volatility was reduced overall at the close.
4) The correlation between overnight volatility (the absolute value of the overnight return) and opening volatility (volatility over the first several minutes) was reduced after the calls were instituted. This suggests decreased volatility persistence and improved efficiency of price discovery for Nasdaq-listed stocks.[4]

[3] This pattern suggests that studies of intra-day volatility and return patterns do not need to discard the first and last half-hour of trading data (as is frequently done in certain areas of asset pricing and market microstructure research). Instead, all data except those associated with the very first and last few minutes of trading can be used.

[4] As we discuss later, the quality of price discovery can be measured by the correlation between overnight return volatility and opening volatility. Because it typically takes some amount of time for the market to process information that arrives during the overnight period, a positive correlation can exist between overnight return volatility and volatility during the opening minutes. A superior opening and closing mechanism that allows the opening and closing prices to be set more efficiently should decrease the volatility correlation. That is, this correlation should become closer to zero.

5) The calls induced a re-organization of order flow, with a significant jump in trading volume occurring primarily in the opening period as the new market structure drew order flow from pre-open trading.

The paper is organized as follows. Section 2 reviews the pressures that led Nasdaq to institute its calls, Section 3 summarizes prior evidence on a call auction's effect on the quality of opening and closing prices, and Section 4 sets forth our hypotheses. Section 5 describes our data, while Section 6 contains the analysis and empirical results. Section 7 concludes. The stocks included in the analysis are listed in Appendix 1, Nasdaq's Closing Cross procedure is described in Appendix 2, and robustness tests based on a matched sample of New York Stock Exchange stocks are reported in Appendix 3.

2. The Pressures That Led Nasdaq to Institute its Calls

The forces that led Nasdaq to introduce its two Crosses underscore the importance that the financial community places on having appropriately set opening prices, and the difficulty of achieving them. A number of prominent participants in the Nasdaq marketplace had clearly perceived the problem of inefficient pricing at the open and at the close before the two Nasdaq calls were introduced, and the company was increasingly being pressured by various voices in the industry to "clean up" these prices. As early as May 16, 2000, Arthur Levitt, then-chairman of the U.S. Securities and Exchange Commission, in a letter to Frank Zarb, then chairman and chief executive officer of the National Association of Securities Dealers, wrote, "I urge the NASD to pursue a unified opening procedure, and in the interim, to press forward with measures to make the opening process more reliable and fair to investors." On the other hand, the NASD was also meeting staunch resistance from its dealer community which felt threatened by the innovation.

In Fall 2003, Nasdaq finally decided to introduce a closing call. The critical factor that led it to do so was that a competing market, the American Stock Exchange, responding to a strongly expressed request from Standard & Poor's for better closing prices, started planning a closing call of its own that would be used for Nasdaq stocks. Another consideration at the time was the need to handle the extremely heavy trading volume that was expected for the upcoming rebalancing of the Russell 2000 index on June 25, 2004. This annual event had the potential to generate extreme volatility at the close in nearly 1,700 Nasdaq stocks by funds seeking to track the Russell index. Accordingly, Nasdaq accelerated its introduction of Closing Cross, and it succeeded in achieving the goal.[5]

3. Market Structure and the Quality of Opening and Closing Prices

For over two decades, equity exchanges around the globe have been experiencing enormous structural change and the broad topic of how market structure affects stock return and risk measures has received much attention in the microstructure literature.[6] Because they are now being widely used around the world to open and to close equity markets, electronic call auctions in particular are an important trading facility to study.[7] Nevertheless, evidence of their effect on market quality has been subject to some question, and interest in them has continued in the microstructure literature. Nasdaq, by introducing its opening and closing calls in 2004, has given us an excellent opportunity to assess the effect that a call auction can have on the quality of prices. In essence, we are testing a joint hypothesis: that opening and closing prices do reflect transitory inefficiency, and that the call auction has mitigated this inefficiency.[8]

Opening prices may be affected by transitory inefficiency because the opening is a time when overnight news is processed by the market and translated into new share values, and price discovery is perceived to be a protracted, noisy process. Closing prices

[5] For further discussion, see Pagano and Schwartz (2005). We have been advised by Nasdaq that their own internal studies have indicated that the crosses have dampened price volatility at the open and the close. Further, the Closing Cross has successfully handled extremely high volume at times of particularly stress (e.g., at the Russell June rebalancings). As reported in Smith (2006), in the period from mid-June 2004 to the end of December 2004, trading volume for most days was between 3 and 8 million shares, while at the June 25 Russell 2000 rebalancing, 333 million shares were crossed.

[6] Most strikingly, electronic order-driven platforms have come to the fore and human-intermediated floor-based systems and dealer markets have dwindled in importance.

[7] The New York Stock Exchange opens trading with a call auction that is run by the Exchange specialists and it is not fully electronic.

[8] As the measurement intervals decrease, the transitory component's contribution to total volatility increases relative to the permanent component's contribution. Therefore, any diminution of total volatility, measured over ultra-fine intervals, that is attributable to a change in market structure would reflect a reduction in its transitory component.

may be affected by transitory inefficiency because the closing is a time when traders, feeling increasing pressure to "get the job done," speed up their order entry and, in so doing, cause price dislocations and accentuated volatility. Further, the use of market on close (MOC) and limit on close (LOC) orders by participants seeking to execute at market closing prices exactly can cause pricing disruptions.

Presumably, the quality of price setting at openings and closings can be improved by superior market design. Market structure affects the way in which orders are coordinated (i.e., how they are turned into executed trades and transaction prices), and order coordination is accomplished differently in continuous and call auction trading. In continuous trading, orders are matched according to the sequence in which they have arrived at the market, trades are typically bi-lateral, and transaction prices are generally distributed over a (potentially wide) range of price points during even relatively brief time intervals. In contrast, with call auction trading, orders are batched together for simultaneous execution in a single trade that is generally multi-lateral, and all matching and crossing orders execute at a single price. If the sequence of order arrivals over a brief time period is not economically meaningful, we expect that the multiplicity of prices in continuous trading will reflect more transitory noise than the single price that would be set in a call auction.[9,10]

A number of academic studies have shown that price volatility is accentuated at the start and at the close of a trading day.[11] This accentuation indicates the existence of

[9] When trades are separated by only seconds (or less), the actual sequence in which they occur can itself be perturbed by the vagaries of order formation and entry (including the relative speed with which the decisions of different participants are made and their orders are transmitted to the market). In this context, the sequence of transaction prices, consolidated over different trading venues and recorded over very short intervals, might be influenced more by random factors and less by any economically meaningful effects.

[10] For an early discussion of the attributes and efficiency properties of call auction trading, see Economides and Schwartz (1995).

[11] For empirical evidence of the U-shaped intra-day volatility pattern, see Wood, McInish, and Ord (1985), Harris (1986), Lockwood and Linn (1990), and Ozenbas, Schwartz and Wood (2002). Admati and Pfleiderer (1988) and Foster and Viswanathan (1990) provide some theoretical rationales for this observed pattern, such as the costs a market maker faces due to differences in public versus private information, as well as the risks of holding an inventory of risky assets. In addition, Paroush, Schwartz, and Wolf (2007) suggests that, particularly at market openings, transaction prices can be perturbed and cause intra-day fluctuations in volatility due to divergent expectations (i.e., investors "agree to disagree" on the value of a risky asset).

pricing dislocations, and it has been suggested in the microstructure literature that the call auction arrangement has the potential to ameliorate this inefficiency. A single price call auction concentrates multiple buyers and sellers at specific points in time, a procedure that can lead to enhanced liquidity and improved price discovery.[12] Hillion and Souminen (2000), Barclay, Hendershott, and Jones (2005), Pagano and Schwartz (2003, 2005), and Smith (2007) all support the view that call auctions improve the quality of openings and/or closings.[13] Kandel, Rindi, and Bosetti's (2008) examination of the Borsa Italiana's closing call auction yields results that are consistent with our findings: the Borsa's closing call, like the two Nasdaq calls, attracted a sizable portion of trading volume, and it also significantly reduced the bid-ask spread and volatility in the final minute of continuous trading.[14]

A different light is shed on the matter, however, by Ellul, Shin, and Tonks's (2005) contrast of call and dealer market mechanisms. These authors' empirical analysis of trading on the London Stock Exchange suggests that the call "suffers from a high failure rate to open and close trading especially when trading conditions are difficult" (p. 779). The difficult conditions cited by these authors include asymmetric information, slow trading, and price uncertainty. Briefly stated, these marketplace realities can result in what Ellul et al. (2005) refer to as the "coordination motives for trading." Namely, participants who would otherwise be willing to trade with each other will hold their

[12] For more details on the costs and benefits of call auctions see Ellul, Shin, and Tonks (2005) and the references therein, particularly Bacidore and Lipson (2001), Madhavan (1992), Domowitz and Madhavan (2001), and Pagano (1989).

[13] In each of these studies, the exchange operator (the Nasdaq Stock Market for all of the studies except the Pagano and Schwartz, 2003, and Hillion and Souminen, 2000, studies which focus on Euronext-Paris) introduced a call auction to open and/or to close trading. Barclay, Hendershott, and Jones (2005) study the impact of Nasdaq's introduction of an opening call auction on particularly stressful days (i.e., on "triple witching" days where stock index futures and options, as well as individual stock options, expire). Similar to what Pagano and Schwartz (2003, 2005) found for the introduction of an electronic closing call auction at Euronext-Paris and the Nasdaq Stock Market, respectively, Barclay et al. (2005) observe that the opening calls did significantly improve market efficiency. Smith (2007) corroborates the Pagano and Schwartz (2005) finding that market quality improved following the introduction of Nasdaq's Closing Call.

[14] Madhavan and Panchapagesan's (2000) study of the opening price mechanism at the NYSE establishes that specialist activities can improve the quality of the opening price. Biais, Hillion, and Spatt (1999), and Cao, Ghysels, and Hatheway (2000) analyze pre-opening behavior at Euronext-Paris and Nasdaq, respectively; both find that pre-opening activity (e.g., providing indicative bids and offers) is informative and can improve a market's quality at its openings. Barclay and Hendershott (2003) report similar improvements in market quality attributable to pre-open and post-close trading activity over the full 24-hour day.

orders back if they believe that others will also be holding back (for the same reason). Chakraborty, Pagano, and Schwartz's (2008) theoretical analysis of order submission to a call auction yields a similar result. Chakraborty et al. further suggest, however, that a call's success can depend critically on its structure (whether or not it is transparent, and whether or not it includes intermediaries whose role is to "animate" the market, et cetera).

Based on the above discussion, one can conclude, as Kandel, Rindi and Bosetti (2008) also state, that the evidence on the efficiency of call auction trading is not definitive, and that further assessment is important. In particular, it remains an open question as to how the introduction of Nasdaq's opening and closing calls have affected price discovery, intra-day volatility, and trading volume. We gain further insight into the issue by our treatment of ultra-fine measurement intervals (one minute and ten-second periods) and through the comprehensive set of indicators that we examine (volatility, volatility persistence, inter-temporal return correlations, and volume effects).

4. Hypotheses Tested

While econometric procedures can be used to capture the transitory component of opening and closing prices (e.g., Hasbrouck, 1993), a complementary approach is to assess the effect that a market structure change such as Nasdaq's institution of its two calls has had on total volatility. Presumably, any diminution of total volatility that is attributable to the introduction of the two Nasdaq calls would reflect a reduction in its transitory component if the time interval chosen for the analysis is brief enough so that the transitory component's contribution to total volatility is high relative to the permanent component's contribution.

We examine the impact that Nasdaq's innovation has had on the informational efficiency of prices as reflected in price volatility, volatility persistence, and return correlation. In so doing, we first focus on the accentuation of opening and closing volatility relative to mid-day volatility, and then assess the success that Nasdaq's two calls have had in containing this accentuation. We use two volatility measures: 1) a high-low price range within an interval (the difference between the highest and the lowest prices in the interval) divided by the average price over the interval, and 2) a relative range measure, which is the ratio of the range for the opening (or closing) intervals to the mid-day range. Relative range controls for differences in volatility across firms and over time. To assess further the efficiency of price discovery, we examine the correlation between overnight and opening volatilities, as well between short-period, end-of-day returns and overnight returns. We compare these correlations (along with volatility and volume measures) across the months of February 2004 and February 2005.

Specifically, we formulate and test the following three hypotheses.

Hypothesis 1. *Nasdaq's Opening and Closing Crosses reduced volatility accentuations in the immediate neighborhood of the opening and closing for Nasdaq-listed stocks.* If the crosses have improved market quality, then we should see a reduction in volatility at and near market openings and closings relative to base levels of volatility.

Hypothesis 2. *The Nasdaq Opening and Closing Crosses have improved the efficiency of price discovery for trading in Nasdaq-listed stocks.*
To test this hypothesis, we analyze the correlation between overnight and opening volatility. If Hypothesis 2 is correct, we would expect opening and closing prices to be set more efficiently and, therefore, for overnight information to have less of an effect on volatility during the following day's opening minutes. We also assess the correlation between closing returns (the price change from 3:59 pm to the time of the close) and overnight returns. If a price is perturbed at the close, the dislocation should be ameliorated in the subsequent opening price. In short, any reduction in volatility persistence and in return reversal behavior would be supportive of this hypothesis.

Hypothesis 3. *The Opening Cross attracted order flow from the continuous market, especially from pre-opening trading, and from the first minutes of the trading day.* A similar re-organization of the order flow is not necessarily expected at the closing for two reasons: the continuous trading environment that precedes the open is less efficient than that which precedes the close, and there is no appreciable trading after the close from which to draw order flow.[15] To assess this re-organization of the order flow, we analyze trading volume and the number of trades during sub-periods around the open and the close.

We test these hypotheses using Nasdaq data, and confirm our findings by running comparable tests on a matched sample of New York Stock Exchange firms. Observing systematic changes for the Nasdaq firms but not for the NYSE firms suggests that the Nasdaq findings are not attributable to other market wide factors.

5. The Data

Using data from the Center for Research in Security Prices (CRSP), we selected the 110 largest Nasdaq companies based on their market capitalization at the end of 2003. Because of the very brief intra-day time spans that we employ, our empirical analysis focuses on only the largest Nasdaq firms; for our purposes, smaller firms do not generally generate sufficient trading activity within these fine moments of time.

We construct a weekly return volatility measure, *Retstd* (using prices from each Wednesday close to each following Wednesday close) based on returns for the months of February 2003 through January 2004. We matched the list of Nasdaq companies with NYSE companies using the NYSE Trade and Quote (TAQ) database. Our matching variables are equity market capitalization and weekly return volatility. This yielded a final sample of 104 companies with available data during the months of February 2004 and February 2005. The average market capitalization of the Nasdaq sample ranges from $3.5 billion for the smallest 20 firms to $65.7 billion for the largest 20 firms. The symbols for the Nasdaq and NYSE firms are given in Appendix 1, and the robustness test results for the matched sample of NYSE stocks are reported in Appendix 3.

The months of February 2004 and February 2005 were chosen because they allow a reasonable amount of time before the Closing Cross's introduction on March 29, 2004, and after the Opening Cross's implementation was completed on December 13, 2004.

[15] The attraction of order flow to both calls may be somewhat muted, however for two reasons: 1) Nasdaq displays indicated clearing prices during the bookbuilding process that precedes each of the calls, which gives participants transparent reference prices to trade at, and 2) in the ten minutes preceding each cross, standard market and limit orders are not permitted and only imbalance orders (sell orders priced higher than the 4:00 pm closing price, and buy orders priced lower) are permitted. We describe the Closing Cross in more detail in Appendix 2.

That is, the February 2004 data enable us to examine trading activity at least one month prior to both the closing and the opening calls' introductions, and the February 2005 data provide adequate time after the events for market participants to learn how best to utilize both of the new call auctions' capabilities. Also, comparing the same month (February) across the two years controls for possible seasonality in trading activity that could have occurred at the Nasdaq Stock Market. Fortuitously, overall market volatility was similar for these two months (the CRSP value weighted daily return volatility was 0.63 percent in February 2004 and 0.66 percent in February 2005).

We obtain trade and quote information for the 390 1-minute intervals of the trading day (9:30-16:00), the thirty 10-second intervals of the opening five minutes (9:30-9:35), and the thirty 10-second intervals of the closing five minutes (15:55:00-16:00:00).[16] For each interval, we compute the highest, the lowest, and the average prices. When transaction prices are not available, we use the highest and the lowest mid-quote, and replace the average trade price with the average mid-quote price. Stock return volatility is measured (in basis points) by the percentage high-low price range (*Range*), which we define as the difference between the highest and the lowest prices, relative to the average price during the interval.[17]

To control further for differences in return volatility across firms and over time, and to focus on the intra-day changes in return volatility, we also constructed the variable "relative range" (*R_Range*). For each day and each stock, we compute the average mid-day range over all of the mid-day intervals between 10:30-15:00.[18] The relative ranges for the opening (or closing) intervals are then computed as the ratio of the range for the opening (or closing) intervals to the mid-day range.

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[16] Nasdaq has advised us that reporting delays for conventional trades rarely exceed 5 seconds. Trades executed later in the day by market makers at earlier, pre-arranged prices such as "Sold Sales" on the NYSE and "Prior Reference Price" trades on the Nasdaq system are omitted from our analysis, as these transaction prices would distort the ultra short-term volatility estimates.

[17] Range vis-à-vis absolute returns can more accurately capture the volatility that Nasdaq's crosses are designed to reduce. Alizadeh, Brandt, and Diebold (2002) and Brandt and Diebold (2006) show that the range-based volatility estimator is highly efficient and approximately Gaussian.

[18] To ensure a cleaner break between the opening and closing half-hour periods and the mid-day period, we do not include the second half-hour and the second-to-last half-hour in our computation of the latter.
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The variable *Spread*, measured in basis points, is the average of the actual quoted spreads divided by the average price during the interval. The variable *Numtrades* captures the total number of trades during the interval. The variable *Avgtdsize* is defined as the share trading volume divided by the number of trades during the interval. Similar to the construction of *R_Range*, we compute *R_Spread, R_Numtrades,* and *R_Avgtdsize* for the opening and closing intervals as the ratios of *Spread, Numtrades,* and *Avgtdsize* to their corresponding mid-day levels, respectively.

6. Analysis and Results

6.1 The intra-day volatility pattern

As noted, it is widely documented that intra-day return volatility for common stocks describes a U-shaped pattern (i.e., the first and the last thirty minutes of trading exhibit elevated levels of volatility relative to that observed during the middle of the trading day). We probe deeper into this pattern by examining volatility behavior within the first and the last 30-minute periods.[19]

Figure 1 shows the average volatility (*Range*) across the Nasdaq stocks for one-minute intervals during February 2004 (Panel A) and February 2005 (Panel B). To obtain this figure, we first calculate the mean volatility measures of *Range* over the nineteen trading days, for each of the two months, for each stock and each time interval. We then also calculate, for each of the two months, the cross-sectional median of the mean volatility for each individual stock and for each time interval. In both months, volatility describes a roughly staple-shaped pattern.. What is most striking is that the first and the last five minutes of trading exhibit volatility levels that are several times higher than those observed for the other intervals in the trading day.

[19] There are other ways to measure intra-day returns and volatility. For example, Aït-Sahalia, Mykland, and Zhang (2005), and Bandi and Russell (2006) examine high-frequency (i.e., intra-day) data to identify the optimal time intervals to measure short-term returns so that one can efficiently decompose observed returns into two sub-components: one related to changes in the asset's "fundamentals" (efficient volatility) and the other attributable to microstructure "noise." Bandi and Russell's (2006) decomposition procedure, however, would yield only two values per day for each stock (the fundamental/efficient volatility and the microstructure noise volatility) whereas we require numerous minute and sub-minute volatility measures for each day. In addition, these approaches ignore the intra-day "seasonality" in volatility, a main focus of our paper.

We construct a volatility ratio that enables us to contrast the standardized importance of volatility over a sequence of one-minute intervals in the opening and closing periods. Specifically, in keeping with Andersen, Bollerslev, Diebold and Labys (2003), we construct realized volatility measures for the first one-minute interval through the thirtieth one-minute interval, and for the thirtieth-to-last one-minute interval through the last one-minute interval as follows:[20]

$$RV_n = \sum_{i=1}^{n} Range_i^2$$

Where n corresponds to 1, …, 30. We then define a volatility ratio,[21]

$$Ratio_{n,N} = RV_n \big/ RV_N$$

where N denotes the longer period. $\text{Ratio}_{n,N}$ shows the percentage of volatility for the N-minute period that is accounted for by the first n minutes of that longer interval.

The volatility ratio for both the opening and the closing minutes are shown in Table 1. The column labeled "Mean" under the "Volatility Ratio" heading of Table 1 shows that, on average, the volatility estimate for the first minute of trading is 42.3% of the total volatility measured over the first five minutes, and is 17.7% of the estimated volatility over the first half-hour of trading (these values are reported for the Opening period rows labeled as $\text{Ratio}_{1/5}$ and $\text{Ratio}_{1/30}$, respectively). The volatility measured over the first five minutes of trading is 39.9% of the first half-hour estimate ($\text{Ratio}_{5/30}$). Similarly, for the closing minutes, the last minute of trading is 51.3% of the final five-minute volatility measure, and is 20.4% of the final half-hour volatility ($\text{Ratio}_{1/5}$ and

[20] Andersen et al. (2003) show formally that the concept of realized variance (measured with high frequency intra-day return data) is, according to the theory of quadratic variation and under suitable conditions, an asymptotically unbiased estimator of the integrated variance and thus it is a canonical and natural measure of return volatility. Note that since we use range as the volatility measure for our main analysis later, the realized variance measures are constructed using the range instead of high frequency returns. The purpose here is to estimate, albeit approximately, the contribution of the opening minutes' range to the first five-minute and 30-minute ranges.

[21] Note that this volatility ratio differs from that first suggested by Hasbrouck and Schwartz (1988) and Lo and MacKinlay (1988), where the ratio of longer to shorter period volatility was designed to reflect the correlation structure in returns. Stoll and Whaley (1990) also use a relative variance ratio which they apply to open-to-open and close-to-close daily returns in order to study the impact of the NYSE opening process on market quality.

$Ratio_{1/30}$, respectively, for the Closing period rows). Lastly, the estimated volatility for the final five minutes is 36.6% of the final half-hour volatility ($Ratio_{5/30}$).

In light of the magnitude of volatility in the opening and closing minutes of trading, we examine yet shorter measurement intervals. Figure 2 focuses on *Range* during the opening and closing 10-second intervals in the opening and closing five minutes of trading. We again see that volatility successively spikes up through the sub-minute intervals that are successively closer to either the open or the close.

These relatively brief time intervals contribute significantly to the opening and closing period volatility. They are also economically important, given the proportionate amount of trading that occurs during these volatile moments in the trading day. The median contribution to trading volume for the first two minutes of continuous trading (9:30-9:32) is 50% of the total volume for the first five minutes of trading, and 25% of the volume during the first 15 minutes. More strikingly, the final minute of trading accounts for 25% of the trading volume during the last five minutes of continuous trading.[22]

Overall, the above results show that the first and the last five-minute volatility estimates contribute substantially to the intra-day volatility pattern. Inefficient price-setting at the open and the close is suggested by this opening and closing volatility because this pattern is more likely to be driven by the transitory components of intra-day price movements. This inference can be confirmed if the volatility accentuation decreases after the two calls were introduced. These brief opening and closing time intervals are also economically significant and, accordingly, we focus on them for the remainder of the paper.

6.2 Volatility differences between February 2004 and February 2005

Figures 1 and 2 provide visual evidence in support of Hypothesis 1: namely, the opening and closing volatilities were less in February 2005 compared to February 2004 (i.e., we choose two periods before and after the two Nasdaq crosses were introduced).

[22] In addition, the combined median trading volume during the first and last two minutes of trading represents 3.9% of the total volume for the entire trading day in February 2005.

We formally test this hypothesis by analyzing the volatility patterns for one-minute and ten-second intervals for the opening and closing minutes of trading.

1. Univariate Comparisons

Table 2 presents the univariate comparisons of mean and median volatility measures during the one-minute intervals of *Range* and *R_Range* for Nasdaq stocks during February 2004 and February 2005. For both the mean and median volatilities, the differences between these two months were assessed using a *t*-test and the non-parametric Wilcoxon test, respectively. Table 2 summarizes the results for the full sample of 104 Nasdaq firms.

The statistics reported in the table confirm the visual evidence in Figure 1 that the volatility measures (*Range* and *R_Range*) both decreased from February 2004 to February 2005 in both the opening minutes and in the closing minutes of trading. As shown in Table 2, the differences are generally in the expected direction and many are statistically significant. For the first three 1-minute intervals at the market's open, the reductions in the median range are 6.0, 9.1, and 3.8 basis points, respectively, and they are all statistically significant at the .01 level. This translates into 11%, 22%, and 13% decreases relative to their corresponding levels in February 2004. The decreases in volatility are most striking for the closing minutes. For the last five one-minute intervals before the close, the declines in the median range are 3.1, 4.2, 4.8, 1.7, and 12.6 basis points, respectively, all are statistically significant, and they correspond to 23%, 30%, 32%, 12%, and 34% decreases relative to their levels in February 2004. The findings for *R_Range* are very similar to those just noted. The pattern of reduced volatility after the introduction of Nasdaq's crosses is also robust across different size groups (i.e., the largest 20 and the smallest 20 stocks). Consistently, the magnitude of the volatility decline is biggest during the opening and the closing five minutes.

We investigate the opening and the closing periods more closely by analyzing volatility measures for the 10-second intervals within the first five minutes and the last five minutes of trading. Table 3 compares the volatility measures for February 2004 and February 2005 for the opening period (Panel A) and for the closing period (Panel B). For the opening intervals, the greatest reduction in the median *Range* occurs within the first two minutes of the open. For the closing intervals, the greatest reduction in the median *Range* occurs in the last two minutes before the close. Unlike the 10-second intervals for the opening two minutes (where the intervals within each minute exhibit similar levels of volatility), the volatility in the last two 10-second intervals of the closing minute is three to five times greater than in the preceding intervals. After the Nasdaq crosses were introduced, the largest volatility reduction occurred within these last two 10-second intervals. This suggests that the volatility spike in the closing seconds of trading in particular has been accentuated by participants attempting to transact at the closing price exactly, an objective that the call has made less disruptive and considerably easier to achieve.

2. Multivariate Analysis

To control for potential changes in overall market conditions during the sample period (other than the implementation of the opening and closing crosses), we perform panel regression analyses for the sixty 10-second intervals during the first and the last five minutes of the trading day.[23] Table 4 provides summary statistics for the regression variables, while Tables 5 and 6 present the results for the opening and the closing intervals, respectively. In both tables, we summarize the coefficient estimates and robust standard errors, adjusted for possible firm clustering (the latter are shown in parentheses).[24] Overall, the cross-sectional regression models capture a fair amount of the variability in the *Range* and *R_range* measures, as summarized by the reasonably high adjusted R^2 statistics (ranging from .261 to .456 in Tables 5 and 6). Interestingly, the R^2s are appreciably higher for the close than the open.

We first focus on *Range* as our volatility measure. With it, regression model 1 in Table 5, Panel A shows that the 10-second volatilities in the first five minutes of trading in February 2005 are, on average, 3.75 basis points lower than in February 2004 (as

[23] The number of observations is based on 104 companies times 38 trading days over the two months, times 30 ten-second intervals, less a small number of intervals lost because of incomplete data.

[24] The results (which are available upon request) remain similar if the robust standard errors are adjusted for possible date clustering.

shown by the parameter estimate for the *after* variable in model 1).[25] For the 5-minute opening period, the first three minutes (denoted as *min1, min2, min3*) have significantly higher volatility (13.34, 3.50, and 0.63) compared to the last two minutes of the opening period (referred to as *min4* and *min5*). After the Crosses are introduced, model 2 indicates that the decrease in volatility is significantly greater for intervals during the first three minutes – the incremental reductions in volatility (captured by the parameter estimates for the *min_a1*, *min_a2*, and *min_a3* post-Cross dummy variables) are 6.38, 4.24 and 0.59 bps, respectively. Regarding the control variables, intra-day volatility increases with the spread (measured in basis points), the number of trades, average trade size, and a stock's weekly return volatility.

Table 5, Panel B summarizes the results using the *R_Range* volatility measure. We find similar volatility reductions for this measure across the five models. Compared to a year earlier, the opening period's relative range ratio in February 2005 is, on average, 0.22 less (as shown by the parameter estimate for the *after* variable in model 1). The value of 0.22 indicates that the 2004 *R_Range* value of 5.40 (reported for the 9:31-9:32 time interval in the fourth column of Table 2) was, on average, reduced to 5.18 following the introduction of the crosses (all other factors constant). In model 2, the decrease in volatility is significantly greater for the first three minutes, and the marginal reductions in this relative volatility measure (compared to *min4* and *min5*) are 0.525, 0.422, and 0.065, respectively. In addition, *R_Range* increases with the spread, the number of trades, average trade size, and the weekly return volatility; it also increases with market capitalization.[26]

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[25] In interpreting this and other basis point reductions, it is helpful to keep in mind that, e.g., a 3.75 basis point reduction translates into a 1.125¢ reduction in price volatility for a $30 stock.

[26] The positive relationship between a stock's market cap and its return volatility at the open might be due to the tendency for large cap stocks to open more quickly and, in so doing, to lead the overall market in terms of price discovery at the opening (as observed in Bernhardt and Davies, 2006). In other words, the volatility of larger cap stocks may be higher because these stocks disproportionately carry the burden of discovering opening prices, while trading in smaller cap stocks lags behind as investors wait to see how the large cap stocks are behaving. Frieder and Subrahmanyam (2005) document that retail investors are more likely to invest in U.S. stocks with strong brand names while institutional investors are more likely to invest in large cap, high beta stocks (and avoid smaller, relatively neglected stocks). This finding suggests that both retail and institutional investors prefer large cap stocks, although for different reasons, and thus the volatility of large cap stocks might be relatively high. Bernhardt and Davies (2006) report that large cap stocks' intra-day returns typically lead those of small cap stocks, possibly due to large cap stocks' tendency to serve as a bellwether for future broad market movements.

Table 6 reports the results of a multivariate analysis based on 10-second volatility estimates that are similar to those shown in Table 5 at, and leading up to, the close. To capture the relatively large volatility spike in the last two 10-second intervals of the last minute, we also incorporate dummy variables that correspond to the final five 10-second intervals within the last minute (denoted as *sec2* through *sec6*).[27]

Table 6, Panel A incorporates regression dummies that account for differences in the level of volatility, defined as *Range*, between February 2004 and February 2005. The parameter estimate for the *after* variable in model 1 shows that, compared to a year earlier, the 10-second interval volatilities within the final five minutes of trading in February 2005 are, on average, 1.383 basis points lower. Compared to the fourth and fifth final minutes of trading (referred to here as *min4* and *min5*, or 15:55-15:57), the final three 1-minute intervals (*min3 – min1*) have significantly higher volatility in model 1 (0.191, 0.715, and 0.832 bps, respectively). Within the final minute, *Range* increases for each 10-second interval. Relative to the first 10-second interval of the final minute, the subsequent increases in the 10-second interval's volatility based on model 1 are 0.367, 0.511, 0.633, 1.250, and 2.199 bps, respectively. Further, volatility increases with the spread, the number of trades, and the weekly return volatility.

In model 2, the decrease in volatility is significantly greater for intervals during the last three minutes of trading: the marginal declines (compared to min(-4) and min(-5)) are 0.449, 0.454, and 3.690 bps, respectively. The decreases are especially large in the final minute. Moreover, within the final minute, volatility decreases the most in the last two 10-second intervals. Relative to the first of the 10-second intervals, model 3 shows that the last two 10-second intervals displayed additional decreases of, respectively, 1.240 and 1.192 bps.

Using *R_Range* as an alternative relative volatility measure, Table 6, Panel B summarizes the regression results for the closing 5-minute period. Similar to the results shown in Panel A, with regard to the market structure change, regression model 1 shows that the 10-second interval closing volatility ratio in February 2005 is, on average, 0.124

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[27] As can be seen in Figure 2, there is a sharp, sudden spike in volatility right before the close whereas the behavior of the sub-minute volatility estimates following the open is more gradual in nature. Thus, the empirical specification for the closing volatility regressions reported in Table 6 explicitly controls for these differences by including the sub-minute dummy variables, *sec2* through *sec6*.

lower than its comparable February 2004 value. Moreover, the decrease in volatility is significantly greater for intervals during the last three minutes and, based on model 2, the marginal reductions in the *R_Range* ratio (compared to min(-4) and min(-5)) are 0.027, 0.067, and 0.337, respectively. The declines in this volatility measure are especially large during the final minute. Additionally, within the final minute, the largest decreases are observed during the last three 10-second intervals. Relative to the first 10-second interval, model 3 indicates that the relative volatility ratio during the final three 10-second intervals showed additional decreases of 0.042, 0.117 and 0.059, respectively.

In summary, our regression results clearly support Hypothesis 1, that the opening and closing crosses dampened the volatility accentuation that previously characterized Nasdaq's openings and closings. Our observation that superior market design has reduced the volatility accentuation strongly suggests that opening and closing prices had previously reflected considerably more transitory components.

6.3 The efficiency of price discovery

It typically takes some time for a market to process information that arrives during the overnight period. Therefore, the opening price may not fully incorporate the effect of the overnight information on prices, and it may take minutes or longer for prices to attain "equilibrium levels" after the open. This delay in price discovery would lead to a positive correlation between overnight return volatility and volatility during the opening minutes. With regard to the efficiency of closing prices, any distortion at the close that is reversed at the open would cause returns measured at the close (e.g., from 3:59 pm to the close) to be negatively correlated with the overnight return. In this subsection, we examine the call auctions' effect on the quality of opening and closing prices as reflected in both volatility and return correlations.

1. Correlations between Overnight and Opening Volatility

More overnight information causes larger overnight returns (in absolute terms), which could also lead to greater return volatility in the opening minutes of the following trading day. A superior market opening and closing mechanism that enables opening and closing prices to be set more efficiently should sharpen price discovery at these times and, in so doing, decrease volatility in the continuous market that immediately follows the open. Turning to Hypothesis 2, we therefore expect the correlation between the overnight return volatility and volatility during the following day's opening minutes to be lower after the two Nasdaq crosses were instituted.

Table 7, Panel A displays the correlation between the overnight return volatility and the following day's opening volatility. As shown in the last column of this panel, the correlation of the overnight return volatility with the average volatility of the 1-minute intervals during the first five minutes of trading decreases from +0.26 in February 2004 to +0.19 in February 2005. The two correlations are significantly different with a p-value of 0.046.[28] This decrease is consistent with Hypothesis 2 which states that, after the introduction of the two crosses, opening prices are discovered more efficiently, which places less stress on price discovery during the first five minutes after the open.

In Table 7, Panels B through D, we present the correlation results for sub-samples ranked by market capitalization (in descending size order). From these sub-samples, it is clear that the correlation result is driven by the 20 largest firms, for which there is a significant decline in correlation between the overnight return volatility and the average five-minute opening volatility. The correlation between the overnight volatility and the average range during the first minute, *range1*, drops from a statistically significant +0.516 to a statistically insignificant -0.028 after the closing call's introduction. In contrast, the serial correlation between these volatilities is significantly higher in 2005 for the smaller size groups. This size-related disparity could occur if, with the calls in place, the largest cap stocks take a stronger leadership role in price discovery; we conjecture that this can result in smaller cap stocks delaying trading at the open in order to "wait and see" how the general trend for the larger stocks unfolds.[29]

2. Correlations between Closing and Overnight Returns

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[28] To compare these two correlation estimates, we first transform the correlation coefficients using the Fisher Z-transform (see Papoulis, 1990): Zf = 1/2 * ln((1+corr) / (1-corr)). The difference: z = (Zf1 - Zf2) / √(1/(n1-3) + 1/(n2-3)), is approximately Standard Normally distributed, where n1 and n2 are the number of observations used in computing the two correlations. We can use this z-value to determine the level of significance of the difference between two correlations.

[29] In support of this interpretation, we observe a large spike in volume in the opening call for the large cap stocks after the opening call was introduced.

We define r1 as the logarithmic return based on the price at 3:59 pm and the closing price (which for February 2004 was 4:00 pm and for February 2005 was 4:00 pm plus a small interval, delta). For February 2005, we decompose r1 into two returns: r1a (the one-minute return from 3:59-4:00 pm) and r1b (the return from 4:00 pm to the official closing price—which is usually determined within the one-minute period, 4:00-4:01 pm). For both months, we define r2 as the overnight logarithmic return based on the previous day's closing price and the current day's opening price). If the closing volatility is at least partly driven by price discovery noise at the close, then this noise component should be temporary, and it should be reversed in subsequent trading during the following day.

The closing cross should dampen price discovery-related noise if it has provided a superior market design. Superiority should be further reflected in a lessening of any negative serial correlation between the closing returns and the subsequent overnight returns. In particular, after the closing cross's introduction, we expect the correlation between r1 and r2 to be a smaller negative number. The correlation between today's 3:59-4:00 pm return and the subsequent overnight return and (corr(r1a, r2)) should also be less negative. In addition, we examine the correlation between today's 3:59-4:00 pm return and the post-4:00 pm closing return (corr (r1a, r1b)) to understand the relation between price in the closing cross and the return during the final minute of trading in the continuous market.

The results in Table 8, Panel A for the full sample show that, before the implementation of the Nasdaq crosses, the correlation between the final return on a trading day and the subsequent overnight return, corr(r1, r2), is -0.055, and it is statistically significant. This negative correlation is consistent with the closing return being influenced by price discovery noise that is temporary and thus corrected by the overnight return. In 2005, corr(r1, r2) is a statistically insignificant -0.043. Further, the 2005 correlation between the current today's 3:59-4:00 return and the subsequent overnight return [corr(r1a, r2)] is an insignificant -0.004. These reductions in the overnight correlations indicate weaker reversals between the previous day's closing return and the ensuing overnight return. The changes in the r1a-r2 correlations display the correct sign although, as can be seen at the bottom of Table 8, Panel A, their pre- and post-crossing differences are insignificant.

Table 8, Panels B-D present the results for our three size groups, respectively. We see that the reduction in the negative correlation is highly statistically significant for both the largest and the smallest quintiles (it changes from -0.241 to -0.015 for the 20 largest firms, and from -0.315 to -0.031 for the smallest 20). Curiously, however, the mid-cap firms (which represent the middle three quintiles of our sample) show a significant increase in negative correlation (-0.033 to -0.138).

In summary, our analysis of the closing return reversals indicates, at least for the largest and the smallest Nasdaq firms in our sample, that the closing returns' correlations with overnight returns decreased significantly in absolute value after the two crosses were introduced. The finding is consistent with Hypothesis 2 that opening and closing price discovery for Nasdaq stocks was more efficient after this market structure innovation.

6.4 The effects on trading activity

We next turn to the impact that the Nasdaq crosses have had on trading activity around market openings and closings. Specifically, we examine *volume* and *numtrades* during 1-minute intervals for the 5 minutes preceding the open, for the 25 minutes following the open, for the final 25 minutes preceding the close, and for the 5 minutes following the close of the continuous market. We do not necessarily expect that the overall share volume will have changed appreciably during the opening and closing periods. However, based on the auctions' potential to concentrate order flow, we do expect the crosses to pull in share volume from the continuous market (predominantly from the pre-opening period and the minutes immediately following the open, and from the five minutes or so immediately preceding the close). We further expect the total number of trades to decrease around the times of the crosses because each auction batches what would otherwise have been multiple trades (in the continuous market) into a single, large multi-lateral trade.

Figure 3 provides visual evidence in support of Hypothesis 3: namely, that the Opening Cross attracted order flow away from the pre-opening period and the first minutes of continuous trading. Panels A and B of Figure 3 illustrate a clear shift in trading volume toward the time of the Opening Cross. Panels C and D of this figure pertain to order flow during the minutes of continuous trading around the Closing Cross. Although the Closing Cross attracted greater order flow at the end of the trading day, it did not have a dramatic effect on trading activity during the final minutes of continuous trading.

To examine the effects of the Nasdaq crosses on trading activity in more detail, we replicated the univariate tests shown in Table 2, focusing not on the two volatility measures, but on two trading activity variables: average trading volume (*volume*) and the average number of trades (*numtrades*). As shown in Table 9, a substantial (and statistically significant) decline in the volume and number of trades occurred in the 9:26 to 9:30 pre-opening period after the Nasdaq crosses were implemented. Median Nasdaq trading volume during 9:30-9:31 rose by 133% (from 5,475 shares to 12,767 shares) after the opening call's introduction, while per-minute median trading volume for the four minutes *preceding* the open showed decreases ranging from 35% to 89%. This supports our belief that the 9:30-9:31 volume spike is attributable to Nasdaq's opening cross.

The pattern described for the full sample of 104 Nasdaq stocks also applies to the 20 largest Nasdaq stocks. The 20 smallest Nasdaq stocks did not show a decline in pre-opening volume, but did experience a significant increase in volume at the time of the opening cross (9:30-9:31).[30]

Our results show that the number of trades declined over these early morning minutes, which suggests that the Opening Cross successfully concentrated orders into one large trade at the open. The median number of trades during 9:30-9:31 dropped significantly from 18.83 in February 2004 to 10.77 in February 2005. Thus, the opening call appears to be doing its intended job of concentrating orders, which sharpens price discovery and thereby reduces volatility and the transitory component of opening prices. Regarding the Closing Cross, Table 9 shows a statistically insignificant rise in median volume (4,701 shares or 11.3%) during 16:00-16:01, although the increase is smaller than at the open (7,292 shares) and the number of trades did not change significantly. Nevertheless, this increase in mean volume (from 41,488 shares to 46,169 shares) during

[30] These results are not reported here to conserve space but are available upon request.

the minute of the cross (16:00-16:01) suggests that the closing call was also successful in concentrating order flow, and that the consolidation has improved the efficiency of the closing prices.

The Nasdaq sub-minute results are shown in Table 10. No meaningful pattern is apparent for volume, but the number of trades increased somewhat after the opening cross (e.g., for minutes 9:31 through 9:35). Similarly, except for the last ten seconds prior to the close when it spiked substantially, volume is relatively unchanged around the close (Table 10, Panel B). There is weak evidence that the number of trades increased prior to the close.

In summary, consistent with Hypothesis 3, the call auctions have re-organized the order flow. This is particularly apparent during the pre-opening period: the sum of all of the volume declines in the minutes from 9:25 to 9:30 and from 9:31-9:32 roughly equals the increase in share volume during the opening cross minute, 9:30-9:31.[31] At the end of the trading day, volume increased in the minute of the Closing Cross, while pre-close trading in the continuous market was not significantly altered. This contrasts with Kandel, Rindi, and Bosetti's (2008) finding for the Borsa Italiana sample that volume decreases in the last five minutes of the continuous market.

Drawing orders and trades into the opening minute could increase price volatility in the ensuing minutes to the extent that the market depth in these ensuing minutes is lessened. On the other hand, sharper price discovery at the open could eliminate subsequent price adjustments and thus translate into less volatility in the ensuing minutes. The fact that volatility decreased in the minutes immediately following the open suggests that, on net, market quality has been improved (i.e., the sharper price discovery in the cross dominates any possible negative effect of reduced market depth).

6.5 Robustness check

To check the robustness of our results, we compared our findings for Nasdaq-listed firms with a matched sample of NYSE-listed firms. These results, which are

[31] The 19,782 average share decline shown in Table 9 for the 9:31-9:32 minutes is not statistically significant, but because of its sheer magnitude, could have economic importance. On the other hand, the median drop of 13,041 shares during this time period is significant at the .10 level.

reported in more detail in Appendix 3, show that the effects found in our Nasdaq stocks are not present in the sample of NYSE stocks. The NYSE sample also displayed considerable minute-by-minute variation in the sign, size, and significance of the volatility measures; apparently the test statistic is itself inherently volatile. In contrast, the consistency for the Nasdaq sample supports the hypothesis that the Nasdaq volatility diminution was due to a single causal factor – its market structure innovation. We conclude that the phenomena described above are specific to Nasdaq stocks and are not an artifact of other possible changes in market conditions and/or potential time trends in the market environment during our sample period.

7. Conclusion and Further Discussion

Using ultra-fine measurement intervals of ten seconds and one minute, we have conducted a targeted analysis of the impact that Nasdaq's two call auctions have had on the informational efficiency of prices at market openings and closings. Substantial trading in the neighborhood of the open and the close indicates the economic importance of the first and the last minutes of trading, and the high volatility that characterizes these moments suggests that opening and closing prices contain considerable transitory components. It is precisely this pricing inefficiency that led several loud voices in the industry (the most effective being Standard & Poor's) to pressure Nasdaq to introduce its opening and closing call auctions.

Our empirical evidence strongly supports the claims that any number of market participants had been making concerning the quality of price formation at these critical times, and we find that the calls did indeed ameliorate the inefficiency. First and foremost, volatility had been high, and the calls brought it down significantly.

More specifically, our major findings are fivefold:

1. The three most volatile minutes of the trading day are the first two minutes following the open, and the final minute preceding the close. This finding indicates that the accentuation of intra-day volatility is concentrated within relatively brief periods during the day and the intra-day volatility pattern is more staple-shaped than U-shaped.

2. The introduction of the opening and closing Nasdaq call auctions (known as the Nasdaq Crosses) has significantly reduced volatility at these two critical times (as reported in Appendix 3, similar volatility reductions in a matched sample of NYSE stocks did not occur).
3. The Nasdaq Crosses concentrated the day's opening volatility closer to the first minute of continuous trading, and volatility declined overall in the neighborhood of the close.
4. The volatility persistence (the correlation between overnight and opening minute's volatility), and the negative correlation between closing and overnight returns, both declined in absolute value after the call auctions were introduced. This further suggests that these auctions have increased the efficiency of price discovery.
5. Order flow was re-organized following the market structure change: economically and statistically significant jumps in trading volume occurred during the opening and closing moments of trading.

Comprehensively viewed, our findings indicate that Nasdaq's market structure innovation has improved the quality of price formation at two particularly important and stressful times of the trading day: the market's open and its close. These findings are of interest to investors and other market participants, along with a broader audience such as regulators and academic researchers.[32] Nevertheless, after the two calls were instituted, volatility spikes, although reduced, continue to characterize the opening and closing minutes of the trading day. Apparently the call auctions, while having a beneficial impact on market quality, are not a complete panacea, and opening and closing prices most likely continue to reflect transient components. If so, further market structure innovation (including improvements in the design of the calls themselves) remains desirable. In the meantime, both practitioners and academic researchers should interpret

[32] For example, the improvement in market quality due to the calls' introduction suggests that regulators might prefer to have markets open and close with calls because these auctions can lead to fewer instances of market manipulation. Academicians who pursue asset pricing and/or market microstructure research can also benefit from our finding that the accentuation in price volatility is concentrated within the first 1-2 minutes immediately following the open and preceding the close. Our results suggest that researchers could use nearly all of the data during a trading day (e.g., that they need not discard the first and last half-hour of trading data, as is done in many studies).

the informational content of opening and closing prices with care in relation to the various uses to which these prices are put.

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Table 1. Volatility Ratios for the Opening and the Closing Minutes

The table provides summary statistics for the volatility ratio for the opening and the closing minutes using data from February 2004 and February 2005. We define realized volatility measures for the first 1 minute through the first 30 minutes and for the last 1 minute through the last 30 minutes, as $RV_n = \sum_{i=1}^{n} Range_i^2$, where *Range* is the difference between the highest and the lowest prices, relative to the average price during a 1-minute interval and *n* corresponds to minutes 1, …, 30. The *volatility* ratio is then defined as $Ratio_{n,N} = RV_n / RV_N$. For the opening minutes, $Ratio_{n,N}$ refers to the volatility ratio of the first *n* minutes to the first *N* minutes of the opening. For the closing minutes, $Ratio_{n,N}$ refers to the volatility ratio of the last *n* minutes to the last *N* minutes of the closing. The columns labeled *p25* and *p75* represent the volatility ratios for the lowest and third quartiles.

		Volatility Ratio					
		Mean	Median	S.D.	p25	p75	n
Opening	$Ratio_{1,5}$	0.423	0.397	0.249	0.223	0.600	3947
	$Ratio_{2,5}$	0.628	0.656	0.239	0.460	0.822	3947
	$Ratio_{3,5}$	0.759	0.813	0.204	0.643	0.919	3947
	$Ratio_{4,5}$	0.884	0.935	0.139	0.842	0.978	3947
	$Ratio_{1,30}$	0.177	0.128	0.160	0.060	0.248	3952
	$Ratio_{2,30}$	0.262	0.219	0.187	0.114	0.369	3952
	$Ratio_{3,30}$	0.312	0.276	0.195	0.158	0.437	3952
	$Ratio_{4,30}$	0.358	0.332	0.199	0.204	0.490	3952
	$Ratio_{5,30}$	0.399	0.374	0.201	0.244	0.540	3952
Closing	$Ratio_{1,5}$	0.513	0.524	0.244	0.319	0.708	3952
	$Ratio_{2,5}$	0.664	0.701	0.215	0.526	0.835	3951
	$Ratio_{3,5}$	0.780	0.826	0.177	0.691	0.916	3952
	$Ratio_{4,5}$	0.888	0.929	0.124	0.852	0.974	3952
	$Ratio_{1,30}$	0.204	0.161	0.164	0.077	0.291	3952
	$Ratio_{2,30}$	0.255	0.221	0.172	0.120	0.356	3951
	$Ratio_{3,30}$	0.295	0.266	0.177	0.155	0.408	3952
	$Ratio_{4,30}$	0.330	0.304	0.180	0.190	0.449	3952
	$Ratio_{5,30}$	0.366	0.346	0.182	0.225	0.489	3952

Table 2. The average *Range* and *R_Range* for one-minute intervals

The table presents the univariate comparisons of mean and median volatility measures, *Range* and *R_range,* during the one-minute interval for the selected Nasdaq stocks during February 2004 (before) and February 2005 (after), respectively. *Range*, measured in basis points, is the difference between the highest and the lowest prices, relative to the average price during the interval. *R_Range* is the ratio of *Range* for the opening (or closing) intervals to the mid-day range, which is the average *Range* over one-minute intervals between 10:30-15:00 for the same stock on the same day. Significance levels are computed for the percentage difference (before-after) in mean (medians) using a t-test and Wilcoxon two-sided t-test. The 10%, 5%, and 1% levels is indicated by *, **, and *** respectively.

	Mean						Median					
	Range (bps)			*R_Range*			*Range (bps)*			*R_Range*		
Interval	before	after	% diff.	before	after	% diff.	before	after	% diff.	before	after	% diff.
9:30-9:31	58.0	53.7	-7.4	7.9	8.0	0.4	57.3	51.3	-10.5 ***	7.5	7.7	1.7
9:31-9:32	44.5	34.9	-21.6 ***	5.4	4.7	-12.6 ***	41.2	32.1	-22.1 ***	5.4	4.5	-16.0 **
9:32-9:33	32.5	28.1	-13.7 **	3.8	3.5	-7.3 **	29.2	25.4	-12.8 ***	3.8	3.4	-10.0 **
9:33-9:34	30.2	26.7	-11.5 *	3.6	3.5	-4.4	28.3	23.7	-16.4	3.5	3.4	-1.5
9:34-9:35	28.4	25.1	-11.5 *	3.5	3.2	-6.3	25.1	22.5	-10.4	3.2	3.1	-2.4
9:35-9:36	27.1	25.8	-4.6	3.3	3.5	4.5	26.4	23.1	-12.5	3.2	3.4	5.8
9:36-9:37	26.1	23.7	-9.3	3.1	3.0	-2.8	24.1	20.9	-13.5 *	3.0	2.9	-3.7
9:37-9:38	25.3	23.0	-9.0	3.0	3.0	0.1	24.3	20.0	-17.7 **	2.8	2.9	0.9
9:38-9:39	24.6	22.0	-10.5 *	2.9	2.9	-1.0	23.0	19.8	-14.0 *	2.8	2.8	-0.5
9:39-9:40	23.3	20.5	-12.3 **	2.8	2.7	-6.7 *	21.1	17.1	-19.1 *	2.8	2.6	-6.8 **
15:50-15:51	12.7	14.2	11.9	1.6	1.9	16.3 **	11.0	11.9	7.5	1.5	1.8	24.8 ***
15:51-15:52	12.5	12.5	-0.3	1.5	1.5	3.1	11.9	8.9	-25.3 *	1.4	1.4	-2.9
15:52-15:53	12.8	11.9	-6.8	1.6	1.5	-5.3	11.5	9.1	-21.4 ***	1.4	1.4	-5.3
15:53-15:54	13.4	12.9	-3.7	1.7	1.6	-5.5	13.1	8.8	-33.2 ***	1.6	1.4	-11.6 **
15:54-15:55	14.5	12.0	-17.4 **	1.8	1.5	-19.9 ***	13.6	9.1	-33.3 ***	1.7	1.3	-20.7 ***
15:55-15:56	14.5	13.1	-9.4	1.8	1.7	-8.5 *	13.5	10.4	-22.9 **	1.6	1.5	-6.9
15:56-15:57	15.3	12.7	-16.6 **	1.9	1.6	-13.6 ***	14.1	9.9	-29.8 ***	1.8	1.4	-19.8 ***
15:57-15:58	16.5	13.2	-20.5 ***	2.1	1.7	-19.0 ***	15.4	10.6	-31.5 ***	1.9	1.5	-21.2 ***
15:58-15:59	17.7	16.5	-7.2	2.3	2.2	-4.4	14.8	13.1	-11.9 ***	2.1	2.0	-4.6
15:59-16:00	40.5	27.7	-31.4 ***	5.6	4.0	-29.0 ***	37.4	24.8	-33.6 ***	5.0	3.9	-22.6 ***

Table 3. The average *Range* and *R_Range* for ten-second intervals

The table presents the univariate comparisons of mean and median volatility measures, *Range* and *R_range,* during the ten-second interval for the selected Nasdaq stocks during February 2004 (before) and February 2005 (after), respectively. *Range*, measured in basis points, is the difference between the highest and the lowest prices, relative to the average price during the interval. *R_Range* is the ratio of *Range* for the opening (or closing) ten-second intervals to the one-minute mid-day range, which is the average *Range* over one-minute intervals between 10:30-15:00 for the same stock on the same day. Significance levels are computed for the percentage difference (before-after) in mean (medians) using a t-test and Wilcoxon two-sided t-test. The 10%, 5%, and 1% levels is indicated by *, **, and *** respectively. Panel A and B summarizes the results for the opening and the closing periods, respectively.

Table 3. Panel A. Opening period

	Mean								Median							
	Range (bps)				*R_Range*				*Range (bps)*				*R_Range*			
Interval	before	after	% diff.		before	after	% diff.		Before	after	% diff.		before	after	% diff.	
9:30:00-9:30:10	35.3	34.5	-2.5		4.5	4.9	9.3		36.1	31.5	-12.8		4.5	4.9	8.0	
9:30:10-9:30:20	32.8	22.3	-31.9	***	4.0	2.9	-29.1	***	33.5	20.9	-37.6	***	4.3	2.8	-35.1	***
9:30:20-9:30:30	30.2	20.2	-33.0	***	3.6	2.6	-27.8	***	30.8	17.9	-41.9	***	3.6	2.5	-30.9	***
9:30:30-9:30:40	30.9	19.2	-37.7	***	3.7	2.4	-34.5	***	29.7	17.8	-40.0	***	3.6	2.3	-36.5	***
9:30:40-9:30:50	25.4	15.7	-38.1	***	2.9	1.9	-34.7	***	24.0	13.9	-41.9	***	2.9	1.8	-37.9	***
9:30:50-9:31:00	22.8	14.4	-36.6	***	2.5	1.8	-26.8	***	21.3	13.2	-38.0	***	2.3	1.7	-25.9	***
9:31:00-9:31:10	20.2	12.1	-40.2	***	2.2	1.5	-31.5	***	17.8	10.2	-42.6	***	2.2	1.4	-36.3	***
9:31:10-9:31:20	19.4	10.0	-48.4	***	2.1	1.1	-46.1	***	17.3	8.5	-50.6	***	2.1	1.1	-45.5	***
9:31:20-9:31:30	17.9	9.6	-46.5	***	1.8	1.1	-39.8	***	15.4	7.8	-49.1	***	1.9	1.0	-44.2	***
9:31:30-9:31:40	13.1	7.6	-41.7	***	1.3	0.9	-33.3	***	9.4	5.6	-40.9	***	1.2	0.8	-36.7	***
9:31:40-9:31:50	11.6	9.2	-20.9	**	1.2	1.1	-8.4		8.6	7.8	-8.9	*	1.1	1.1	-5.3	
9:31:50-9:32:00	11.0	9.7	-11.8		1.1	1.1	-1.9		9.6	7.5	-21.3	**	1.0	1.1	1.2	
9:32:00-9:32:10	11.0	8.2	-25.5	***	1.1	0.9	-17.1	**	9.4	6.3	-33.0	***	1.1	0.8	-30.1	**
9:32:10-9:32:20	10.8	8.4	-22.0	**	1.1	0.9	-17.7	***	10.0	6.0	-39.5	**	1.1	0.9	-21.8	***
9:32:20-9:32:30	10.7	7.8	-27.3	***	1.1	0.9	-20.3	***	8.6	6.0	-29.7	***	1.0	0.8	-26.1	***
9:32:30-9:32:40	9.9	7.5	-23.9	**	1.0	0.8	-18.4	**	8.5	5.0	-41.0	**	0.9	0.7	-22.8	**
9:32:40-9:32:50	9.1	7.8	-14.5		0.9	0.8	-8.8		7.2	6.3	-12.1		0.8	0.8	1.5	
9:32:50-9:33:00	8.8	7.7	-13.4		0.9	0.8	-8.8		7.7	5.8	-25.1		0.9	0.7	-21.3	**
9:33:00-9:33:10	8.7	7.6	-12.4		0.9	0.9	-3.4		7.2	6.1	-15.1		0.8	0.8	-6.7	
9:33:10-9:33:20	8.8	7.5	-15.1	*	0.9	0.9	-4.7		7.9	6.4	-19.3	*	0.9	0.8	-5.5	
9:33:20-9:33:30	8.9	7.4	-17.5	**	0.9	0.8	-11.8	*	7.9	5.5	-29.4	***	0.9	0.7	-22.8	***
9:33:30-9:33:40	8.6	6.6	-23.3	***	0.9	0.7	-17.5	**	7.3	5.6	-23.3		0.9	0.7	-22.7	***
9:33:40-9:33:50	7.9	7.4	-5.5		0.8	0.8	0.8		6.5	6.0	-8.2		0.8	0.8	-2.3	
9:33:50-9:34:00	8.8	7.3	-17.8	*	0.9	0.8	-10.2		6.7	5.3	-21.4		0.8	0.7	-14.7	*
9:34:00-9:34:10	7.9	6.9	-13.1		0.8	0.8	-7.3		6.2	5.7	-7.7		0.8	0.7	-8.7	
9:34:10-9:34:20	8.4	6.6	-21.0	**	0.9	0.7	-21.3	***	6.5	5.4	-17.2	*	0.8	0.6	-21.8	*
9:34:20-9:34:30	7.8	6.5	-17.4	*	0.8	0.7	-14.7	**	6.2	4.5	-27.4	*	0.8	0.7	-17.8	**
9:34:30-9:34:40	7.6	6.1	-19.4	**	0.8	0.7	-16.0	**	7.4	4.3	-41.0	**	0.8	0.6	-25.5	***
9:34:40-9:34:50	7.7	6.8	-12.0		0.8	0.8	-5.8		6.1	5.3	-13.0		0.8	0.8	-1.0	
9:34:50-9:35:00	9.1	7.7	-14.9	*	1.0	0.9	-8.9	*	8.2	6.3	-22.7	*	1.0	0.9	-13.4	**

Table 3. Panel B. Closing period

	Mean								Median							
	Range (bps)				*R_Range*				*Range (bps)*				*R_Range*			
Interval	before	after	% diff.		before	after	% diff.		Before	after	% diff.		before	after	% diff.	
15:55:10-15:55:10	5.3	4.6	-13.6		0.6	0.5	-12.9	***	4.8	3.0	-37.8	***	0.6	0.5	-17.4	***
15:55:10-15:55:20	4.9	4.0	-17.6		0.6	0.4	-19.8	***	4.0	2.7	-32.2	***	0.5	0.4	-27.1	***
15:55:20-15:55:30	4.6	4.6	0.2		0.5	0.5	-1.3		3.7	3.1	-17.6	*	0.5	0.5	-7.6	
15:55:30-15:55:40	4.6	4.4	-4.3		0.5	0.5	-2.7		3.9	3.3	-15.5	**	0.5	0.4	-8.2	*
15:55:40-15:55:50	4.4	4.2	-3.9		0.5	0.4	-12.4	**	3.4	2.7	-20.1	*	0.5	0.4	-17.4	*
15:55:50-15:56:00	5.0	4.9	-2.1		0.6	0.6	-2.7		4.1	3.4	-17.8	*	0.6	0.5	-13.4	*
15:56:00-15:56:10	5.2	4.4	-16.5		0.6	0.5	-15.3	***	4.3	3.1	-27.6	***	0.6	0.5	-14.7	*
15:56:10-15:56:20	4.7	4.0	-16.0		0.5	0.4	-15.4	***	3.8	2.9	-22.4	***	0.5	0.4	-15.4	***
15:56:20-15:56:30	5.6	4.4	-20.9	**	0.6	0.5	-20.6	***	5.1	3.0	-40.0	***	0.6	0.4	-33.0	***
15:56:30-15:56:40	5.3	4.2	-20.2	*	0.6	0.5	-19.9	***	4.2	3.0	-28.6	***	0.6	0.4	-29.9	***
15:56:40-15:56:50	4.8	3.9	-18.6	*	0.6	0.4	-22.5	***	3.9	2.7	-31.9	***	0.5	0.4	-24.0	***
15:56:50-15:57:00	5.0	4.7	-5.7		0.6	0.6	-4.1		4.2	3.4	-20.2	*	0.5	0.5	-5.5	
15:57:00-15:57:10	5.4	4.4	-18.3	*	0.6	0.5	-15.9	***	4.2	3.3	-21.9	***	0.6	0.5	-19.0	***
15:57:10-15:57:20	5.0	4.5	-10.5		0.6	0.5	-13.7	***	4.3	3.3	-22.4	***	0.6	0.5	-17.2	***
15:57:20-15:57:30	5.8	4.8	-16.7		0.6	0.5	-13.7	***	4.9	3.3	-33.5	***	0.6	0.5	-20.1	***
15:57:30-15:57:40	5.5	4.2	-23.9	**	0.6	0.5	-26.7	***	4.6	2.7	-40.6	***	0.6	0.4	-28.8	***
15:57:40-15:57:50	5.2	4.4	-15.8		0.6	0.5	-19.1	***	4.4	3.2	-26.1	***	0.5	0.4	-16.2	***
15:57:50-15:58:00	6.5	5.4	-16.0		0.7	0.6	-16.9	***	5.7	3.7	-35.5	***	0.7	0.5	-19.2	***
15:58:00-15:58:10	5.9	5.8	-1.7		0.7	0.7	3.1		4.9	3.9	-19.0	**	0.6	0.6	1.3	
15:58:10-15:58:20	5.3	5.4	1.2		0.6	0.6	2.8		4.2	3.6	-14.5		0.5	0.6	3.1	
15:58:20-15:58:30	6.0	6.2	2.7		0.7	0.8	11.8	*	4.7	4.5	-3.8		0.6	0.7	4.4	
15:58:30-15:58:40	6.5	5.7	-12.6	**	0.8	0.7	-8.2	***	5.5	4.8	-13.4	***	0.7	0.6	-10.6	***
15:58:40-15:58:50	6.7	5.0	-25.0		0.8	0.6	-26.7		5.5	3.6	-33.6	***	0.7	0.5	-28.6	***
15:58:50-15:59:00	6.9	6.4	-7.9		0.8	0.8	-6.9		5.8	4.6	-20.3	**	0.8	0.7	-7.3	
15:59:00-15:59:10	6.7	5.9	-11.7		0.8	0.7	-8.6	*	6.0	4.5	-25.3	**	0.7	0.7	-5.9	**
15:59:10-15:59:20	7.6	7.1	-6.7		0.9	0.8	-13.9	**	6.8	4.9	-28.7	**	0.8	0.8	-10.6	**
15:59:20-15:59:30	10.0	8.1	-19.2	***	1.3	1.1	-16.3	***	8.7	7.0	-19.3	**	1.1	1.0	-12.4	***
15:59:30-15:59:40	12.5	8.4	-32.4	***	1.6	1.1	-32.4	***	10.5	6.9	-34.1	***	1.5	1.0	-28.9	***
15:59:40-15:59:50	20.5	10.7	-47.6	***	2.9	1.4	-52.1	***	19.2	9.0	-53.1	***	2.4	1.3	-46.4	***
15:59:50-16:00:00	33.7	19.1	-43.3	***	7.8	2.8	-64.5	*	28.1	15.8	-43.7	***	3.8	2.5	-35.1	***

Table 4. Summary statistics for regression variables

The table provides summary statistics for regression variables during the opening and the closing five minutes of the trading day for the selected Nasdaq stocks during the two months February 2004 and February 2005. *retstd* is the standard deviation of a stock's percentage weekly returns, measured over the period of 2/2003 to 1/2004. *lmcap* is the logarithmic of the market capitalization measured at the end of January 2004. The rest of the variables are measured during ten-second intervals of the open and the close. *Range*, measured in basis points, is the difference between the highest and the lowest prices for the, relative to the average price during the interval. The variable *Spread*, measured in basis points, is the average of the actual quoted spread relative to the average price during the interval. The variable *Numtrades* captures the total number of trades during the interval. The variable *Avgtdsize* is defined as the share trading volume (*Volume*) divided by the number of trades during the interval. *R_Range* is the ratio of *Range* for the opening (or closing) ten-second intervals to the mid-day range, which is the average *Range* over one-minute intervals between 10:30-15:00 for the same stock on the same day. Similar to the construction of *R_Range*, we compute *R_Spread, R_Numtrades,* and *R_Avgtdsize* for the opening and closing intervals as the ratio of *Spread, Numtrades,* and *Avgtdsize* to their corresponding mid-day level, respectively.

	Mean	Median	S.D.	Skewness	Kurtosis	Lower Quartile	Upper Quartile	n
retstd	5.41	5.15	1.93	0.57	-0.32	4.04	6.70	471960
lmcap	9.01	8.71	0.98	1.31	1.76	8.28	9.48	471960
range	30.92	0.00	907.59	79.21	8264.62	0.00	6.86	474240
spread	20.05	9.18	43.60	6.51	50.01	4.77	18.50	378522
volume	9455	1300	40802	24	1158	300	5500	474240
numtrades	9.42	3.00	22.76	9.12	227.36	1.00	8.00	474240
avgtdsize	1474	350	7388	29	1443	193	895	424690
r_range	2.71	0.00	106.96	105.44	13921.73	0.00	0.76	474240
r_spread	1.79	1.01	3.25	8.67	140.20	0.56	1.89	378522
r_volume	1.39	0.30	4.46	21.76	1656.54	0.09	0.88	474240
r_numtrades	0.65	0.37	1.39	59.89	9767.52	0.18	0.72	474240
r_avgtdsize	2.09	0.84	6.73	19.40	782.81	0.49	1.53	424690

Table 5. Multivariate regression analysis of volatility during the opening minutes

The table reports the regression analysis for ten-second interval volatility estimates during the opening five minutes of the trading day for the selected Nasdaq stocks during the two months February 2004 and February 2005. Panel A uses *Range* as the volatility measure and Panel B uses *R_range* as the volatility measure. *retstd* is the standard deviation of a stock's percentage weekly returns, measured over the period of 2/2003 to 1/2004. *lmcap* is the logarithmic of the market capitalization measured at the end of January 2004. The rest of the variables are measured during ten-second intervals of the open and the close. *Range* is the difference between the highest and the lowest prices for the, relative to the average price during the interval. *R_Range* is the ratio of *Range* for the opening (or closing) ten-second intervals to the mid-day range, which is the average *Range* over one-minute intervals between 10:30-15:00 for the same stock on the same day. *mini, where i=1,2,3,* is a dummy variable that equal to 1 if the interval is within the ith minute of the open and 0 otherwise. *after* is a dummy variable that equals to 1 for 2005 and 0 for 2004. *min_ai* is equal to the product of *mini* with *after*. The variable *Spread*, measured in basis points, is the average of the actual quoted spread relative to the average price during the interval. The variable *Numtrades* captures the total number of trades during the interval. The variable *Avgtdsize* is defined as the share trading volume divided by the number of trades during the interval. Similar to the construction of *R_Range*, we compute *R_Spread, R_Numtrades,* and *R_Avgtdsize* for the opening and closing intervals as the ratio of *Spread, Numtrades,* and *Avgtdsize* to their corresponding mid-day level, respectively. The Huber/White/sandwich robust standard errors with firm level clustering are shown in parentheses. The 10%, 5%, and 1% significance levels are indicated by *, **, and *** respectively.

Panel A: Volatility measure: *Range*

	1	2
min1	13.339***	16.528***
	(0.596)	(0.753)
min2	3.501***	5.611***
	(0.297)	(0.454)
min3	0.625***	0.914***
	(0.177)	(0.214)
after	-3.747***	-1.489***
	(0.350)	(0.311)
min_a1		-6.380***
		(0.700)
min_a2		-4.237***
		(0.436)
min_a3		-0.594**
		(0.252)
Lmcap	0.064	0.095
	(0.500)	(0.498)
Retstd	1.713***	1.717***
	(0.313)	(0.314)
spread	0.272***	0.274***
	(0.058)	(0.058)
numtrades	0.213***	0.211***
	(0.043)	(0.043)
avgtdsize (10^{-2})	0.042**	0.042**
	(0.021)	(0.020)
constant	-6.976	-8.411
	(5.532)	(5.518)
Adj. R^2	0.261	0.265
N	117926	117926

Table 5. Panel B: Volatility measure: *R_Range*

	1	2
min1	1.490***	1.750***
	(0.067)	(0.094)
min2	0.307***	0.515***
	(0.032)	(0.040)
min3	0.031	0.061**
	(0.022)	(0.025)
after	-0.220***	-0.018
	(0.034)	(0.027)
min_a1		-0.525***
		(0.098)
min_a2		-0.422***
		(0.040)
min_a3		-0.065**
		(0.028)
lmcap	0.258***	0.259***
	(0.036)	(0.036)
retstd	0.115***	0.116***
	(0.029)	(0.029)
R_spread	0.322***	0.325***
	(0.025)	(0.024)
R_numtrades	1.641***	1.632***
	(0.149)	(0.149)
R_avgtdsize	0.010**	0.010**
	(0.005)	(0.004)
constant	-3.364***	-3.479***
	(0.439)	(0.443)
Adj. R^2	0.297	0.299
N	117926	117926

Table 6. Multivariate regression analysis of volatility during the closing minutes

The table reports the regression analysis for ten-second interval volatility estimates during the closing five minutes of the trading day for the selected Nasdaq stocks during the two months February 2004 and February 2005. Panel A uses *Range* as the volatility measure and Panel B uses *R_range* as the volatility measure. *retstd* is the standard deviation of a stock's percentage weekly returns, measured over the period of 2/2003 to 1/2004. *lmcap* is the logarithmic of the market capitalization measured at the end of January 2004. The rest of the variables are measured during ten-second intervals of the open and the close. *Range* is the difference between the highest and the lowest prices for the, relative to the average price during the interval. *R_Range* is the ratio of *Range* for the opening (or closing) ten-second intervals to the mid-day range, which is the average *Range* over one-minute intervals between 10:30-15:00 for the same stock on the same day. *mini,* where *i=1,2,3,* is a dummy variable that equals to 1 if the interval is within the i^{th} minute of the close and 0 otherwise. *after* is a dummy variable that equals to 1 for 2005 and 0 for 2004. *min_ai* is equal to the product of *mini* with *after*. *sec_i*, where *i=1, 2, 3, 4, 5*, is a dummy variable that equals to 1 if the interval is within the *i*th ten-second interval of the close. *sec_ai* is the product of *seci* with *after*. The variable *Spread*, measured in basis points, is the average of the actual quoted spread relative to the average price during the interval. The variable *Numtrades* captures the total number of trades during the interval. The variable *Avgtdsize* is defined as the share trading volume divided by the number of trades during the interval. Similar to the construction of *R_Range*, we compute *R_Spread, R_Numtrades,* and *R_Avgtdsize* for the opening and closing intervals as the ratio of *Spread, Numtrades,* and *Avgtdsize* to their corresponding mid-day level, respectively. The Huber/White/sandwich robust standard errors with firm level clustering are shown in parentheses. The 10%, 5%, and 1% significance levels are indicated by *, **, and *** respectively.

Panel A: Volatility measure: *Range*

	1	2	3
min1	0.832***	2.677***	1.428***
	(0.146)	(0.232)	(0.171)
min2	0.715***	0.941***	0.944***
	(0.083)	(0.104)	(0.104)
min3	0.191***	0.415***	0.417***
	(0.055)	(0.079)	(0.079)
sec_1	2.199***	2.203***	2.807***
	(0.119)	(0.120)	(0.151)
sec_2	1.250***	1.251***	1.875***
	(0.064)	(0.064)	(0.105)
sec_3	0.633***	0.631***	0.857***
	(0.047)	(0.047)	(0.074)
sec_4	0.511***	0.508***	0.599***
	(0.052)	(0.052)	(0.068)
sec_5	0.367***	0.370***	0.183*
	(0.086)	(0.086)	(0.097)
after	-1.383***	-0.428**	-0.424**
	(0.202)	(0.179)	(0.178)
min_a1		-3.690***	-1.178***
		(0.282)	(0.200)
min_a2		-0.454***	-0.448***
		(0.126)	(0.126)
min_a3		-0.449***	-0.446***
		(0.128)	(0.128)
sec_a1			-1.192***
			(0.138)
sec_a2			-1.240***
			(0.117)
sec_a3			-0.438***
			(0.092)
sec_a4			-0.163*
			(0.086)
sec_a5			0.372**
			(0.153)
lmcap	-0.218	-0.216	-0.202
	(0.210)	(0.210)	(0.209)
retstd	0.520***	0.524***	0.530***
	(0.110)	(0.110)	(0.110)
spread	0.552***	0.549***	0.545***
	(0.058)	(0.059)	(0.060)
numtrades	0.113***	0.113***	0.111***
	(0.023)	(0.022)	(0.022)
avgtdsize(10^{-2})	0.008	0.010	0.013*
	(0.007)	(0.007)	(0.008)
Constant	-1.325	-1.811	-1.926
	(2.236)	(2.222)	(2.215)
Adj. R^2	0.442	0.447	0.451
N	109444	109444	109444

Table 6. Panel B: Volatility measure: *R_Range*

	1	2	3
min1	0.045***	0.214***	0.115***
	(0.015)	(0.031)	(0.022)
min2	0.031***	0.065***	0.065***
	(0.008)	(0.010)	(0.010)
min3	0.008	0.022**	0.022**
	(0.006)	(0.009)	(0.009)
sec_1	0.180***	0.181***	0.213***
	(0.009)	(0.010)	(0.017)
sec_2	0.110***	0.111***	0.170***
	(0.009)	(0.009)	(0.017)
sec_3	0.064***	0.064***	0.086***
	(0.009)	(0.009)	(0.013)
sec_4	0.047***	0.047***	0.061***
	(0.008)	(0.008)	(0.011)
sec_5	0.038***	0.038***	0.042**
	(0.009)	(0.010)	(0.017)
after	-0.124***	-0.034***	-0.035***
	(0.013)	(0.013)	(0.013)
min_a1		-0.337***	-0.137***
		(0.060)	(0.033)
min_a2		-0.067***	-0.067***
		(0.016)	(0.016)
min_a3		-0.027**	-0.027**
		(0.012)	(0.012)
sec_a1			-0.059***
			(0.020)
sec_a2			-0.117***
			(0.018)
sec_a3			-0.042***
			(0.012)
sec_a4			-0.025
			(0.016)
sec_a5			-0.007
			(0.023)
lmcap	0.032***	0.032***	0.031***
	(0.009)	(0.009)	(0.009)
retstd	0.015**	0.014**	0.014**
	(0.006)	(0.006)	(0.006)
R_spread	0.450***	0.449***	0.445***
	(0.023)	(0.022)	(0.022)
R_numtrades	0.943***	0.936***	0.929***
	(0.061)	(0.060)	(0.060)
R_avgtdsize	0.004***	0.005***	0.006***
	(0.002)	(0.002)	(0.002)
constant	-0.716***	-0.747***	-0.730***
	(0.104)	(0.106)	(0.104)
Adj. R^2	0.453	0.455	0.456
N	109444	109444	109444

Table 7. Correlation of overnight volatility and opening volatility

This table presents the correlation of the overnight volatility with the volatility of the opening minutes on the following day. $|r_{o/n}|$ is the overnight return volatility measured as the absolute value of the overnight returns. *Range1* is the *Range* measure over the 1st minute of the open. *Avgrange2-5* is the average value of *Range* measured over the first 2-5 minutes, respectively. The P-values are shown in parentheses. *N* is the number of observations.

Panel A: Full sample correlation

	Range1	Avgrange2	Avgrange3	Avgrange4	Avgrange5
2004/02					
$\lvert r_{o/n}\rvert$	0.18743	0.2223	0.2506	0.25416	0.26208
P-value	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
N	*1560*	*1560*	*1560*	*1560*	*1560*
2005/02					
$\lvert r_{o/n}\rvert$	0.13284	0.16488	0.18552	0.19203	0.19317
P-value	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
N	*1456*	*1456*	*1456*	*1456*	*1456*
Test of the difference					
P-value	0.124	0.102	0.061	0.073	0.046

Panel B: Correlation of the 20 largest firms

	Range1	Avgrange2	Avgrange3	Avgrange4	Avgrange5
2004/02					
$\lvert r_{o/n}\rvert$	0.51643	0.5129	0.55329	0.55417	0.55688
P-value	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
N	*300*	*300*	*300*	*300*	*300*
2005/02					
$\lvert r_{o/n}\rvert$	-0.02841	-0.0056	0.0142	0.02191	0.02807
P-value	*(0.636)*	*(0.926)*	*(0.813)*	*(0.715)*	*(0.640)*
N	*280*	*280*	*280*	*280*	*280*
Test of the difference					
P-value	0.000	0.000	0.000	0.000	0.000

Table 7. Panel C: Correlation of the 64 middle size firms

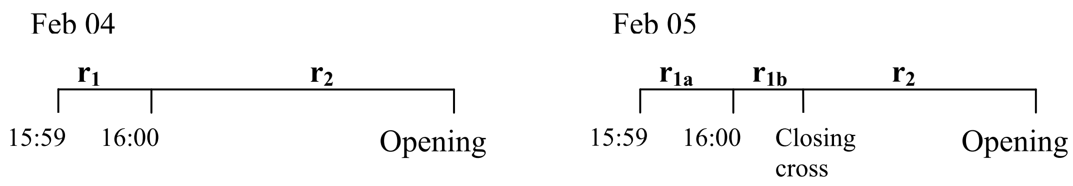
	Range1	Avgrange2	Avgrange3	Avgrange4	Avgrange5
2004/02					
$\|r_{o/n}\|$	0.16107	0.1972	0.2264	0.23061	0.23732
P-value	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
N	*960*	*960*	*960*	*960*	*960*
2005/02					
$\|r_{o/n}\|$	0.37093	0.44018	0.47919	0.4923	0.48833
P-value	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
N	*896*	*896*	*896*	*896*	*896*
test of the difference					
P-value	0.000	0.000	0.000	0.000	0.000

Table 7. Panel D: Correlation of the 20 smallest firms

	Range1	Avgrange2	Avgrange3	Avgrange4	Avgrange5
2004/02					
$\|r_{o/n}\|$	0.15462	0.22509	0.25658	0.26604	0.29559
P-value	*(0.007)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
N	*300*	*300*	*300*	*300*	*300*
2005/02					
$\|r_{o/n}\|$	0.4049	0.44299	0.47231	0.47827	0.48032
P-value	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*	*(0.000)*
N	*280*	*280*	*280*	*280*	*280*
test of the difference					
P-value	0.001	0.003	0.003	0.003	0.009

Table 8. Correlation of closing return and overnight return

This table presents the correlation of the closing return and the subsequent overnight return. For February 2004, we define r1 as the one-minute logarithmic return based on the price at 3:59 pm and the closing price at 4:00 pm. For February 2005, we decompose the return from 3:59 pm until closing (r1) into two returns: r1a (the one-minute return from 3:59-4:00 pm) and r1b (the return from 4:00 pm to the official closing price—which is usually determined within the one-minute period, 4:00-4:01 pm). For both months, we define r2 as the overnight logarithmic return based on the previous day's closing price and the current day's opening). The P-values are shown in parentheses. *N* is the number of observations. The 10%, 5%, and 1% significance levels are indicated by *, **, and *** respectively.



Panel A. Full sample correlations

	r1		r2		r1a
Feb-04					
R2	-0.055	**			
P-value	*(0.03)*				
N	*1560*				
Feb-05					
	r1		r2		r1a
R2	-0.043				
P-value	*(0.10)*				
N	*1456*				
R1a	0.486	***	-0.004		
P-value	*(0.00)*		*(0.88)*		
N	*1976*		*1456*		
R1b	0.863	***	-0.048	*	-0.023
P-value	*(0.00)*		*(0.07)*		*(0.31)*
N	*1976*		*1456*		*1976*
P value of correlation test					
corr(r1,r2) before= corr(r1,r2)after			0.744		
corr(r1,r2) before= corr(r1a, r2)after			0.162		

Table 8. Panel B: Correlation of the 20 largest firms

Feb-04						
	r1					
R2	-0.241	***				
P-value	*(0.00)*					
N	*300*					
Feb-05						
	r1		r2		r1a	
R2	-0.015					
P-value	*(0.81)*					
N	*280*					
R1a	0.485	***	0.054			
P-value	*(0.00)*		*(0.36)*			
N	*380*		*280*			
R1b	0.886	***	-0.045		0.023	
P-value	*(0.00)*		*(0.45)*		*(0.65)*	
N	*380*		*280*		*380*	
P value of correlation test						
corr(r1,r2) before= corr(r1,r2)after			0.006			
corr(r1,r2) before=(r1a, r2)after			0.000			

Panel C: Correlation of the 64 middle sized firms

Feb-04						
	r1					
r2	-0.033					
P-value	*(0.30)*					
N	*960*					
Feb-05						
	r1		r2		r1a	
r2	-0.138	***				
P-value	*(0.00)*					
N	*896*					
r1a	0.464	***	-0.036			
P-value	*(0.00)*		*(0.28)*			
N	*1216*		*896*			
r1b	0.865	***	-0.139	***	-0.043	
P-value	*(0.00)*		*(0.00)*		*(0.14)*	
N	*1216*		*896*		*1216*	
P value of correlation test						
corr(r1,r2) before= corr(r1,r2)after			0.023			
corr(r1,r2) before= corr (r1a, r2)after			0.945			

Table 8. Panel D: Correlation of the 20 smallest firms

Feb-04

	r1	
r2	-0.315	***
P-value	*(0.00)*	
N	*300*	

Feb-05

	r1		r2	r1a
r2	-0.031			
P-value	*(0.61)*			
N	*280*			
r1a	0.539	***	-0.063	
P-value	*(0.00)*		*(0.30)*	
N	*380*		*280*	
r1b	0.840	***	0.004	-0.005
P-value	*(0.00)*		*(0.95)*	*(0.92)*
N	*380*		*280*	*380*
P value of correlation test				
corr(r1,r2) before= corr(r1,r2)after			0.000	
corr(r1,r2) before= corr (r1a, r2)after			0.002	

Table 9. Trading Activity: *Volume* and *Numtrades* for one-minute intervals

The table presents the univariate comparisons of mean and median volume-related measures, *Volume* and *Numtrades,* during the one-minute interval for the selected Nasdaq stocks during February 2004 (before) and February 2005 (after), respectively. *Volume* is the number of shares traded during each time interval. *Numtrades* is the number of trades executed during each time interval. Significance levels are computed for the percentage difference (before-after) in mean (medians) using a t-test and Wilcoxon two-sided t-test. The 10%, 5%, and 1% levels is indicated by *, **, and *** respectively.

	Mean						Median					
	Volume (shares)			*Numtrades*			*Volume (shares)*			*Numtrades*		
Interval	before	After	% diff.	before	after	% diff.	before	after	% diff.	before	after	% diff.
9:26-9:27	3068.2	464.8	-84.9 ***	8.20	0.41	-95.0 ***	1289.5	137.1	-89.4 ***	5.33	0.26	-95.2 ***
9:27-9:28	3517.8	1115.0	-68.3 ***	9.38	0.86	-90.9 ***	1681.8	382.8	-77.2 ***	7.43	0.60	-92.0 ***
9:28-9:29	4199.1	1799.7	-57.1 ***	11.32	1.39	-87.7 ***	2278.4	957.8	-58.0 ***	8.93	1.04	-88.4 ***
9:29-9:30	6161.7	3592.9	-41.7 **	15.76	2.48	-84.3 ***	2698.7	1749.1	-35.2 ***	10.65	1.82	-82.9 ***
9:30-9:31	14955.3	40099.8	168.1 ***	33.57	21.25	-36.7 **	5474.6	12766.8	133.2 ***	18.83	10.77	-42.8 ***
9:31-9:32	85082.5	65300.1	-23.3	138.93	130.58	-6.0	32638.7	19596.8	-40.0 *	84.50	62.58	-25.9 *
9:32-9:33	41655.2	38116.0	-8.5	71.93	84.47	17.4	14030.3	9277.3	-33.9	44.75	34.40	-23.1
9:33-9:34	34679.2	34737.9	0.2	60.68	77.54	27.8	13825.6	7545.8	-45.4	36.46	26.84	-26.4
9:34-9:35	33755.6	36678.1	8.7	63.38	85.86	35.5	13943.5	9345.9	-33.0	35.46	33.60	-5.3
9:35-9:36	35390.6	35976.4	1.7	63.84	82.82	29.7	15599.1	10170.2	-34.8	39.15	33.98	-13.2
9:36-9:37	33012.5	37039.5	12.2	62.88	88.25	40.3 *	12109.3	9682.6	-20.0	36.76	37.34	1.6
9:37-9:38	31816.2	36274.2	14.0	61.10	82.80	35.5 *	10934.9	9309.7	-14.9	34.43	37.12	7.8
9:38-9:39	32616.6	34661.3	6.3	59.71	81.70	36.8 *	13284.4	11155.2	-16.0	34.72	34.99	0.8
9:39-9:40	31126.4	35771.2	14.9	60.02	80.37	33.9 *	13339.2	10338.7	-22.5	34.28	34.92	1.9
9:40-9:41	30490.1	32509.3	6.6	57.63	77.06	33.7	11769.8	9075.3	-22.9	37.42	32.18	-14.0
15:51-15:52	26706.8	37785.0	41.5	49.72	83.82	68.6 ***	11739.7	13353.7	13.7	34.47	45.31	31.5 ***
15:52-15:53	25191.9	29497.2	17.1	49.55	63.72	28.6 *	13546.2	10930.4	-19.3	34.51	34.59	0.2
15:53-15:54	27408.7	31104.7	13.5	51.66	67.45	30.6 *	11120.2	10771.5	-3.1	33.54	34.46	2.8
15:54-15:55	27331.6	31490.0	15.2	53.21	66.29	24.6	12511.6	10315.4	-17.6	37.34	37.18	-0.4
15:55-15:56	29963.6	32989.9	10.1	58.48	71.82	22.8	14635.3	10699.4	-26.9	38.25	40.36	5.5
15:56-15:57	30361.8	37917.8	24.9	57.00	81.43	42.9 **	14981.6	13043.8	-12.9	39.12	41.98	7.3 *

15:57-15:58	35118.2	37639.7	7.2		63.88	80.92	26.7		15635.7	14354.5	-8.2		42.96	44.30	3.1	
15:58-15:59	43973.4	41419.2	-5.8		72.46	85.96	18.6		20262.5	15200.8	-25.0		47.40	46.64	-1.6	
15:59-16:00	50654.7	57650.5	13.8		77.94	107.11	37.4	**	21473.5	22137.3	3.1		51.54	53.78	4.3	
16:00-16:01	89604.7	124662.5	39.1		150.87	158.32	4.9		41487.5	46188.5	11.3		102.15	98.04	-4.0	
16:01-16:02	882.2	3557.4	303.3	***	0.52	0.15	-71.5	***	305.1	390.5	28.0	*	0.25	0.08	-66.1	***
16:02-16:03	114.2	173.8	52.2		0.01	0.01	-54.8	*	0.0	0.0			0.00	0.00		
16:03-16:04	0.0	0.0			0.00	0.00			0.0	0.0			0.00	0.00		
16:04-16:04	0.0	0.0			0.00	0.00			0.0	0.0			0.00	0.00		
16:05-16:06	0.0	0.0			0.00	0.00			0.0	0.0			0.00	0.00		

Table 10. Trading Activity: *Volume* and *Numtrades* for ten-second intervals

The table presents the univariate comparisons of mean and median volume-related measures, *Volume* and *Numtrades,* during the ten-second interval for the full sample of Nasdaq stocks during February 2004 (before) and February 2005 (after), respectively. *Volume* is the number of shares traded during each time interval. *Numtrades* is the number of trades executed during each time interval. Significance levels are computed for the percentage difference (before-after) in mean (medians) using a t-test and Wilcoxon two-sided t-test. The 10%, 5%, and 1% levels is indicated by *, **, and *** respectively. Panel A and B summarizes the results for the opening and the closing periods, respectively.

Panel A. Opening period

	Mean							Median							
	Volume (shares)			*Numtrades*				*Volume (shares)*				*Numtrades*			
Interval	before	after	% diff	before	after	% diff		before	after	% diff		before	after	% diff	
9:30:00-9:30:10	22165	17776	-19.8	42.5	38.6	-9.3		7440	6217	-16.4		22.8	19.5	-14.1	
9:30:10-9:30:20	16590	10957	-34.0	26.0	21.9	-15.9		5800	3048	-47.4	**	13.0	9.9	-24.0	**
9:30:20-9:30:30	14238	10352	-27.3	20.6	18.9	-8.4		4735	2577	-45.6	*	12.0	8.5	-29.0	*
9:30:30-9:30:40	13413	9981	-25.6	19.6	19.8	0.8		4166	2527	-39.3	*	12.6	9.9	-21.6	
9:30:40-9:30:50	10176	8341	-18.0	16.0	16.4	2.7		3464	2152	-37.9	*	9.0	6.9	-23.4	
9:30:50-9:31:00	8797	8414	-4.4	15.3	17.1	11.9		2628	2333	-11.2		8.4	8.3	-1.0	
9:31:00-9:31:10	8078	7000	-13.3	14.3	15.0	4.6		2560	1674	-34.6		8.3	7.0	-15.2	
9:31:10-9:31:20	8255	6763	-18.1	14.0	15.5	10.4		2633	2010	-23.7		7.9	7.1	-10.0	
9:31:20-9:31:30	7748	6491	-16.2	13.3	14.8	11.7		2460	1926	-21.7		8.2	7.6	-8.2	
9:31:30-9:31:40	6404	6077	-5.1	11.4	13.6	19.0		1890	1617	-14.4		6.5	5.8	-9.4	
9:31:40-9:31:50	5902	6267	6.2	10.6	14.8	39.3	*	2135	1812	-15.1		7.0	6.8	-3.5	
9:31:50-9:32:00	6106	6862	12.4	11.4	15.6	37.0	*	2281	1722	-24.5		7.3	6.9	-5.6	
9:32:00-9:32:10	5845	6478	10.8	11.1	13.8	24.0		2153	1555	-27.8		7.0	5.5	-21.3	
9:32:10-9:32:20	6100	5818	-4.6	11.2	13.6	21.9		2328	1609	-30.9		6.6	5.8	-12.7	
9:32:20-9:32:30	6004	6209	3.4	11.0	14.2	28.8		2005	1411	-29.6		6.6	5.7	-13.4	
9:32:30-9:32:40	6021	5942	-1.3	10.2	13.4	31.0		2128	1795	-15.6		6.2	6.2	-0.8	
9:32:40-9:32:50	6113	6029	-1.4	10.8	13.8	27.0		2021	1682	-16.8		6.5	6.7	4.2	
9:32:50-9:33:00	5770	5941	3.0	10.3	14.3	38.1	*	2388	1813	-24.1		6.5	6.6	0.5	
9:33:00-9:33:10	5909	6469	9.5	11.2	15.3	36.4	*	2202	1942	-11.8		7.0	6.7	-4.5	
9:33:10-9:33:20	5909	6324	7.0	11.2	15.3	36.4	*	2461	1929	-21.6		7.1	6.8	-4.2	
9:33:20-9:33:30	5601	6047	8.0	11.4	15.2	34.1	*	1947	1933	-0.8		7.1	7.2	1.1	
9:33:30-9:33:40	5882	6096	3.6	11.7	13.8	17.7		2639	1487	-43.7		7.6	6.1	-19.4	*
9:33:40-9:33:50	5807	6647	14.5	11.0	15.2	38.1	*	1962	1816	-7.5		7.3	6.2	-15.1	
9:33:50-9:34:00	5764	6564	13.9	10.7	16.0	48.6	**	2224	1772	-20.3		6.1	7.0	14.1	
9:34:00-9:34:10	6007	6473	7.8	11.0	14.6	32.9		2304	1725	-25.1		7.3	6.9	-6.1	
9:34:10-9:34:20	5923	6580	11.1	11.0	14.2	28.6		2510	1807	-28.0	*	7.5	6.0	-19.6	
9:34:20-9:34:30	6003	6003	0.0	11.2	14.2	26.8		2376	1880	-20.9	*	6.8	5.9	-13.0	
9:34:30-9:34:40	6930	6025	-13.1	11.1	14.2	28.0		2429	1834	-24.5		6.1	6.3	2.8	
9:34:40-9:34:50	5823	5854	0.5	11.2	15.1	35.5	*	2361	2298	-2.7		7.1	6.9	-3.4	
9:34:50-9:35:00	5924	6542	10.4	12.3	15.9	30.0	*	2692	2216	-17.7		8.2	8.6	5.9	

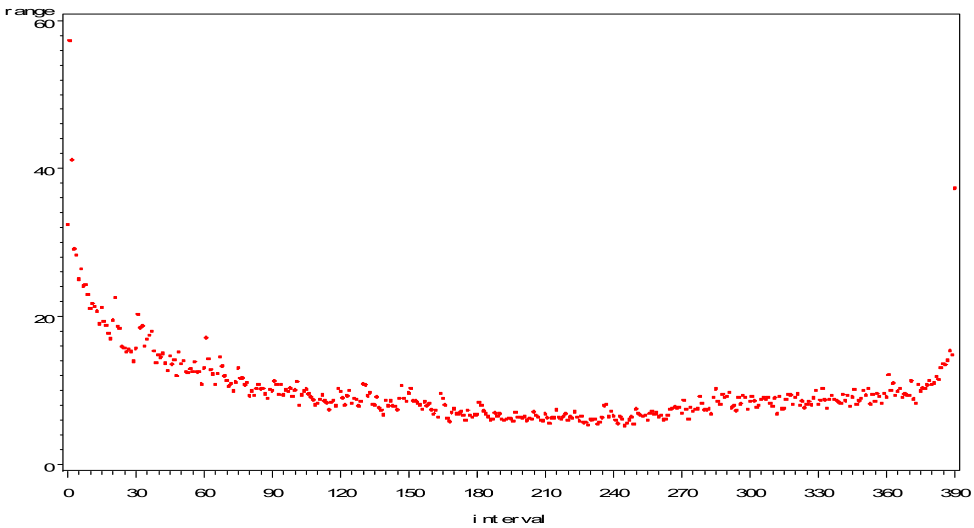
Table 10. Panel B. Closing period

	Mean								Median							
	Volume (shares)				*Numtrades*				*Volume (shares)*				*Numtrades*			
Interval	Before	after	% diff		Before	after	% diff		before	after	% diff		before	after	% diff	
15:55:10-15:55:10	5552	5938	7.0		10.5	13.5	28.9	*	2369	2297	-3.0		6.9	8.2	18.4	
15:55:10-15:55:20	4913	5767	17.4		9.4	12.5	32.7	*	2138	2061	-3.6		6.5	7.0	7.8	
15:55:20-15:55:30	5034	6152	22.2		9.3	14.5	57.0	***	2052	2349	14.5		6.1	7.4	21.6	*
15:55:30-15:55:40	4819	6351	31.8		9.1	12.7	40.6	**	2265	2406	6.2		6.0	6.9	14.0	
15:55:40-15:55:50	4599	6476	40.8		8.5	13.0	52.7	**	2178	2422	11.2		5.7	7.2	25.9	**
15:55:50-15:56:00	5633	7389	31.2		10.9	15.6	43.1	**	2494	2543	2.0		7.7	7.9	3.7	
15:56:00-15:56:10	5842	6755	15.6		10.7	14.7	38.3	**	2469	2126	-13.9		7.0	8.2	16.3	
15:56:10-15:56:20	5453	5613	2.9		9.9	12.1	22.5		2200	2046	-7.0		6.6	7.1	8.0	
15:56:20-15:56:30	6714	6696	-0.3		12.4	14.1	13.7		3042	2852	-6.3		8.8	7.8	-12.0	
15:56:30-15:56:40	6235	6200	-0.6		11.4	13.1	15.2		2810	2222	-20.9		6.9	7.3	5.2	
15:56:40-15:56:50	5253	5851	11.4		9.5	12.3	30.3		2044	1827	-10.6		5.4	6.0	12.6	
15:56:50-15:57:00	5727	6711	17.2		10.5	15.1	43.6	**	2772	2864	3.3		7.7	8.6	11.8	*
15:57:00-15:57:10	7281	7258	-0.3		12.0	15.1	26.1		3303	2393	-27.5		7.4	7.6	1.7	
15:57:10-15:57:20	5823	6503	11.7		10.2	13.6	34.0	*	2678	1998	-25.4		6.6	7.1	7.7	
15:57:20-15:57:30	8212	6365	-22.5		13.3	13.7	3.2		3189	2448	-23.2		8.1	8.2	1.9	
15:57:30-15:57:40	7047	6208	-11.9		11.7	12.5	6.9		3265	2034	-37.7	*	7.8	5.8	-26.0	
15:57:40-15:57:50	6310	6202	-1.7		10.4	13.0	25.1		2944	2363	-19.7		7.0	6.8	-3.1	
15:57:50-15:58:00	9424	9043	-4.0		15.4	18.6	20.9		3852	3443	-10.6		10.5	10.3	-2.0	
15:58:00-15:58:10	7459	10622	42.4		12.3	19.8	60.9	***	3284	3766	14.7		7.9	10.3	30.1	***
15:58:10-15:58:20	7440	9631	29.5		11.1	17.4	56.4	***	3594	3330	-7.4		6.6	8.6	30.0	
15:58:20-15:58:30	8981	9827	9.4		13.5	19.8	46.3	**	3823	4054	6.0		9.2	11.7	26.7	
15:58:30-15:58:40	8403	8603	2.4		13.6	17.0	25.1		3223	3784	17.4		9.2	9.7	5.3	
15:58:40-15:58:50	8365	8940	6.9		13.2	14.3	8.4		3179	2866	-9.8		8.1	7.1	-12.6	
15:58:50-15:59:00	10109	10119	0.1		14.6	19.1	31.0	*	3766	3550	-5.7		9.0	10.0	11.2	
15:59:00-15:59:10	8878	10533	18.6		13.7	19.9	45.1	**	4031	4231	5.0		8.5	9.7	13.6	
15:59:10-15:59:20	9842	10868	10.4		15.1	20.7	37.4	**	3535	4034	14.1		8.8	10.7	22.2	
15:59:20-15:59:30	11987	12980	8.3		20.0	26.3	31.1	*	5653	5605	-0.9		13.1	16.9	28.7	
15:59:30-15:59:40	13312	11926	-10.4		22.0	23.9	8.8		6133	5132	-16.3		15.0	13.8	-8.2	
15:59:40-15:59:50	20348	15136	-25.6		34.6	30.3	-12.4		9623	5018	-47.9	*	24.4	16.6	-32.0	**
15:59:50-16:00:00	26271	67197	155.8	***	46.2	37.6	-18.6	*	12464	22939	84.0	***	35.3	24.9	-29.5	***

Figure 1. 1-minute interval volatility

The figure presents the median *Range* across the Nasdaq stocks for one minute intervals during February 2004 (Panel A) and February 2005 (Panel B), respectively. *Range*, measured in basis points, is the difference between the highest and the lowest prices, relative to the average price during the interval. We calculate the mean volatility measures of *Range* over the nineteen trading days for each of the two months for every individual stock and each time interval. We then calculate, for the stocks in each of the two months, the cross-sectional median of the stocks' mean volatility values for each interval. Intervals 1 to 390 correspond to the 390 minutes between 9:30-16:00.

Panel A. Median *Range* for February 2004



Panel B. Median *Range* for February 2005

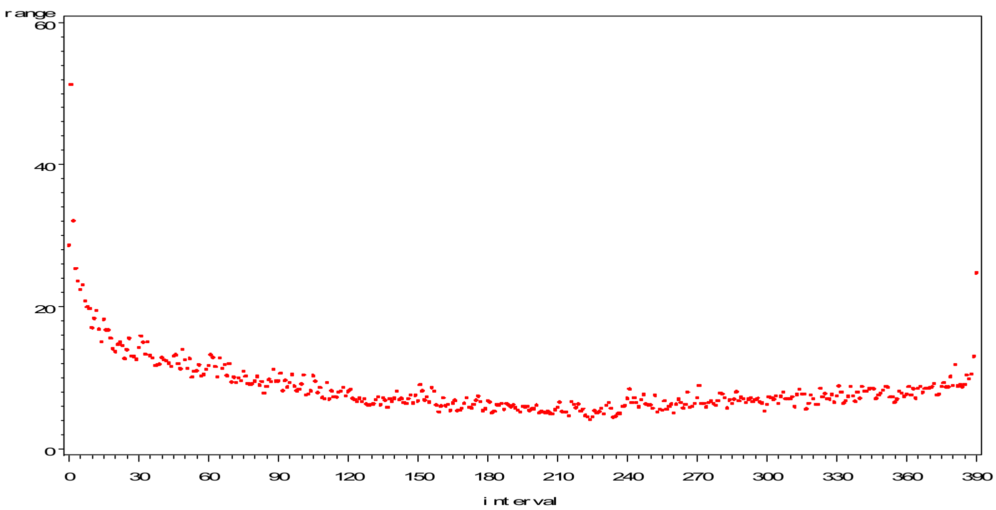


Figure 2. 10-second interval volatility for the opening and the closing minutes

The figure presents the median *Range* across the Nasdaq stocks for ten-second intervals during February 2004 (Panel A) and February 2005 (Panel B), respectively. *Range*, measured in basis points, is the difference between the highest and the lowest prices, relative to the average price during the interval. We calculate the mean volatility measures of *Range* over the nineteen trading days for each of the two months for every individual stock and each time interval. We then calculate, for the stocks in each of the two months, the cross-sectional median of the stocks' mean volatility values for each interval. Intervals 1 to 30 correspond to the thirty 10-second intervals between 9:30-9:35. Intervals 31 to 60 correspond to the thirty 10-second intervals between 15:55-16:00.

Panel A. Median *Range* for February 2004

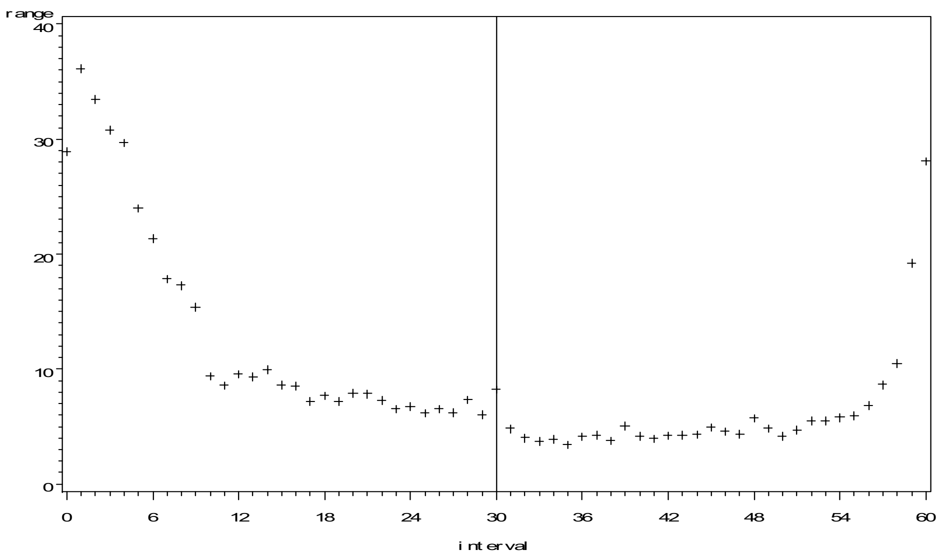


Figure 2. Panel B. Median *Range* for February 2005

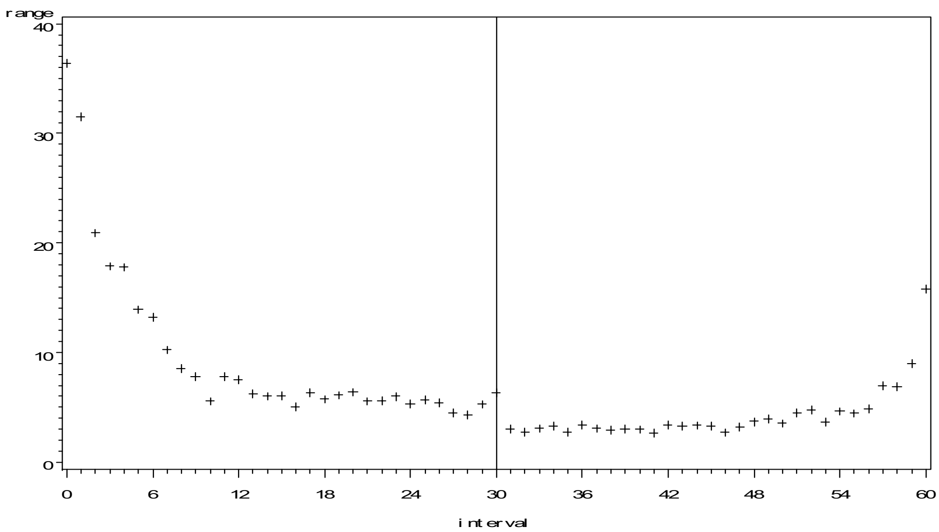
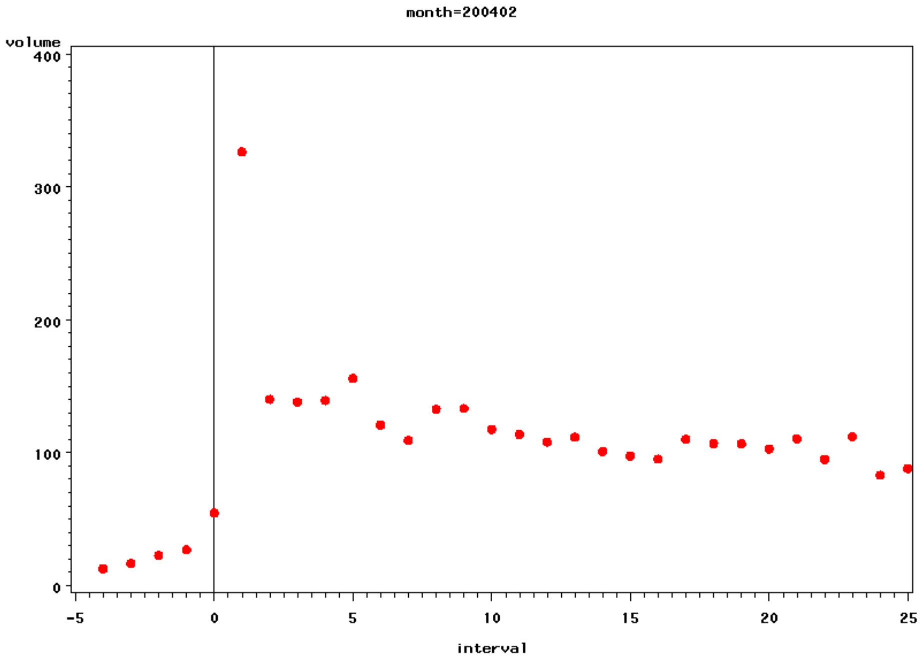


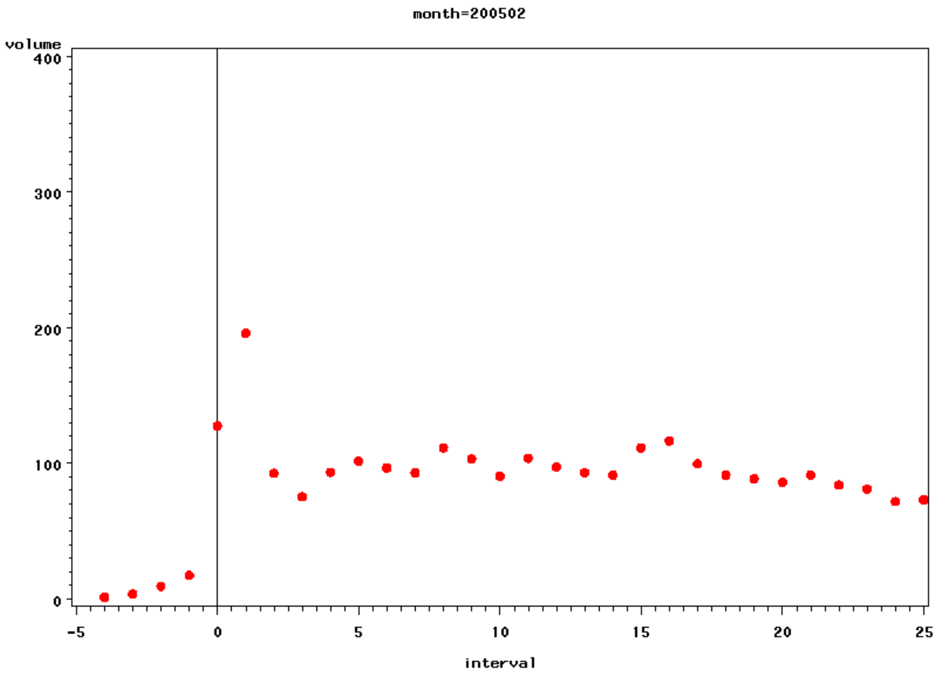
Figure 3. 1-minute interval volume

The figure presents the median *Volume* (in 100 shares) across the Nasdaq stocks for one minute intervals during the opening periods and closing periods for February 2004 and February 2005. Panel A and B shows the opening periods' volume for 2004 and 2005. Panel C and D shows the closing periods' volume for 2004 and 2005. *Volume* is the number of shares traded during each time interval. We calculate the mean of *Volume* over the nineteen trading days for each of the two months for every individual stock and each time interval. We then calculate, for the stocks in each of the two months, the cross-sectional median of the stocks' mean volatility values for each interval. Intervals -4 to 25 correspond to the 30 minutes between 9:26-9:56. Interval 0 corresponds to the minute between 9:30-9:31, during which the opening cross occurred. Intervals 365 to 395 correspond to the 30 minutes between 15:35-16:05. Interval 390 corresponds to the minute between 16:00-16:01, during which the closing cross occurred.

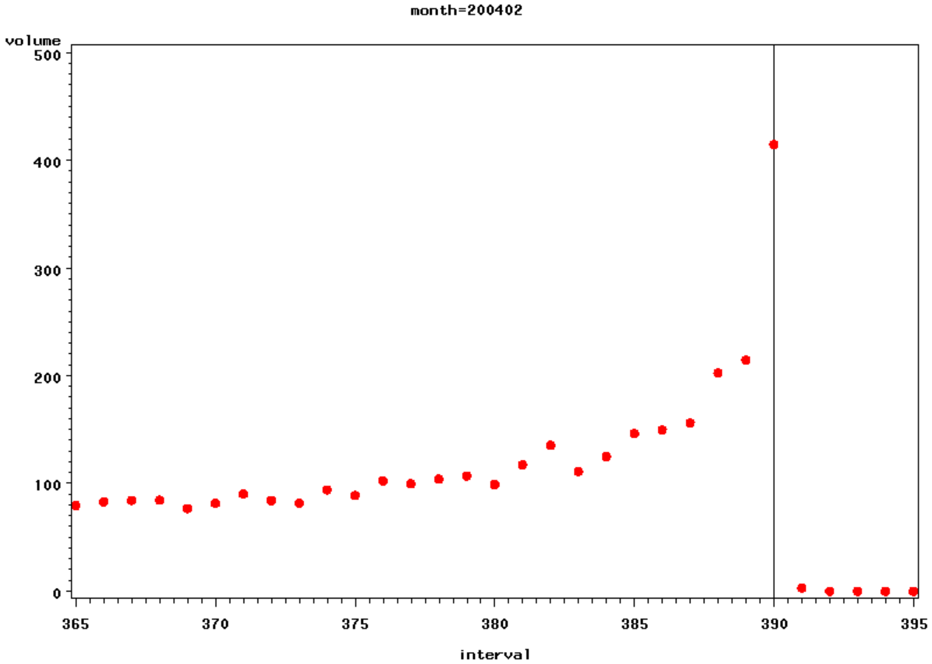
Panel A. Median Opening *Volume* for February 2004



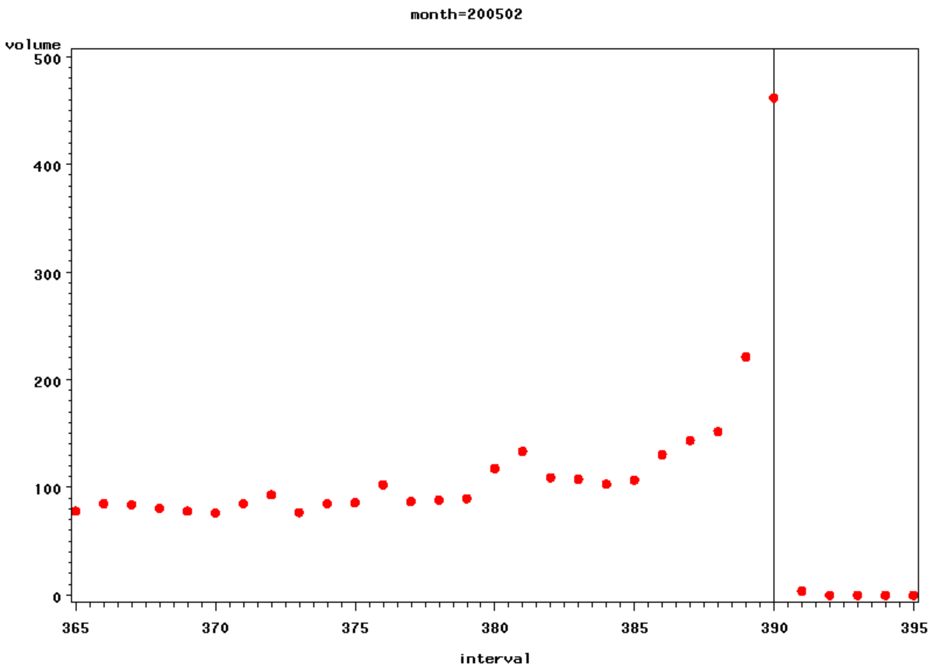
Panel B. Median Opening *Volume* for February 2005



Panel C. Median Closing *Volume* for February 2004



Panel D. Median Closing *Volume* for February 2005



Appendix 1. Ticker Symbols for Stocks used in the Analysis

Nasdaq Firms			
MSFT	APOL	TROW	WFMI
INTC	LLTC	SAFC	SIAL
CSCO	GENZ	BPOP	ROST
DELL	SYMC	MCHP	EXPD
AMGN	BBBY	NTLI	PMCS
ORCL	KLAC	CDWC	IVGN
CMCSA	JNPR	SNPS	TLAB
QCOM	NTRS	MEDI	NVDA
EBAY	BRCM	ESRX	FAST
AMAT	BMET	ZION	DLTR
FITB	CHIR	MLNM	LRCX
YHOO	INTU	NVLS	XMSR
NXTL	PCAR	BEAS	UTSI
AMZN	DISH	HBAN	AMKR
IACI	ADBE	NOVL	MRBK
SUNW	ALTR	APCC	PIXR
MXIM	AAPL	CBSS	CTSH
COST	NTAP	CECO	ISIL
VRTS	CTAS	SNDK	CMVT
BIIB	HCBK	VRSN	ATML
XLNX	JDSU	PDCO	CIEN
SBUX	FISV	SSCC	XRAY
PAYX	CINF	MERQ	CTXS
ERTS	AMTD	LVLT	RHAT
GILD	SEBL	QLGC	CELG
SPLS	SANM	FDRY	GNTX

Matched Sample of NYSE Stocks			
C	BEN	RSH	OCR
MWD	T	NI	LIZ
MO	EDS	SSP	SEE
MRK	XRX	ET	HNT
ABT	CB	EOG	DYN
TWX	DG	LM	FL
DIS	LU	ODP	IRF
WYE	AGN	ROK	STU
LOW	SLR	SII	CPS
TXN	LTR	MWV	VSH
ALL	HRB	Q	KMX
F	UVN	SFA	CAL
EMC	MON	LSI	MIK
CA	LNC	TMK	AV
COF	JBL	FFH	SCG
GLW	AES	CVC	PLL
BBY	IPG	WEC	BE
STT	THC	FCS	CNP
A	AOC	MXO	PVN
SCH	NFB	TER	OSI
RTN	NSM	DST	ELX
WY	PBG	UIS	TCB
FON	ASD	CVH	DCN
MEL	WMB	JNS	WDC
ADI	VLO	WSM	AVT
TJX	AMD	KG	EAT

Appendix 2.

Nasdaq's Closing Cross Procedure[37]

Nasdaq's Opening and Closing Crosses are, with only minor differences, identically structured. In this Appendix we describe the Closing Cross. For further discussion, see Smith (2006).

Closing Cross includes new order handling, display and price determination procedures; safeguards against unduly large price changes; and three new order types: market-on-close (MOC) orders, limit-on-close (LOC) orders, and imbalance orders (IO). MOC and LOC orders are market and limit orders that can be executed only in Closing Cross. Imbalance orders (which the facility starts accepting at 3:30 pm) are Closing Cross only limit orders that are designed to reduce any buy-sell imbalance that may exist at prices set at the 4:00 pm close of the continuous market. Specifically, an IO sell will execute only if it is priced at or above the 4:00 pm Nasdaq offer, and an IO buy will execute only if it is priced at or below the 4:00 pm Nasdaq bid (consequently, IO orders will never trade against each other). Consequently, IO sell orders execute only against buy imbalances that drive price up, IO buy orders execute only against sell imbalances that drive price down, and buy-sell IO orders never execute against each other. IO orders can be entered until the time of the cross (but cannot be cancelled after 3:50 pm); MOC and LOC orders cannot be entered after 3:50 pm.

Between 3:50 pm and 4:00 pm, Nasdaq disseminates information about imbalances, indicative clearing prices, and the number of on-close and IO shares that could be matched at an indicative clearing price. At 4:00 pm, no further orders are accepted, and the clearing prices are determined. An algorithm is used to determine the clearing prices and the specific orders that trade. Maximization of the number of shares that execute is the first criterion used for setting the call auction's clearing price. Time and price priorities imposed, with MOC orders receiving the highest priority. All executed orders for a stock clear at a single price; executions includes buy orders at the stock's clearing price and higher, and sell orders at the stock's clearing price and lower.

The Nasdaq computer sets the closing price stock-by-stock and reports all orders that execute for a stock as a single print. Generally, the reports are completed within 4 seconds of the 4:00 pm cross, and Nasdaq Official Closing Prices (NOCPs) are disseminated at 4:01:30 pm.

[37] Appendix 2 draws from Pagano and Schwartz (2005).

Appendix 3.
Robustness checks with matched sample of NYSE stocks

We have run additional robustness checks to assess the possibility that our findings of increased market quality at market openings and closings for Nasdaq stocks after the two Nasdaq calls were introduced have reflected, not the impact of the calls, but changes in market conditions and/or potential time trends in the market environment that occurred during our sample period. To this end, we have compared our results for Nasdaq-listed firms with a matched sample of NYSE-listed firms. The findings are discussed in this Appendix.

The daily CRSP return file for 2003 (full year) was used for the matching. Daily returns and trading volumes were used to generate weekly returns based on Wednesday-to-Wednesday closing prices and weekly volume statistics. The Nasdaq companies were then matched to the corresponding NYSE companies based on their market capitalization at the end of 2003 and their weekly return volatility, which is measured one year prior to February 2004. We selected the NYSE firms that minimize the mean squared matching error (defined as the sum of the squared percentage differences in both the stocks' logarithmic market capitalizations and the weekly return volatilities). The matched NYSE firms are listed in Appendix 1.

In Table A3.1, Panels A-C, we display test results using the median values of *Range* and *R_Range* for all observations within the matched NYSE sample. For the opening *1-minute intervals*, some significant increases and decreases in the range and relative range statistics are observed for the NYSE stocks during the period, February 2004-February 2005, but there are no significant changes for the closing 1-minute interval volatility measures. For the *10-second intervals* within the first and the last 20-30 seconds of trading, the volatilities for the NYSE stocks are actually higher in 2005 than in 2004 (Table A3.1, Panel C shows that the range during the last 10 seconds of trading rose from 8.42 bps to 10.56 bps). Overall, however, the 10-second interval volatility estimates during the first and the last five minutes of trading do not exhibit any pattern of significant differences between February 2004 and February 2005. This observation contrasts sharply with the significant pattern of changes observed for the Nasdaq stocks over the same time period.

In Table A3.2, Panels A-C, we display test results using the median volume-related measures (volume and number of trades) for all observations within the matched NYSE sample. NYSE trading volume declined for nearly the entire 9:25-9:40 period for February 2005 compared to February 2004. Strikingly, a significant volume *drop* occurred between 9:29 and 9:30 for the NYSE stocks (see Table A3.2, Panel A).[38] In contrast, Nasdaq's trading volume declined significantly only during the pre-call period (9:25-9:29) and it *jumped* dramatically during the times of the opening and closing calls.

We conclude that the Nasdaq and NYSE matched samples indeed exhibit significantly different behavior. The differences in both intra-day volatility and trading volume patterns shown in Tables A3.1 and A3.2 for the NYSE sample give us confidence that the results for the Nasdaq stocks have not been driven by market-wide factors that affect both NYSE and Nasdaq stocks, but by the introduction of the electronic call auctions that apply to the Nasdaq marketplace.

[38] Volume decreased during the 9:25-9:29 period at both the NYSE and Nasdaq. Thus, it appears that overall volume and trading activity was down during the pre-opening period in February 2005 relative to February 2004 on both exchanges, but the Nasdaq opening cross bucked this trend for the 9:29-9:30 time period. Interestingly, NYSE volume decline continued throughout nearly the entire early morning period of 9:25-9:40, while Nasdaq's decline was concentrated in the pre-opening period. These results are confirmed by both the mean and median results in Tables 9 and A3.2 (and thus are not being influenced by a few outliers).

Table A3.1 Volatility for matched NYSE firms

The table presents the univariate comparisons of the median volatility measures, *Range* and *R_range,* during the one-minute interval for the matched NYSE stocks during February 2004 (before) and February 2005 (after), respectively. *Range*, measured in basis points, is the difference between the highest and the lowest prices, relative to the average price during the interval. *R_Range* is the ratio of *Range* for the opening (or closing) intervals to the mid-day range, which is the average *Range* over one-minute intervals between 10:30-15:00 for the same stock on the same day. Significance levels are computed for the difference (before-after) in mean (medians) using a t-test and Wilcoxon two-sided t-test. The 10%, 5%, and 1% levels is indicated by *, **, and *** respectively. Panel A presents the one-minute volatility measures for the opening and the closing minutes. Panels B and C summarizes the ten-second volatility measures for the opening and the closing minutes, respectively.

Panel A. 1-minute interval median volatility

Range (bps)				*R_Range*		
Interval	Before	After		before	after	
9:31	4.59	110.92	***	0.47	7.67	***
9:32	13.23	11.39		1.427	1.307	
9:33	18.45	13.64	*	2.086	1.492	*
9:34	14.5	16.2		1.9	1.618	*
9:35	20.16	13.97	***	1.917	1.599	
9:36	25.37	13.77	***	1.84	1.505	**
9:37	15.55	16.93		1.659	1.739	
9:38	22.36	14.82	***	2.017	1.498	***
9:39	15.71	14.73	**	1.694	1.623	*
9:40	24.27	15.49	***	2.09	1.498	***
15:51	6.1	7.8		0.631	0.842	**
15:52	6.59	6.31		0.629	0.748	
15:53	6.88	6.79		0.711	0.785	
15:54	6.32	5.47		0.716	0.772	
15:55	6.45	6.94		0.742	0.794	
15:56	7.54	7.22		0.793	0.937	
15:57	7.29	7.35		0.863	0.845	
15:58	7.44	7.56		0.827	0.829	
15:59	7.7	8.47		0.849	1.067	
16:00	7.61	8.82		0.83	1.113	

Table A3.1 Panel B. 10-second interval median volatility for the opening minutes

	Range (bps)			*R_Range*		
Interval	before	after		before	after	
9:30:10	0	0.04	***	0	0.002	***
9:30:20	0	0.24	***	0	0.016	***
9:30:30	0.01	0.15	**	0.001	0.006	**
9:30:40	0.04	0.33		0.002	0.021	*
9:30:50	0.06	0.45	*	0.005	0.033	**
9:31:00	0.09	0.86	*	0.008	0.045	**
9:31:10	0.07	0.61	*	0.007	0.028	
9:31:20	0.14	0.68	**	0.005	0.041	**
9:31:30	0.23	0.69		0.016	0.064	
9:31:40	0.1	0.64	*	0.001	0.042	
9:31:50	0.47	0.59		0.017	0.06	
9:32:00	0.25	0.78	**	0.002	0.057	**
9:32:10	0.53	1.02		0.036	0.097	
9:32:20	0.59	0.98		0.042	0.057	
9:32:30	0.38	0.77		0.015	0.049	
9:32:40	0.41	1.26	*	0.05	0.086	
9:32:50	0.46	0.96		0.028	0.117	
9:33:00	0.3	1.08		0.018	0.098	
9:33:10	0.63	1.52	*	0.032	0.106	
9:33:20	0.38	0.81	*	0.029	0.074	
9:33:30	1.1	0.97		0.091	0.11	
9:33:40	0.8	1.00		0.049	0.102	
9:33:50	0.57	0.88		0.044	0.069	
9:34:00	0.73	1.09		0.031	0.092	
9:34:10	0.92	1.19		0.055	0.084	
9:34:20	0.94	1.02		0.068	0.083	
9:34:30	0.85	1.14		0.09	0.087	
9:34:40	0.77	1.09		0.083	0.109	
9:34:50	0.69	0.82		0.054	0.078	
9:35:00	0.61	0.93		0.056	0.102	

Table A3.1 Panel C. 10-second interval median volatility for the closing minutes

	Range (bps)			*R_Range*		
Interval	before	after		before	after	
15:55:10	4.37	11.45		0.358	0.42	
15:55:20	2.08	8.61	**	0.243	0.552	***
15:55:30	2.83	5.43		0.312	0.525	*
15:55:40	1.78	10.36	***	0.212	1.044	***
15:55:50	2.83	3.76	*	0.283	0.32	*
15:56:00	2.27	2.79		0.236	0.246	
15:56:10	2.87	4.64	*	0.329	0.343	
15:56:20	2.68	3.9		0.355	0.371	
15:56:30	2.37	5.02		0.249	0.47	*
15:56:40	2.35	3.82		0.297	0.261	
15:56:50	2.81	4.67		0.312	0.37	
15:57:00	4.69	3.45		0.286	0.307	
15:57:10	2.65	3.6		0.28	0.26	
15:57:20	2.83	4.87	*	0.28	0.341	
15:57:30	2.78	3.99	*	0.315	0.359	
15:57:40	4.47	4.28		0.453	0.334	
15:57:50	2.4	6		0.255	0.389	
15:58:00	2.1	3.34		0.304	0.314	
15:58:10	3.28	3.25		0.272	0.22	
15:58:20	1.97	4.83	*	0.326	0.393	**
15:58:30	5.05	3.36		0.364	0.298	
15:58:40	21.08	3.6		0.407	0.31	
15:58:50	3.03	3.63		0.403	0.32	
15:59:00	3.65	3.13		0.291	0.322	
15:59:10	3.87	5.28		0.322	0.496	
15:59:20	6.1	2.81		0.492	0.261	
15:59:30	3.67	4.57		0.364	0.363	
15:59:40	2.86	3.74		0.306	0.386	
15:59:50	3.02	6.5	**	0.264	0.476	**
16:00:00	8.42	10.56	*	0.874	1.129	**

Table A3.2 Trading Activity for matched NYSE firms

The table presents the univariate comparisons of the median volume-related measures, *Volume* and *Numtrades,* during the one-minute interval for the full sample of matched NYSE stocks during February 2004 (before) and February 2005 (after), respectively. *Volume* is the number of shares traded during each time interval. *Numtrades* is the number of trades executed during each time interval. Significance levels are computed for the percentage difference (before-after) in mean (medians) using a t-test and Wilcoxon two-sided t-test. The 10%, 5%, and 1% levels is indicated by *, **, and *** respectively. Panel A presents the one-minute volume-related measures for the opening and the closing minutes. Panels B and C summarizes the ten-second volume-related measures for the opening and the closing minutes, respectively.

Panel A. 1-minute interval median values

Volume (shares)				*Numtrades*		
interval	Before	after		Before	after	
9:26	17384	9005.9	***	7.25	4.2	**
9:27	18343.7	9036.6	***	7.6	4.2	**
9:28	18128.6	10154.1	***	7.66	4.23	**
9:29	17623.8	10043.7	***	7.56	4.54	**
9:30	17889.5	10081.4	***	7.63	4.69	**
9:31	20675.8	10166.2	**	7.8	4.47	***
9:32	17235.8	11155	**	7.92	6.35	
9:33	13171.4	8996.7	*	7.97	6.16	*
9:34	11250.9	6915.7	**	6.63	6.07	
9:35	9220.7	6381.1	**	5.49	5.25	
9:36	6844.1	5865.5		5.39	5.89	
9:37	6896	4545	*	5.37	5.54	
9:38	5501	5514.4		5.02	5.86	
9:39	5295	4720.5		5.26	5.95	
9:40	5018.3	4316.9		5.09	5.72	
15:51	6119	6227		6.08	7.07	*
15:52	6084.6	6554		5.89	6.69	*
15:53	7362.5	7068.1		6	7.36	*
15:54	6075.4	6574.5		6.46	7.02	
15:55	7032.4	6137.9		6.58	7.15	
15:56	6714.6	7753.3		6.46	8.15	**
15:57	7637.4	8299.2		6.65	7.69	*
15:58	8801.8	8255.4		7.16	7.72	
15:59	9726.2	10691.8		6.68	8.51	**
16:00	9323.9	11845.8		6.77	10.18	***
16:01	5870.1	6431.1		1.18	1.11	
16:02	16331.5	17708.3		1.57	1.51	
16:03	12210.7	11057.5		1.07	1.08	
16:04	8568.9	6479.3		0.76	0.66	
16:05	6077.7	4295.4		0.56	0.43	

Table A3.2 Panel B. 10-second interval median values for the opening minutes

	Volume (shares)			*Numtrades*		
Interval	before	After		before	after	
9:30:10	16985.3	17937.4		4.8	4.15	
9:30:20	17160.2	16805.4		4.8	3.92	
9:30:30	15618.9	13614.6		4.56	3.74	*
9:30:40	13982.2	13116.4		4.8	3.35	*
9:30:50	13734.4	10057.3		4.55	3.43	
9:31:00	13050.3	10176.4		4.38	3.29	
9:31:10	12868.9	8988.9		3.87	3.09	
9:31:20	10985.1	8005.9	*	3.65	3.02	
9:31:30	9662.6	6615.6	**	3.31	2.83	
9:31:40	10171.8	5928.5	***	3.29	2.71	
9:31:50	8969.2	5487.8	**	3.35	2.81	
9:32:00	7595.5	5295.3	*	3	2.76	
9:32:10	7401.4	5377.6	*	2.66	2.78	
9:32:20	6954.6	4693.6		2.71	2.59	
9:32:30	5929.9	4678.2	*	2.65	2.45	
9:32:40	5560.3	4292.5		2.53	2.26	
9:32:50	5083.3	3536.1	**	2.44	2.33	
9:33:00	4943.7	3326.7	**	2.36	2.13	
9:33:10	4335.5	3037.7	*	2.39	2.27	
9:33:20	3991.5	2949.6	*	2.34	2.15	
9:33:30	3426.5	2832.6		2.14	2.21	
9:33:40	3218.8	2175.7		2.07	2.02	
9:33:50	2629.9	2072		1.94	2.05	
9:34:00	2286.6	2173		1.78	1.87	
9:34:10	2023.2	1923.1		1.81	1.89	
9:34:20	2010.2	1822.2		1.75	1.78	
9:34:30	1644.2	1902.9		1.68	1.91	
9:34:40	1551.1	1769.9		1.55	1.84	*
9:34:50	1160.1	1683.6		1.5	1.77	
9:35:00	1264.5	1351.6		1.56	1.76	*

Table A3.2 Panel C. 10-second interval median values for the closing minutes

	Volume (shares)			Numtrades		
Interval	Before	after		Before	after	
15:55:10	1050.8	1600.2		1.28	1.64	*
15:55:20	1346.2	1307.9		1.27	1.43	
15:55:30	1242.2	1209.1		1.25	1.4	
15:55:40	1294.3	1534		1.21	1.44	**
15:55:50	1232.9	1118		1.16	1.27	
15:56:00	1079.2	1285.4		1.25	1.46	
15:56:10	1296	1620.9		1.28	1.42	
15:56:20	1357.2	1483.7		1.16	1.33	
15:56:30	1321.7	1230.6		1.25	1.18	
15:56:40	1664	1625.8		1.35	1.38	
15:56:50	1486.1	1379.2		1.32	1.23	
15:57:00	1297.2	1132.5		1.18	1.34	
15:57:10	1525.6	1273.9		1.3	1.35	
15:57:20	1561.9	1287.2		1.29	1.46	*
15:57:30	1712.7	1284.3		1.28	1.44	
15:57:40	1732.1	1378.7		1.4	1.33	
15:57:50	1739	1580.3		1.4	1.24	*
15:58:00	1447.6	1510.7		1.41	1.32	
15:58:10	1618.6	2062.5		1.52	1.51	
15:58:20	1644.9	2033.2		1.35	1.47	
15:58:30	1631.6	2031.1		1.06	1.44	
15:58:40	1862.6	1751.5		1.21	1.42	
15:58:50	1727.4	1728.4		1.21	1.44	*
15:59:00	1752.3	1965.3		1.28	1.54	***
15:59:10	1817.5	2229.2		1.24	1.73	***
15:59:20	1843.7	2063.5		1.27	1.63	***
15:59:30	2020.7	2728.9		1.31	1.69	***
15:59:40	2916.5	3145.3		1.48	1.74	
15:59:50	6000.8	4623.6	**	1.86	1.82	
16:00:00	33301.1	34548.7		4.19	4.63	*

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