News, Trading, and Stock Return Volatility

Vladimir Zdorovtsov*

State Street Global Advisors

ABSTRACT

Existing literature finds that equity return variances over trading periods substantially exceed those over nontrading periods and suggests three potential explanations for the effect: (1) more public information reaches the marketplace during normal business hours; (2) the trading activity of informed investors reveals their private information inducing greater return variance; (3) the process of trading itself introduces noise into stock prices and returns as investors overreact to each other's trades. I offer the first direct test of the public information, private information, and noise hypotheses utilizing data on order flow in the after-hours, pre-market, and regular trading sessions along with a unique extensive dataset of the contemporaneous public information flow for a large sample of Nasdaq securities. Consistent with the findings of prior literature, I show evidence in favor of the private information hypothesis. Contrary to the existing studies, however, my results also support the public information hypothesis.

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* Advanced Research Center, State Street Financial Center, One Lincoln St., Boston, MA 02111; Phone (617) 664-9601; Fax: (617) 664-6133; E-Mail: Volodymyr_Zdorovtsov@ssga.com. The views and opinions expressed do not represent State Street Global Advisors.

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ABSTRACT

Existing literature finds that equity return variances over trading periods substantially exceed those over nontrading periods and suggests three potential explanations for the effect: (1) more public information reaches the marketplace during normal business hours; (2) the trading activity of informed investors reveals their private information inducing greater return variance; (3) the process of trading itself introduces noise into stock prices and returns as investors overreact to each other's trades. I offer the first direct test of the public information, private information, and noise hypotheses utilizing data on order flow in the after-hours, pre-market, and regular trading sessions along with a unique extensive dataset of the contemporaneous public information flow for a large sample of Nasdaq securities. Consistent with the findings of prior literature, I show evidence in favor of the private information hypothesis. Contrary to the existing studies, however, my results also support the public information hypothesis.

I. Introduction

Numerous studies find that the return variances over periods when the exchanges are open significantly exceed those over periods when the exchanges are closed (e.g. Fama (1965), Granger and Morgenstern (1970), Oldfield and Rogalski (1980), Christie (1981), French and Roll (1986), Barclay, Litzenberger, and Warner (1990), Stoll and Whaley (1990)). Three potential explanations for the phenomenon have been offered in the literature: (1) more public information reaches the marketplace during normal business hours; (2) the trading activity of informed investors reveals their private information inducing greater return variance; "If the informed investors are more likely to trade when the exchanges are open, return variances will be high during this period" (French and Roll (1986), p. 6); (3) the process of trading itself introduces noise into stock prices and returns as investors overreact to others' trades leading to more volatile returns over trading periods.[1]

The literature generally concludes that although there is some evidence of noise-induced trading return volatility (e.g. French and Roll (1986) offer an estimate of 4% to 12% of the daily return variance), the bulk of the difference between variances of trading and nontrading windows is attributable to the trading of informed market participants.

I show that the natural experiment approach utilized in the extant studies to control for public information may not be appropriate to the extent that information arrival itself is a function of trading. I provide a more direct empirical test of the competing hypotheses by analyzing the volatility of close-to-open and open-to-close returns for Nasdaq securities with and without active extended-hours trading, while jointly and explicitly controlling for the firm-specific contemporaneous public information flow. My methodology disentangles

[1] For analyses of the effects of noise on return behavior, see Shiller (1981) and Black (1986).

the effects of noise, public information, and private information on stock return volatility. I also contribute to the burgeoning literature analyzing trading activity and return characteristics in the quickly growing extended-hours market. Lastly, I extend the literature linking seasonalities in security returns and public information.

By comparing the variances over multi-day windows spanning days when the exchanges are closed, with the magnitudes of single-day close-to-close variances, existing studies make inferences about the volatilities over trading and nontrading periods. For example, French and Roll (1986) investigate return behavior around weekends and business days when the NYSE and AMEX were closed. Barclay, Litzenberger, and Warner (1990) examine returns on weeks when the Tokyo Stock Exchange was open on Saturdays. By assuming that the characteristics of the flow of public information on a business day when the exchanges are closed or on a Saturday when they are open are similar to those of a typical business day or typical Saturday, respectively, the authors make inferences about the impact of public information flow on return variances. However, an inevitable assumption in these studies is that the incidence of news releases is not a function of the trading activity. While seemingly innocuous, one can offer several likely scenarios of how this conjecture might be violated. For example, a number of theoretical and empirical studies indicate that corporations strategically time information releases conditional upon the presence of trading, as opposed to merely based on the business hours cycle.[2] By obtaining a comprehensive measure of firm-specific time-stamped information releases over the concurrent time window, I am able to control

[2] E.g. see Patell and Wolfson (1982), Gennotte and Trueman (1996), Baginski, Hassell, and Pagach (1996), Bushee, Matsumoto, and Miller (2002), Libby, Mathieu, and Robb (2002).

directly for the effects of public information flow in a disaggregated fashion, and for the possible information engodeneity issues, avoiding such potentially biasing assumptions.

The literature on return volatility largely ignores trades that take place outside regular trading hours (currently 9:30 a.m. to 4 p.m. Eastern time.) Yet, a number of studies suggest that trading activity in extended hours, while typically low in volume, is dominated by informed participants (e.g. Barclay and Hendershott (2001), Chan (2002)). Thus, I posit that stocks with more active extended-hours trading will, ceteris paribus, have greater overnight return variances. Furthermore, if after-hours and pre-market trading convey private information, a shift in the timing of price discovery will occur, reducing the volatility of the subsequent open-to-close returns.[3, 4] Alternatively, if trading only introduces additional noise, an increase in extended-hours volume will lead to greater overnight volatility and will not affect that of the subsequent regular trading session.[5] Figure 1 illustrates the expected variance effects for the private information and noise hypotheses.

A growing literature analyzes stock returns and the characteristics of the trading processes outside regular trading session hours.[6] I add to this literature by examining the extended-hours behavior of stock returns, volumes, volatilities, and their relation to the

[3] Although the terms "after-hours" and "extended-hours" are sometimes used interchangeably, formally, the extended-hours window encompasses all transactions outside of the regular 9:30 a.m. – 4 p.m. session and can be broken into *"after-hours"* (the period starting at 4 p.m. and generally extending until 8 p.m.) and *"pre-market"* (generally accepted as the 7 a.m. – 9:30 a.m. period.) See http://www.nasdaq.com/reference/glossary.stm, http://www.midnighttrader.com/resource_glossary.html.

[4] Note that Barclay and Hendershott (2001) denote the overall extended-hours session as "after-hours" and divide it into "post-close" (4 p.m. – 6 p.m.), "overnight" (6 p.m. – 7:30 a.m.), and "pre-open" (7:30 a.m. – 9:30 a.m.) Although the time segments do not match precisely, my "after-hours" and "pre-market" intervals are similar to their "post-close", and "pre-open." For consistency, I use my terminology throughout the paper.

[5] Utilizing extended-hours trades also allows me to avoid potential confounding effects of the home bias inevitably present in the analyses of internationally listed securities.

[6] E.g., Barclay and Hendershott (2001) focus on the US equity markets, Domowitz and El-Gamal (1999) and Coppejans and Domowitz (1999) study extended-hours Globex session for the S&P 500 and currency contracts.

concurrent firm-specific public information flow for a large sample of Nasdaq securities and over a relatively long time horizon.

A large number of studies relate stock returns, volatilities, and volumes to measures of public information flow.[7] While strong relations have been generally established between the flow of public information and trading volume, the link between information and volatility is found to be relatively weak. I contribute an investigation of the relation between a considerably more comprehensive measure of firm-specific news and the concurrent trading volume and volatility, including over the heretofore-unexamined extended-hours period.

I find that the effects of after-hours and pre-market trading on return volatility are markedly different. The less-informed order flow in after-hours sessions is associated with little price impact and appears to be greatest on low information asymmetry days. The volatilities of close-to-open and open-to-close returns are negatively related to after-hours volume and the volatility ratio is unaffected by such volume.

Conversely, higher trading volume in the pre-market session, typically composed predominantly of anonymous information-based trades, is associated with greater overnight and lower subsequent regular session volatility, indicating that price discovery shifts toward the pre-market hours. Consequently, the volatility ratios decrease in pre-market trading volume.

Unlike the existing studies, I offer evidence in support of the public information hypothesis. Greater flow of public information over trading (nontrading) hours increases

[7] E.g. see Penman (1987), Roll (1988), Cutler, Poterba, and Summers (1989), Haugen, Talmor and Torous (1991), Mitchell and Mulherin (1994), Ederington and Lee (1993), and Berry and Howe (1994).

the open-to-close (close-to-open) return volatility and the ratio of return volatilities is directly related to the news flow differential.

The rest of the paper is organized as follows: Section II offers an overview of the existing literature and the development of hypotheses; Section III presents the data and methodology; Section IV contains the empirical results and Section V concludes.

II. Literature review and hypothesis development

A. Variance ratios, information flow and trading noise

A number of studies find that stock returns are more volatile over exchange trading hours than they are over nontrading periods. French and Roll (1986) analyze equity return behavior around business days when NYSE and AMEX were closed. The authors assume that the flow of public information is not affected by exchange closures but is rather a by-product of the business hours activities. Since private information is conveyed through trading of the informed investors and assuming this trading occurs only during the regular trading session hours, French and Roll (1986) conclude that although up to 12 percent of daily variances is caused by trading noise, it is the trading of the informed investors that leads to the bulk of variance differences. Similarly, Barclay, Litzenberger, and Warner (1990) investigate equity returns during the period when the Tokyo Stock Exchange (TSE) was open on Saturdays. The authors assume that by analyzing weeks with and without Saturday trading, the effects of the flow of public information are held constant. Their analysis shows that during weeks with Saturday trading, weekend variance almost doubles, weekly volume goes up, but weekly variance is unaffected. The higher weekend variance is found to be offset by lower variances on subsequent days as informed traders accelerate their trading. Barclay et al. (1990) conclude that the results are inconsistent with public

information or noise hypotheses and support the rational trading models based on private information.[8]

The existing studies lack a direct test of the effects of public information. While indeed some public information may be merely a by-product of business activities and its arrival would thus largely coincide with the timing of the exchange operations, other research shows that the news release policy frequently contains an element of strategic timing, one of the critical parameters of which is the presence or absence of trading.[9] For example, Baginski, Hassell, and Pagach (1996) find that, consistent with voluntary disclosure predictions of Diamond (1985) and King, Pownall and Waymire (1990), management strategically releases larger earnings surprises outside of the regular trading session hours. Similarly, Gennotte and Trueman (1996) suggest that management will prefer to issue negative information in extended hours and positive news during normal trading hours. Furthermore, the good news will tend to be released in a sequence of separate announcements whereas the negative news will be made public simultaneously. Consistent with these predictions, Patell and Wolfson (1982) and Francis, Pagach, and Stephan (1992) demonstrate that negative announcements tend to cluster outside of the normal exchange trading hours. Libby, Mathieu, and Robb (2002) and Juergens (1999) present evidence of overnight news releases being more significant.[10] Bushee, Matsumoto, and Miller (2002) show that, subsequent to the Regulation Fair Disclosure requiring equal investor access to material information, firms tend to host their conference calls in extended hours to discourage trading by the less sophisticated investors during the calls and

[8] See also Fama (1965), Granger and Morgenstern (1970), Oldfield and Rogalski (1980), Christie (1981), and Stoll and Whaley (1990).

[9] Note also while business hours vary with time zones, trading hours do not.

[10] Interestingly, this element of strategic timing appears to apply even to macroeconomic news. E.g. Ederington and Lee (1993) show that the most influential macroeconomic news releases are made around 8:30 a.m., well ahead of the regular trading session's opening bell.

thereby lower the excess volatility it induces. Lastly, the Securities and Exchange Commission appears to exhibit a preference that firms make corporate announcements during periods without an available trading venue.[11]

To the extent that the arrival of firm-specific information releases is potentially conditional on the presence of trading, the natural experiment approach of earlier studies may not be valid. It is critical to control directly for the flow of contemporaneous firm-specific news in testing the effects of public information on equity return variances.

In a related branch of literature, several studies examine the link between stock returns, their volatility, and the flow of public information (e.g. Berry and Howe (1994), Cutler, Poterba, and Summers (1989), Ederington and Lee (1993), Haugen, Talmor and Torous (1991), Penman (1987), Roll (1988), and Schwert (1981)). Most analyses employ aggregate measures of public information and aggregate stock return metrics and find only weak relations. Mitchell and Mulherin (1994) note that since most of the information is firm-specific, the relation is obscured by the aggregation process. They devise a measure of firm-specific returns and present evidence that it is significantly correlated with public information flow.[12]

Given this evidence, I posit that extended-hours and regular session return volatility will be increasing in the volume of public information releases over the respective time periods.

B. Evidence of informed trading in extended hours

Rational trading models (e.g. Kyle (1985) and Admati and Pfleiderer (1988)), predict that it is optimal for traders with private information to trade when the liquidity

[11] Special Study: Electronic Communication Networks and After-Hours Trading. Division of Market Regulation , June 2000. See http://www.sec.gov/news/studies/ecnafter.htm

[12] For a rational expectations models tying exogenous information shocks to trading volume and price volatility, see He and Wang (1995).

traders are most active. However, such models assume that the informed agents have a sufficiently low information decay rate. In many instances, the informational advantage is short-lived. The preponderance of traders participating in the extended-hours sessions plausibly either have or believe they have such a short-lived advantage. Indeed, given significantly greater extended-hours transactions costs, agents with long-lived information would likely delay their trades until the more liquid regular sessions.

Barclay and Hendershott (2001) provide the first and thus far only systematic empirical investigation of the extended-hours trading in US equities. They present compelling evidence that such trades are substantially more informative and lead to significant price discovery, despite considerably higher spreads and generally low extended-hours volume.[13] The average trade size is two to three times larger, due to lack of retail orders outside of the regular session.[14] A related study (SEC (2000)) finds that although the extended-hours session is more a "market of stocks" than a "stock market",

[13] Barclay and Hendershott (2001) find that the spreads in extended-hours are more than two times larger than those during the regular session. It should be mentioned, however, that this estimate is likely downward biased. To arrive at it, the authors have to assume that the asymmetric component of the spread is not different from the regular trading session. In light of the evidence of a higher proportion of information-based trading in extended hours and on anonymous electronic trading systems in general, this assumption is likely violated (e.g. see Theissen (2002), Huang (2000), and Barclay, Hendershott, and McCormick (2001, 2002)). For evidence of substantially higher spreads and lower volume in the FTSE-100 futures contract automated trading pit, see Henker (1998).

[14] Until fairly recently, extended-hours trading was available almost exclusively only to institutional and professional traders. Although the advent and expansion of electronic communication networks (ECNs) has enabled individual investors to place anonymous orders eligible for execution in extended hours, the existing empirical and anecdotal evidence suggests their activities outside of the regular session hours remain immaterial. *"After-hours trading can be a risky environment that is ill suited to many investors. To a large extent the after-hours market place is a news driven market… depending on your brokerage firm and how they have implemented their after-hours trading session, the market centers that your orders can interact with may not include all possible execution venues. As a result your order may not be executed at the most favorable price available amongst all the market participants… Since large institutions often play a bigger role in moving stock prices up and down in the thinly traded ECN environment, investors can find themselves whipsawed by even more severe price volatility in the after-hours market than is the case during regular exchange hours. In short, the after-hours trading market is no place for amateurs!"* - warns one investment oriented web site (www.investingonline.com). This sentiment is shared by the SEC and the NASD. For example, under the existing NASD rules 2110 and 2210, member firms have an obligation to disclose the material risks of extended-hours trading to their retail customers before permitting customers to engage in this activity. See also SEC. After-Hours Trading: Understanding the Risks. http://www.sec.gov/investor/pubs/afterhours.htm

trading is relatively active for stocks subject to major corporate news announcements issued outside of the regular session hours.

The extant rational trading models suggest that prices will be most informative at times of high trading volume due to the high numbers of privately informed traders. However, although the *absolute* number of informed participants is likely lower in extended-hours trading, their *relative* number is potentially substantially higher, as discretionary transaction-cost-elastic liquidity traders opt to defer their trades until the less costly regular session. The lower proportion of liquidity and retail traders and, consequently, a greater ratio of informed to uninformed participants will result in a more informed order flow.

Barclay and Hendershott (2001) and Chan (2002) show that whereas most order flow in after-hours is relatively uninformed and represents position adjustment and hedging, the pre-market session trading is primarily information-based. Accordingly, the authors find that price discovery in the pre-market window is substantially greater.[15]

Barclay and Hendershott (2001) demonstrate that while volatility per unit of time is generally lower in extended hours than it is during the trading day, volatility *per trade* is higher. The authors conclude that when trading is conducted by the most informed market participants, significant price discovery can occur even on low trading volume.

Spierdijk, Nijman, and Soest (2002) examine the behavior of illiquid stocks in periods of high and low market activity and show that consistent with Easley, Kiefer, O'Hara, Paperman (1996) and Gramming, Schiereck, Theissen (2001), the risk of trading with the informed is greater for illiquid stocks, mainly not because of too many informed

[15] Similarly, Barclay, Hendershott, and McCormick (2001, 2002) develop and empirically confirm a theoretical model that predicts a higher percentage of informed traders on ECNs. They show that although ECN trading volume is lower, it has a substantially greater permanent price impact and explains approximately two thirds more price volatility compared to market-maker trades.

traders, but due to too few uninformed traders. The study points out that for infrequently traded securities, there are periods of very active trading and the information content of trading intensity for illiquid stocks is larger than it is for liquid stocks.

The parallels between these findings and the characteristics of the relatively illiquid extended-hours sessions for otherwise often liquid securities are striking. Aside from the suggested similarities in the mix of information-based and liquidity-based trading, Barclay and Hendershott (2001) show that the extended-hours trading is concentrated on relatively few high volume days. Furthermore, Forster and George (1999) find that for cross-listed stocks, foreign trading facilitates price discovery if there is sufficient trading volume in the foreign market. Thus, I expect that similar to Spierdijk et al. (2002) the trading intensity of the typically illiquid extended-hours session will be more informative compared to that of the regular session.

C. Extended-hours trading and price discovery

Greene and Watts (1996) examine stock price reactions to overnight earnings news and show that the Nasdaq opening price impounds more overnight information compared to that on NYSE. Similarly, Masulis and Shivakumar (1999) find that the price adjustment to overnight seasoned equity offering announcements is significantly faster on Nasdaq than it is on NYSE or AMEX. Cao, Ghysels, and Hatheway (2000) argue that the faster adjustment to overnight information on Nasdaq is a result of the nonbinding quote signaling by Nasdaq market-makers during the pre-market session. Cao et al. (2000) dismiss any trades during this period given their seemingly low number and use crossed and locked quotes as a proxy for the posited signals. The authors find that quotes become locked or crossed in pre-market typically on days with arrival of overnight information. However, as pointed out by Barclay and Hendershott (2001), the number of quote revisions

is close to the number of trades in the pre-market session and the market-makers may prefer to profit from their information anonymously via ECNs rather than give it away through nonbinding quotes. Furthermore, given that ECN quotes are included in the Nasdaq montage along with market-maker quotes (often stale from the previous day's session) since the implementation of new Order-Handling Rules in 1996, locked or crossed quotes can result from limit orders submitted by market-makers though ECNs as they trade on their information. This scenario appears likely in light of the evidence of heavy use of ECNs by market-makers when the latter prefer to remain unidentified. For example, Simaan, Weaver, and Whitcomb (1998) find that market-makers actively utilize ECNs to "lay off" their positions via anonymously posted limit orders.

Bacidore and Lipson (2001) find that the overnight price discovery for Nasdaq securities is much larger than it is for securities listed on the NYSE and that this difference appears to be an increasing function of firm size. They also find that a greater percentage of the daily volume is executed at the open on NYSE compared to Nasdaq. Subsequent to the start of the regular session trading, the morning price discovery on NYSE exceeds that of Nasdaq. It is reasonable to hypothesize that this is attributable to substantially greater volume of extended-hours trading in Nasdaq securities. For example, Barclay and Hendershott (2001) find that such volume accounts for almost four percent of daily trading volume on Nasdaq and for only 0.5 percent on NYSE and that it is positively related to daily volume (and, therefore, firm size). Indeed, Barclay and Hendershott (2001) note that given this difference in extended-hours volume, the studies investigating the speed with which information is incorporated into the opening prices across markets are problematic.

Hong and Wang (2000) develop a theoretical model that shows how the incidence of periodic market closures alone can generate empirical patterns including higher trading

around market open and close and higher volatility over trading periods than over nontrading periods, even assuming constant information flow. Thus, insofar as extended-hours trading diminishes this closure effect, one can expect the disparity in volatilities of returns over close-to-open and open-to-close windows to be smaller for stocks with more active trading outside of the regular session, ceteris paribus. In addition to the above-listed arguments, a number of theoretical studies (e.g. Easley and O'Hara (1992), also see Domowitz and El-Gamal (1999) for a list of examples) link volatility to trading volume. Given the evidence presented above, I conjecture that overnight return variances will increase in extended-hours trading volume.

D. Hypotheses

If return variance is caused by the arrival of public information, then:

Public Information Hypothesis (H1): The close-to-open and open-to-close return volatilities will be positively related to the volumes of public information releases over the respective time periods.

If return variance is caused by trading of informed market participants, the volatility of overnight returns will increase in extended-hours trading volume. Furthermore, if the rise in close-to-open variance is due to the greater amount of private information impounded through such trading, the timing of price discovery will shift and the volatility of open-to-close returns will correspondingly decline. More formally:

Private Information Hypothesis (H2A): The close-to-open (open-to-close) return volatility will be increasing (decreasing) in the extended-hours trading volume.

Alternatively, if trading only induces noise as investors overreact to each other's actions, no such shift in the timing of price discovery will occur. The extended-hours

trading will cause additional overnight return variance and will not affect the open-to-close returns. Thus:

Noise Hypothesis (H2B): The close-to-open (open-to-close) return volatility will be increasing in (independent of) the extended-hours trading volume.

Barclay and Hendershott (2001) and Chan (2002) show that whereas most order flow in after-hours is relatively uninformed and represents position adjustment and hedging, the pre-market session trading is primarily information-based. Consequently, I conjecture that the hypothesized private information and/or noise effects will be especially prominent for pre-market trading volume.

III. Data and methodology

A. Sample selection

I start with all Nasdaq securities covered by the Center for Research in Security Prices (CRSP) during the 2000 – 2001 period. I limit my sample to Nasdaq securities for a number of reasons. Numerous existing studies show that the trading mechanism has significant effects on stock return behavior (e.g. Amihud and Mendelson (1987), Miller (1989), Stoll and Whaley (1990), George and Hwang (1995), Madhavan and Panchapagesan (1998), Bacidore and Lipson (2001)). Thus, by restricting the sample to Nasdaq firms, I avoid the potential confounding effects caused by the institutional and procedural differences. Second, the volume and cross-sectional variation of extended-hours trading in NYSE securities is relatively small. Third, and perhaps most important, the pre-market trades for NYSE securities do not appear in the NYSE Trade and Quote (TAQ) database.

The sample is then restricted to stocks that never trade at prices below five dollars per share during this period, yielding 1,571 securities. I leave out penny stocks due to their extreme percentage price swings in extended-hours (e.g., see SEC (2000)). I further require at least 10 trades on at least 250 days during the two-year window spanning exactly 500 trading days.[16] This screen reduces the sample to 1,094 firms. I am able to locate NYSE TAQ data for 1,001 of these firms. Data on capitalization and SIC affiliation is obtained from CRSP as of the last trading day of 2001. I impose the usual screens for out-of-sequence, nonstandard delivery, and erroneous trade prints and obtain all TAQ transactions for each sample firm-day over the 7:30 a.m. – 7 p.m. window.[17,18]

The average company in the sample has capitalization of approximately $2.35 billion with 86 million shares outstanding. The industry coverage is relatively broad with 248 different 4-digit SIC codes spanned. The average (median) number of firms per industry (as defined by the 4-digit SIC code) is four (one).

To obtain a proxy for public information flow, I use a web crawler to search *CBS.MarketWatch.com* and its 20 news sources for all firm-specific information released over the 2000-2001 window.[19] The list of news providers contains Reuters, BusinessWire, PR Newswire, Market Wire, Edgar Online, CNET News.com, CBS News, Knight Ridder,

[16] In this regard, my selection procedure is similar to that of Stoll and Whaley (1990), who require the NYSE stocks in their sample to always trade above three dollars and to have at least 100 days with trades per year.

[17] I require TAQ correction codes of 1 or 0, condition of Regular Way (Blank or *) or T for extended-hours trades, and trade size and price above zero.

[18] Although formally NYSE TAQ does not include transaction data that is reported outside of the Consolidated Tape hours of operation (8:00 a.m. to 6:30 p.m. EST during the sample period of this study), there are some such trades in the database. Telephone conversations with representatives of the NYSE and the Consolidated Tape Association confirmed that such trades are not erroneous. Trades that take place during the 6:30 p.m. – 8:00 a.m. period can be reported to the CTA but are not disseminated unless reported after 8:00 a.m. Although Barclay and Hendershott (2001) and SEC (2000) find that the overall extended-hours volume outside of the Consolidated Tape hours is inconsequential, these trades are preserved for completeness of analysis.

[19] *CBS.MarketWatch.com* is chosen for two primary reasons: possibility of search automation and breadth of coverage. The setup of *CBS.MarketWatch.com* readily allows for search automation since search parameters can be specified directly in the URL address and can thus be varied within the program.

$ TheStreet.com, RealTime Headlines, TV & Radio, New York Times, FT.com, Market Pulse, United Press Intl., among others, and represents a broad array of coverage sources. Conducting the search electronically allows me to have a substantially larger sample and a much more extensive list of news providers compared to those of prior studies analyzing the effects of public information flow. I download up to the last 100 news releases going back from December 31, 2001. The number of news items per firm is bounded from above at 100 due to search limitations. This constraint is binding for 132 companies.[20] For 949 companies, I am able to locate the ticker in the *CBS.MarketWatch.com* database. For 11 of these companies, not a single news release is located. For the remainder of the sample the search generates 40,694 news items time stamped to the minute.[21] The mean (median) number of news releases per company is 43.38 (33). For five firms I am able to locate only one release.

B. Calculation of variance and information flow ratios

I compute the moments for the following return intervals: close-to-close, close-to-open, and open-to-close. A caveat is in order. Not all stocks in the sample necessarily trade every day when the exchange is open.[22] In computing the moments listed above, I omit the days where the exchange is open but the stock does not trade according to my data. This is done for the following reasons: (1) if private information gets impounded through trading, days with no trades cannot be treated as trading days since no trades could

[20] Admittedly, this proxy for public information flow is imperfect (e.g. I expect some news releases to be stale and/or noninformative). However, these criticisms plague most investigations dealing with news flow data and insofar as they equally apply to releases made during and outside of the regular trading session, no bias is expected for my results. Also note that to the extent that the truncated 100 releases obtained are representative of the full population (within and outside of the normal trading hours), no bias is introduced by this constraint for the 132 firms for which is it binding. The results are not sensitive to exclusion of these firms.

[21] It should be mentioned that because *CBS.MarketWatch.com* news items are available on a subscription-free basis, most of the releases are reported delayed. However, the time stamps are not affected by reporting delays.

[22] All but 266 sample firms trade every day. The results are not sensitive to exclusion of these firms.

have served as mediums for private information revelation - including such days as trading days would bias the results against the private information hypothesis; (2) if trading period returns are more volatile due to trading induced price errors and noise, then, clearly, the periods when the stock does not have a single trade even though the exchange is open cannot be counted as trading periods since no trades could contribute to the noise - including such periods in the analysis as trading days would bias the results against the noise hypothesis; (3) if trading periods are more volatile because more information is being revealed when exchanges are open and to the extent that these are regular trading days with an available trading venue, one can argue that public information is arriving accordingly and, consequently, these periods cannot be considered to be nontrading - doing so would bias the results against the public information hypothesis.

Given the above reasoning, the classification for such windows is at best ambiguous and, therefore, I opt to omit them from the analysis. Instead, nontrading period returns are computed as the change in price from the close of a trading day with executed transactions to the open of the next such adjacent trading day without any trading days with zero trades in between.[23]

The volatility ratio on a per hour basis is calculated as follows:

$$\sigma^2_{RATIO\,j} = \frac{\sigma^2_{OpCl\,j} \Big/ HoursTr_j}{\sigma^2_{ClOp\,j} \Big/ HoursNTr_j} \qquad (1)$$

Where:

$\sigma^2_{OpCl\,j}$ - Time series variance of open-to-close returns for security j;

[23] Arguably, this correction also represents an improvement upon the existing studies, which often used midquote returns for trading periods without trades.

$\sigma^2_{CIOp_j}$ - Time series variance of close-to-open returns for security j;

$\overline{HoursTr_j}$ - Average time length of the open-to-close period in hours for security j;

$\overline{HoursNTr_j}$ - Average time length of the close-to-open period in hours for security j.[24]

To explicitly control for the flow of public information over close-to-open and open-to-close periods, I allocate all news releases into these two groups for each security according to their time-stamps. A news flow ratio is calculated as follows:

$$PerHourNewsRatio_j = \frac{NewsTr_j \Big/ \overline{HoursTr_j}}{NewsNTr_j \Big/ \overline{HoursNTr_j}} \qquad (2)$$

Where:

$NewsTr_j$ - Number of news items released over the open-to-close periods for security j;

$NewsNTr_j$ - Number of news releases made over the close-to-open periods for security j;

$\overline{HoursTr_j}$ and $\overline{HoursNTr_j}$ as defined above.

IV. Empirical analysis

A. Intraday dynamics of trading activity

Table 1 summarizes the information on opening and closing transactions of the regular and extended-hours trading sessions. The average firm starts trading in the regular session at 9:42 a.m. and ends at 3:46 p.m. The average size of the opening and closing trades of the regular session is 429 and 854 shares, respectively. The average opening and

[24] The average lengths of the close-to-open and open-to-close periods are calculated to account for their variation across securities. For example, due to more omitted trading days with no trades for some sample firms, they will have relatively more Friday-close-to-Monday-open nontrading returns. The length of open-to-close windows will vary due to discrepancies in the number of shortened trading days across securities (e.g. due to holidays).

closing times are clearly affected by the less frequently traded and halted outlier firms since the median firm opens and closes within a minute of the regular session time bounds. These results are generally comparable to those of Stoll and Whaley (1990), who report that for NYSE securities in 1986, the average opening delay is 15.48 minutes and that an average stock has the last transaction 19.94 minutes prior to the end of regular trading session.

For the days when a security trades in pre-market (after-hours), the average time of the first (last) such trade is 8:46 a.m. (4:36 p.m.) The mean size of these trades is 3,145 (2,407) shares, substantially higher than the opening (closing) transactions of the regular session.

Table 2 presents the information on per-stock per-day trading volume during and outside of the regular trading session. The mean number of trades and share volume over the regular trading session are 1,477 and 942,764; the mean dollar volume is $41.67 million. An average sample stock trades 10.43 (16.31) times in pre-market (after-hours). The average after-hours volume considerably exceeds that of the pre-market session – 33,468 shares versus 9,801 shares and $1.41 million versus $0.44 million.

Figure 2 presents an intraday distribution of the trading volume across finer time increments. Consistent with prior literature (e.g. Foster and Viswanathan (1993) Harris (1986)), I find evidence of a U-shaped pattern in trading volume during the regular trading session both in dollar terms and in the number of trades. I also confirm the evidence in SEC (2000) and Barclay and Hendershott (2001) that the bulk of extended-hours trading volume occurs around the opening and closing of the regular trading session. Consistent with the latter, I find that after-hours volume substantially exceeds pre-market volume –

while the total extended-hours dollar volume represents 4.24% of the aggregate daily volume, more than three quarters of it is transacted in after-hours.

Panels 1 and 2 of Figure 3 display the dynamics of the mean and median trade size across intraday time increments in number of shares and dollar terms, respectively. Consistent with Barclay and Hendershott (2001), the average trade size in extended hours is significantly higher than that in normal trading hours. Unlike Barclay and Hendershott, I find that the average trade size in the pre-market window starts out at a level comparable to that during the regular session and then dramatically surges during the 8:00 a.m. – 8:30 a.m. interval, far exceeding the levels during the rest of the day. This spike is most likely attributable to the fact that although some ECNs begin operating as early as 7:00 a.m., the majority of brokers offer pre-market trading starting at 8:00 a.m. Thus, this time effectively represents the first opportunity to act on new private or public information for the bulk of traders. Similar to Barclay and Hendershott (2001), I find that the trade size abruptly rises after the end of the regular session and peaks around 5:00 p.m.[25]

B. Analysis of public information flow

Table 3 presents descriptive statistics on the flow of public information. The average number of informational releases per firm is 43.38, out of which 13.84 and 29.54 occur during and outside of the regular session trading hours, respectively. Unlike Berry and Howe (1994), Patell and Wolfson (1982), and Francis, Pagach, and Stephan (1992), I find that in aggregate, there are fewer information releases during trading hours than outside of them – 35% versus 65%. Berry and Howe (1994) document that for the aggregated information flow, the per-hour volume of releases made during normal trading

[25] The trade sizes are also similar to those in SEC (2000), which finds that in the January 18-20, 2000 period, the average trade share size is 735 shares during the regular session, surging to 2,242 shares from 4:00 p.m. to 5 p.m. and declining thereafter as the percentage of smaller ECN-executed orders nearly doubles.

hours exceeds that outside such hours by a factor of three. In my case, using the aggregated procedure of Berry and Howe yields a ratio of only 1.26. The discrepancy appears to indicate a general shift of public information flow toward nontrading hours.

Interestingly, however, the mean (median) per-hour news ratio across firms is considerably higher at 3.04 (1.98), indicating that the aggregated results obscure the effects of less informationally intensive firms. While the overall volume of releases for these companies is low (thus having a minor effect on the aggregated ratio), such firms appear to have relatively more news during trading hours.

As can be seen in Table 4 and Figures 4 - 5, the flow of public information is clearly nonconstant. Consistent with Berry and Howe (1994), I find that out of the trading days, Mondays and Fridays are light information days, especially compared to Tuesdays and Thursdays, and that weekends have substantially fewer news items compared to weekdays.[26]

Patell and Wolfson (1982) find that more earnings announcements are delivered after the close on Friday than on other weekdays. Unlike their result, Table 4 and Figure 4 show that for my more general public information proxy, both the number and the percentage of announcements made after 4 p.m. on Fridays are the smallest of all weekdays. Conversely, the proportion of releases made during the regular trading session hours on Fridays is the highest of all weekdays.

Panels 1 and 2 of Figure 5 graphically illustrate the monthly and weekday seasonalities in public information flow across the two sample years. Berry and Howe (1994) and Mitchell and Mulherin (1994) find that November and December are the

[26] Similarly, Mitchell and Mulherin (1994) show that the volume of weekday announcements increases through Thursday and then falls off sharply on Friday. Nofsinger (2001) and Thompson, Olsen, and Dietrich (1987), however, find that the number of news articles across weekdays is similar but increases on Friday.

lightest information months and May and July are the heaviest. They also show that January, April, July, and October have more information because of the quarterly reports. The results presented in Figure 5, Panel 1 are markedly different. First of all, I find that July, October, November, and December contain the greatest number of releases. More importantly, however, while the number of releases remains relatively stable over the first nine sample months, there appears a clear upward trend in the amount of available public information starting with a spike in October 2000.[27] Interestingly, this coincides with the passage of the Securities and Exchange Commission Regulation Fair Disclosure.

While this evidence is intended as suggestive only, I find that, contrary to the suggestions of the opponents of Regulation FD that the quantity of information reaching the market will decline, companies appear to have substituted public communication channels for private venues and the flow of public information has increased since October 2000.[28]

Berry and Howe (1994) document that on a typical day, information flow (as proxied by Reuter's News Service) begins to substantially increase around 8:30 a.m., continues to build until noon and then shows a "lull." The flow then rises again during the remainder of the trading session and peaks between 4:30 p.m. and 5 p.m. Juergens (1999) shows that the volume of Dow Jones News Wire releases and analyst recommendations for a sample of 208 computer firms exhibits an intraday U-shape.

Figure 6 plots the intraday distribution of the number of news releases in 30-minute increments. Panel 1 examines the flow of information on trading days and shows a pattern generally resembling that found in Berry and Howe (1994) with several key differences.

[27] This result is not sensitive to exclusion of the 132 firms for which the maximum of 100 releases constraint is binding.

[28] This is consistent with the findings of Heflin, Subramanyam, and Zhang (2001), who show that the quantity of firms' voluntary disclosures increased post Regulation FD.

First, the flow of information begins to rise considerably earlier. There is a sharp surge in the number of news items starting at 6:00 a.m. The volume of information continues to climb steeply until the beginning of regular session trading at 9:30 a.m. Information flow begins to abate thereafter, gradually diminishing until the end of regular session trading at 4 p.m. In fact, the number of news items made public within the last 30 minutes of normal trading hours is nearly identical to that made from 6:00 a.m. to 6:30 a.m. (729 versus 731). However, immediately after the end of normal trading hours, the rate of information arrival more than quadruples, peaking at 3,224 releases and declining monotonically until 9:00 p.m. Interestingly, no similar patterns are observed for nontrading days, where the rate of information arrival generally increases with time until midday and declines thereafter (Panel 2). Examining the flow of news announcements on five trading days in my sample when the US exchanges close at 1 p.m. (Panel 3), it becomes clear that the flow of public information is indeed closely linked to exchange operating hours. The sharp increase in news volume that is apparent at 4 p.m. for normal trading days appears to shift to 1 p.m. for trading days when the exchanges close at this hour. The effect is statistically significant at conventional levels.

Several conclusions can be drawn from this evidence. First, compared to the results of the earlier studies, there seems to have been a general shift of information flow away from regular trading hours. More importantly, the pattern of information arrival is clearly tied to the boundaries of the normal exchange trading hours, casting doubt on the assumption that information flow is not a function of trading activity, implicitly used in prior return volatility studies, and further corroborating the need for a direct control for the effects of public information.

C. Univariate variance analysis

Figures 7 and 8 graphically illustrate the effects of the extended-hours dollar volume on the close-to-open, open-to-close, and close-to-close return variances in isolation and on the variance ratios, respectively. As can be seen in both figures, the relations are not monotonic. As the extended-hours dollar volume as a fraction of firm capitalization increases to about the sample median level, there appears to be no effect on the overnight (i.e. close-to-open) return variance. On the other hand, the open-to-close variance steadily increases and, as a result, the close-to-close variance and the per-hour variance ratios go up. Increases in the extended-hours volume beyond the median level lead to greater overnight, open-to-close, and close-to-close variances. The rising overnight volatility more than offsets increasing open-to-close volatility and the variance ratios steeply decline.

These results indicate that, consistent with Barclay et al. (1990) and Forster and George (2002), a significant volume of extended-hours trading needs to exist before overnight variances are affected. A likely explanation for the rising open-to-close volatility is that, since extended-hours volume is strongly correlated with open-to-close volume, increases in the former (while not necessarily sufficient to induce a noticeable effect on the overnight variance) are related to increases in the latter, which, in turn, result in greater open-to-close and close-to-close variances and in higher variance ratios.[29] Thus, it is critical to control for the related effects of regular session volume in analyzing those of the extended-hours volume.

Table 5 summarizes the effects of news flow on return volatility and variance ratios. Several results stand out. Consistent with the public information hypothesis, overnight return volatility for companies with lower per-hour news ratio (i.e. greater flow of news

[29] For analysis linking the open-to-close volatility and the daily volume see Stoll and Whaley (1990).

overnight relative to that during regular session hours) significantly exceeds that of firms with the news ratio above sample median. Open-to-close and close-to-close variances are not affected, and the variance ratios are consequently lower. These results appear independent of the potentially related volume effects, since the pre-market, after-hours, and regular session volumes are not significantly different across the high and low news ratio subsets.

Results of the univariate effects of extended-hours volume are presented in Table 6. The average per-hour volatility ratio is 15.95 and is comparable to those of prior studies (e.g. Oldfield and Rogalski (1980), French and Roll (1986), and Stoll and Whaley (1990) report average ratios of 12.78, 13.20, and 16.20, respectively). Consistent with both the private information and the noise hypotheses, the overnight variance increases in relative extended-hours dollar volume. The open-to-close and close-to-close variances are also higher for firms with greater overnight dollar volume. Although this result appears to be contrary to the predictions of the private information hypothesis, it can be potentially attributable to the fact that companies with greater relative extended-hours volume also generally have greater regular session volume (as is clearly seen in Table 6) and the latter in turn leads to greater open-to-close variances. Furthermore, since the extended-hours volume is composed of the after-hours and the pre-market volume and to the extent that these sessions appear to exhibit markedly different trading processes with regard to the informativeness of the order flow (e.g. see Baclay and Hendershott (2001) and Chan (2002)), one needs to examine their effects separately.

Several additional interesting results are worth noting. First, consistent with Patell and Wolfson (1982) and Francis, Pagach, and Stephan (1992), the skewness of overnight returns is negative and further declines in extended-hours volume, indicating that the

information made public and/or revealed through trading during this window tends to be of a negative nature. Second, stocks with more active extended-hours trading sessions open and close the regular sessions considerably closer to the official 9:30 a.m. – 4 p.m. bounds. This effect is significant at conventional levels and holds after controlling for firm size (not reported). Stoll and Whaley (1990) examine NYSE stocks for years 1982 – 1986 and show that for more (less) actively traded firms a delay at the open leads to greater (lower) overnight volatility. The authors suggest that opening delays for actively traded stocks imply large order imbalances at the open, whereas for less active stocks the delays merely denote absence of orders. In results available upon request, I show that the opening delays are associated with lower overnight variances regardless of firm size. However, it should be noted that overnight trading is largely nonexistent during the sample period analyzed in Stoll and Whaley (1990) and is smaller for NYSE securities compared to that for Nasdaq stocks in general. Consequently, if trading in after-hours and pre-market sessions alleviates potential imbalances at the open and helps establish the new opening price (see e.g. Chan (2002)), then one can argue that stocks with inflows of significant private or public overnight information which would have had large opening imbalances, longer opening delays, and greater overnight variances in years without a relatively active extended-hours market, will now have greater extended-hours volume, greater overnight volatility and shorter opening delays. Yielding additional support to this argument is the fact that the average size of the first regular session trade decreases in extended-hours volume.

Table 7 examines the effects of pre-market, after-hours, and total extended-hours relative volume on variance ratios by regular session volume quintiles. The effects of the pre-market and after-hours volume appear to be different. Within the extended-hours volume, it is the pre-market volume that tends to lead to greater overnight variances and

lower variance ratios. The result is less significant for lower regular volume quintiles and is reversed for the lowest quintile. Again, to the extent that pre-market volume is correlated with regular session volume, this indicates that substantial trading activity needs to exist for the overnight variances to be affected.

D. Regression analysis

The evidence presented above indicates that the effects of private information, public information, and noise need to be analyzed jointly. Also, since open-to-close volatility is linked to open-to-close volume (e.g. see Stoll and Whaley (1990)), and because regular session volume and extended-hours volume are correlated, one needs to control for the effects of the regular session volume in determining those of the extended-hours volume.

I address these concerns within a two-way fixed effects OLS regression framework and estimate the following models:[30]

$$LogAbsClOp_{j,t} = \beta_0 + \beta_1 LAGNewsTr_{j,t} + \beta_2 NewsNTr_{j,t} + \beta_3 LAGRELAH_{j,t} + \beta_4 RELPM_{j,t} + \beta_5 LAGRELREG_{j,t} + v_j + u_t + \varepsilon_{j,t} \quad (3)$$

$$LogAbsOpCl_{j,t} = \beta_0 + \beta_1 NewsTr_{j,t} + \beta_2 NewsNTr_{j,t} + \beta_3 LAGRELAH_{j,t} + \beta_4 RELPM_{j,t} + \beta_5 RELREG_{j,t} + v_j + u_t + \varepsilon_{j,t} \quad (4)$$

$$LogRatio_{j,t} = \beta_0 + \beta_1 LAGRELAH_{j,t} + \beta_2 RELPM_{j,t} + \beta_3 RELREG_{j,t} + \beta_4 NewsDiff_{j,t} + v_j + u_t + \varepsilon_{j,t} \quad (5)$$

Where:

$$LogAbsClOp_{j,t} = Ln\left|\frac{ClOp_{j,t}}{ClOpHours_{j,t}}\right| \quad (6)$$

Similarly, $LogAbsOpCl_{j,t}$ is the natural logarithm of the absolute value of the per-hour

[30] Random effects estimations yield similar results. Fixed effects results are presented based on the Hausman specification test.

open-to-close return; $LogRatio_{j,t}$ is the difference between $LogAbsOpCl_{j,t}$ and $LogAbsClOp_{j,t}$; $NewsTr_{j,t}$ is the number of news releases over regular trading session hours; $NewsNTr_{j,t}$ is the number of news items released between the end of the previous trading day's regular session and the beginning of the current trading day's regular session; $LAGNewsTr_{j,t}$ is the number of news releases over the regular trading hours of the preceding trading day; $LAGRELAH_{j,t}$ is the prior trading day's after-hours dollar volume scaled by capitalization; $RELPM_{j,t}$ and $RELREG_{j,t}$ are the pre-market and regular session dollar volumes scaled by capitalization; $LAGRELREG_{j,t}$ is the prior trading day's regular session dollar volume scaled by capitalization; $NewsDiff_{j,t}$ is the difference between $NewsTr_{j,t}$ and $NewsNTr_{j,t}$;[31] v_j, u_t, and $\varepsilon_{j,t}$ are the error terms; $j \in [1,1001]$ and $t \in [1,499]$ denote the firm and the trading day, respectively.

Table 8 summarizes the results. Several key conclusions emerge. Consistent with prior literature and the results shown earlier, I find that the after-hours and the pre-market trading volume exhibit different effects. Specifically, greater pre-market volume leads to substantially higher (lower) close-to-open (open-to-close) return volatility and to considerably lower volatility ratios. This result is consistent with the private information hypothesis and shows that indeed the pre-market trading volume is largely composed of information-motivated trades. Greater informed trading in the pre-market session shifts price discovery toward the close-to-open period, increasing volatility of the overnight returns, reducing that of the open-to-close returns, and leading to lower volatility ratios.

[31] Given the high frequency of zero news volume, using a ratio leads to a considerable reduction in sample size.

Conversely, the after-hours volume is negatively related to the overnight and open-to-close volatility. This evidence is consistent with the suggestion of Barclay and Hendershott (2001) that large liquidity-motivated after-hours trades are more likely to execute on low information asymmetry days and are associated with little price impact. Unlike the pre-market volume, after-hours volume is not significantly related to volatility ratios.

Contrary to the conclusions of the earlier studies, the evidence on the effects of news flow yields credence to the public information hypothesis. Higher volume of public information released outside regular trading hours leads to higher close-to-open return volatility. Consistent with overnight releases being more significant, there is evidence of a spillover of volatility into the subsequent regular session.[32] Greater volume of public information reaching the market during regular trading hours leads to higher open-to-close volatility. Interestingly, not only is there no spillover of volatility into the subsequent overnight period, the volatility of the latter appears to decline. This indicates that the typically less influential daytime releases are completely priced in during normal trading hours, causing the degree of information asymmetry and price uncertainty to decline. Lending further support to the public information hypothesis is the significant positive relation between the volatility ratio and the news flow differential. In other words, greater flow of public information over trading hours versus nontrading hours is associated with higher ratios of open-to-close to close-to-open volatilities.

A theoretical model developed in Holden and Subrahmanyam (1992) shows that aggressive competition among the informed traders leads to faster revelation of their

[32] Note that this is contrary to the predictions of He and Wang (1995), who develop a rational expectations model predicting that public information has a rather short-lived effect and leads to trading only in the contemporaneous period.

information. Thus, if this competition is greater in extended hours due to a higher proportion of informed agents, trading during this period will impound information into prices faster. This prediction combined with the evidence of prior studies suggesting that the news released overnight tends to be more significant and with the fact that there are fewer short-selling restrictions in extended hours, leads one to expect the link between information and variances to be stronger for overnight return windows.[33] The results in Table 8 are generally consistent with this conjecture. Indeed, while the rate of overnight information arrival is strongly related to overnight return variability, the link is less economically pronounced over open-to-close periods.

One potential criticism of the news flow data is the possible presence of redundant news releases merely reiterating the subject matter of an earlier story from a different (or the same) source. To check the sensitivity of the above results to such non-informative releases, I repeat the estimations with the news volume variables replaced by dummy variables equal to one for windows with one or more releases and zero otherwise. The news differential in these specifications is computed as the difference between the values of such dummy variables. The results (not reported) are qualitatively and quantitatively similar.

To further check the robustness of the preceding analysis, I also estimate cross-sectional models relating time-series return variances to measures of information flow and trading volume aggregated at the firm level. The qualitative results available upon request

[33] Although Nasdaq is considering the benefits of the NASD's short sale rule in after-hours trading, it is currently not applicable outside of regular market hours (NASD Notice to Members 94-68). However, some ECNs do not allow short-sale transactions at prices below the close of the previous regular session.

remain largely unchanged. Not surprisingly, the statistically significance declines as power is lost in the aggregation process.[34]

E. Within-Firm Effects of Trading Volume and Information Flow

One advantage of the natural experiment approach employed in the prior studies is the implicit control for the firm-specific characteristics that can potentially affect return volatility, since the same securities are investigated across different time periods. To examine the sensitivity of the above results to the effects of potentially omitted variables, the following procedure is performed: I locate firms that trade every day and have 100 news releases with at least 100 days between the dates of the first and the last news item. These selection screens yield a sample of 107 companies. For each firm, the trading days spanned by the news data are subdivided into "High Pre-Market Volume", "Low Pre-Market Volume", "High After-Hours Volume", "Low After-Hours Volume", "High News Difference", and "Low News Difference," based on the respective mean levels. Table 9 reports average ratios of the absolute value of the per-hour open-to-close return to the absolute value of the per-hour close-to-open return for the corresponding subsamples, the number of firms for which the difference in average ratios across such subsamples is positive and negative, as well as the number of firms for which such differences are significant at the ten percent level.

The findings are in agreement with the conclusions of the preceding analysis. Specifically, consistent with the private information hypothesis, days with the pre-market dollar volume above the mean level have lower volatility ratios for 92 of the 107 examined firms. For the overwhelming majority of such companies the difference is significant at the

[34] Because the dependent variables in these estimations (close-to-open or open-to-close variance) have nonnegative domains, I repeat the analysis using Tobit regressions as well as using OLS after taking natural logarithm of the respective dependent variables. The results are qualitatively and quantitatively unchanged.

ten percent level. Unlike the pre-market volume, the less-informed after-hours dollar volume exhibits no clear link to the volatility ratios. Consistent with the public information hypothesis, days with greater arrival of news over regular trading hours versus nontrading hours are accompanied by higher volatility ratios for 77 of the firms. The relation is significant in 36 cases. In only two instances the difference is significantly negative.

V. Conclusion

I reexamine the puzzling phenomenon of greater asset return volatility over trading periods versus nontrading periods. Data on order flow in the after-hours, pre-market, and regular trading sessions along with a unique extensive dataset covering the concurrent firm-specific public information flow for a large sample of Nasdaq securities over the 2000-2001 period allow me carry out the first direct test of the competing hypotheses and to offer new evidence on the determinants of return volatility.

Consistent with the existing studies, my results support the private information hypothesis. Higher trading volume in the pre-market session, composed predominantly of anonymous information-based ECN trades, is associated with greater overnight return volatility and lower regular session volatility, indicating that price discovery shifts toward the pre-market hours. Consequently, the volatility ratios decrease in pre-market trading volume. Consistent with Barclay and Hendershott (2001), I show that the volume in after-hours is associated with little price impact and appears to be greatest on low information asymmetry days. The volatility of close-to-open and open-to-close returns is negatively related to after-hours volume and volatility ratios are unaffected by such volume.

Unlike the existing studies, however, I also offer evidence consistent with the public information hypothesis. Greater flow of public information over trading

(nontrading) hours increases the open-to-close (close-to-open) return volatility and the ratio of return volatilities increases in the news flow differential.

The evidence on information spillover effects confirms the findings of prior studies that public information released outside regular trading hours tends to be of greater economic significance.

The analysis also presents new evidence on the trading processes in the rapidly evolving extended-hours session and on the dynamics of public information flow.

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Table 1. Opening and Closing Transactions for Pre-Market, Regular, and After-Hours Sessions

The sample consists of 1001 Nasdaq securities, which always trade above five dollars and have at least 10 trades on at least 250 trading days during the 2000-2001 period.

Variable	N	Mean	Median	Minimum	Maximum	Std Dev
FirstPreMarketTradeTime	188,235	8:46:12	8:57:4	7:36:17	9:29:59	00:36:31
FirstPreMarketTradeSize	188,235	3,145.15	500	100	1,540,500.00	14,745.67
RegularSessionOpenTime	489,595	9:42:31	9:30:19	9:30:00	15:59:59	00:40:14
RegularSessionOpenTradeSize	489,595	428.62	200	100	606,000.00	2,203.69
RegularSessionCloseTime	489,595	15:46:30	15:59:18	9:30:01	16:00:00	00:41:21
RegularSessionCloseTradeSize	489,595	854.06	300	100	1,202,600	3971.37
LastAfterHoursTradeTime	352,489	16:36:06	16:11:39	16:00:01	18:33:21	00:44:13
LastAfterHoursTradeSize	352,489	2407.45	400	100	3,565,000.00	16,048.58

Table 2. Trading Volume by Session

Trading volume is presented for the regular (9:30 a.m. – 4 p.m.), pre-market (7:30 a.m. – 9:30 a.m.) and after-hours (4 p.m. – 7 p.m.) sessions. *RegNofTrades* is the number of trades during the regular trading session; *RegVol* is the number of shares traded during the regular trading session in thousands, *RegDollarVol* is the dollar volume transacted during the regular session in thousands; *RelReg* is the ratio of the dollar volume transacted during the regular session to firm capitalization; *AH* and *PM* denote after-hours and pre-market sessions.

Variable	Mean	Median	Minimum	Maximum	Std Dev
RegNofTrades	1,477.02	217.15	4.25	63,505.63	5,079.45
RegVol (,000s)	942.76	145.33	3.53	62,109.96	3,786.34
RegDollarVol (,000s)	41,672.98	3,276.07	38.39	2,480,000.00	179,000.00
RelReg, %	1.36	0.65	0.01	23.09	2.25
AHTrades	16.31	3.32	0.03	784.79	55.68
AHVol	33,468.19	7,634.80	23.46	2,000,881.00	124,284.70
AHDollarVol (,000s)	1,412.12	169.26	0.33	96,399.85	5,939.55
RelAH, %	0.05	0.03	0.00	0.50	0.06
PMNofTrades	10.43	0.86	0.00	661.04	45.82
PMVol	9,801.80	1,183.20	0.00	877,866.60	48,767.03
PMDollarVol (,000s)	436.48	24.88	0.00	34,712.02	2,253.01
RelPM, %	0.01	0.00	0.00	0.24	0.03

Table 3. Information Flow Statistics

This table summarizes average per-firm per-day news release statistics. Time stamped news releases are obtained by a computerized search of cbs.marketwatch.com database. *NofNewsAll, NewsTr,* and *NewsNTr* denote all news releases, trading, and nontrading news releases, respectively; *NewsRatio* is the ratio of the number of releases made over trading hours to the total. *PerHourNewsRatio* is the ratio of the per-hour number of news releases over trading hours to the per-hour news releases over nontrading hours.

	N_Firms	Mean	Median	Std Dev	Min	Max
NofNewsAll	938	43.38	33.00	33.77	1.00	100.00
NewsTr	938	13.84	10.00	12.25	0.00	77.00
NewsNTr	938	29.54	22.00	24.46	0.00	90.00
NewsRatio	938	0.35	0.32	0.20	0.00	1.00
PerHourNewsRatio	918	3.04	1.98	4.37	0.00	61.41

Table 4. Number of News Releases by Weekday and by Session

The aggregate number of news releases by weekday and by trading session.

	TradingHours	NonTradingHours	AfterHoursOnly	% In After-Hours	% Over Trading Hours
Monday	2447	5049	3021	40.30%	32.64%
Tuesday	2780	5705	3153	37.16%	32.76%
Wednesday	2536	5608	3364	41.31%	31.14%
Thursday	2931	6354	3468	37.35%	31.57%
Friday	2338	4099	2211	34.35%	36.32%
Saturday		387			
Sunday		460			

Table 5. Effects of News on Return Volatility

Var_Ratio is the per-hour ratio of open-to-close variances to close-to-open variances; *ClClVar, ClOpVar,* and *OpClVar* denote close-to-close, close-to-open, and open-to-close variances, respectively; *NofNewsAll, NewsTr,* and *NewsNTr* denote all news releases, trading, and nontrading news releases, respectively; *RELEH, RELAH, RELPM,* and *RELREG* represent extended-hours, after-hours, pre-market, and regular session volume scaled by firm capitalization. Average numbers are given for sample subsets composed of stocks with the per-hour ratios of the number of news items over trading periods to number of news items over nontrading periods above and below the median level, respectively.

	Low News Ratio	High News Ratio	p-value
PerHourNewsRatio	1.1720	4.8991	0.0011
VAR_Ratio	15.7304	16.6056	0.0693
ClClVar, %	0.2585	0.2450	0.2402
ClOpVar, %	0.0708	0.0671	0.0000
OpClVar, %	0.2161	0.2022	0.1305
NofNewsAll	47.8388	40.5926	0.0011
NewsTr	10.7015	17.3551	0.0000
NewsNTr	37.1373	23.2375	0.0000
RELEH, %	0.0702	0.0628	0.1848
RELAH, %	0.0561	0.0496	0.1143
RELPM, %	0.0141	0.0131	0.5740
RELREG, %	1.4861	1.3492	0.3716
N	459	459	

Table 6. Effects of Extended-Hours Volume

The averages are presented for firms with relative extended-hours volume below and above the sample median and for the overall sample.

	All	Low RELEH	High RELEH	p-value
VAR_Ratio	15.954	14.750	17.156	0.000
ClClVar, %	0.248	0.142	0.353	0.000
ClOpVar, %	0.068	0.045	0.091	0.000
OpClVar, %	0.206	0.127	0.285	0.000
SkewnessClOp	-2.103	-1.088	-3.116	0.000
SkewnessOpCl	0.461	0.479	0.443	0.383
PerHourNewsRatio	3.036	3.833	2.311	0.000
NofNewsAll	43.384	22.138	63.570	0.000
NewsTr	13.840	7.429	19.931	0.000
NewsNTr	29.544	14.709	43.638	0.000
RegNofTrades	1,477.021	210.534	2,740.981	0.000
AHNofTrades	16.306	3.161	29.425	0.000
PMNofTrades	10.433	1.189	19.658	0.000
Cap (,000s)	2,346,305.480	1,425,569.634	3,265,203.529	0.046
RELEH, %	0.064	0.017%	0.111	0.000
RELAH, %	0.051	0.015%	0.087	0.000
RELPM, %	0.013	0.002%	0.024	0.000
RELREG, %	1.363	0.298%	2.425	0.000
OpenTime	9:42:53	9:53:53	9:31:54	0.000
CloseTime	15:46:05	15:35:52	15:56:17	0.000
OpenTradeSize	434.601	496.653	372.673	0.000
CloseTradeSize	856.490	831.602	881.328	0.027
FirstTradeTime	8:54:11	9:00:19	8:48:07	0.000
LastTradeTime	16:29:39	16:15:56	16:43:20	0.000
N	1001	500	501	

Table 7. Effects of Extended-Hours Volume on Variance Ratios by Regular Session Volume Quintiles

RELEH, RELAH, RELPM, and *RELREG* represent extended-hours, after-hours, pre-market, and regular session volume scaled by firm capitalization.

	RELPM			RELAH			RELEH		
RelRegQuintile	Low	High	p-value	Low	High	p-value	Low	High	p-value
Lowest	9.97	13.39	0.00	9.74	13.63	0.00	9.66	13.71	0.00
2	16.12	15.69	0.72	13.22	18.59	0.00	13.71	18.10	0.00
3	20.08	18.47	0.30	18.80	19.75	0.54	18.66	19.89	0.43
4	19.68	16.25	0.01	17.39	18.54	0.39	17.89	18.04	0.91
Highest	16.92	12.99	0.00	15.65	14.25	0.14	16.42	13.49	0.00

Table 8. Regression Analysis

The following two-way fixed effects models are estimated by OLS:

$$LogAbsClOp_{j,t} = \beta_0 + \beta_1 LAGNewsTr_{j,t} + \beta_2 NewsNTr_{j,t} + \beta_3 LAGRELAH_{j,t} + \beta_4 RELPM_{j,t} + \beta_5 LAGRELREG_{j,t} + v_j + u_t + \varepsilon_{j,t}$$

$$LogAbsOpCl_{j,t} = \beta_0 + \beta_1 NewsTr_{j,t} + \beta_2 NewsNTr_{j,t} + \beta_3 LAGRELAH_{j,t} + \beta_4 RELPM_{j,t} + \beta_5 RELREG_{j,t} + v_j + u_t + \varepsilon_{j,t}$$

$$LogRatio_{j,t} = \beta_0 + \beta_1 LAGRELAH_{j,t} + \beta_2 RELPM_{j,t} + \beta_3 RELREG_{j,t} + \beta_4 NewsDiff_{j,t} + v_j + u_t + \varepsilon_{j,t}$$

Where $LogAbsClOp_{j,t}$ and $LogAbsOpCl_{j,t}$ are the natural logarithms of the absolute values of the close-to-open and open-to-close returns on a per-hour basis, respectively; $LogRatio_{j,t}$ is the difference between $LogAbsOpCl_{j,t}$ and $LogAbsClOp_{j,t}$; $NewsTr_{j,t}$ is the number of news releases over regular trading session hours; $NewsNTr_{j,t}$ is the number of news items released between the end of the previous trading day's regular session and the beginning of the current trading day's regular session; $LAGNewsTr_{j,t}$ is the number of news releases over the regular trading hours of the preceding trading day; $LAGRELAH_{j,t}$ is the prior trading day's after-hours dollar volume scaled by capitalization; $RELPM_{j,t}$ and $RELREG_{j,t}$ are the pre-market and regular session dollar volumes scaled by capitalization; $LAGRELREG_{j,t}$ is the prior trading day's regular session dollar volume scaled by capitalization; $NewsDiff_{j,t}$ is the difference between $NewsTr_{j,t}$ and $NewsNTr_{j,t}$; v_j, u_t, and $\varepsilon_{j,t}$ are the error terms; $j \in [1, 1001]$ and $t \in [1, 499]$ denote the firm and the trading day, respectively.

	LogAbsClOp		LogAbsOpCl		LogRatio	
	Estimate	p-value	Estimate	p-value	Estimate	p-value
Intercept	-9.438	0.000	-5.683	0.000	3.792	0.0001
NewsTr			0.099	0.000		
LAGNewsTr	-0.023	0.001				
NewsNTr	0.196	0.000	0.057	0.000		
LAGRELAH	-1.573	0.003	-4.140	0.000	-0.868	0.209
RELPM	39.790	0.000	-14.386	0.000	-42.994	0.000
RELREG			3.117	0.000	1.342	0.000
LAGRELREG	0.232	0.000				
NewsDiff					0.075	0.000
N	400857		429387		383188	
Adj-Rsqr	0.335		0.164		0.187	

Table 9. Within-Firm Effects of Pre-Market Volume, After-Hours Volume, and News Differential on Volatility Ratios

The analyzed sample consists of 107 firms that trade every day and have 100 news releases with at least 100 days between the first and the last release. For each firm *j*, the trading days spanned by the news data are subdivided into "High Pre-Market Volume", "Low Pre-Market Volume", "High After-Hours Volume", "Low After-Hours Volume", "High News Difference", and "Low News Difference" (*PMHigh, PMLow, AHHigh, AHLow, NewsDiffHigh, NewsDiffLow*, respectively), based on the corresponding company mean levels. The table reports average ratios of the absolute value of the per-hour open-to-close return to the absolute value of the per-hour close-to-open return for the respective subsamples, as well as the number of firms for which the difference in means across such subsamples is positive and negative. *N_Significant* refers to the number of firms for which the above difference is significant at the ten percent level.

PANEL A: Effects of Pre-Market Volume

$\frac{\sum_{j=1}^{107} \overline{\text{Ratio}}_{\text{PMHigh}\,j}}{107}$	$\frac{\sum_{j=1}^{107} \overline{\text{Ratio}}_{\text{PMLow}\,j}}{107}$	$\left(\overline{\text{Ratio}}_{\text{PMHigh}\,j} - \overline{\text{Ratio}}_{\text{PMLow}\,j}\right) < 0$		$\left(\overline{\text{Ratio}}_{\text{PMHigh}\,j} - \overline{\text{Ratio}}_{\text{PMLow}\,j}\right) > 0$	
		N	N_Significant	N	N_Significant
25.2264	39.81024	92	70	15	0

PANEL B: Effects of After-Hours Volume

$\frac{\sum_{j=1}^{107} \overline{\text{Ratio}}_{\text{AHHigh}\,j}}{107}$	$\frac{\sum_{j=1}^{107} \overline{\text{Ratio}}_{\text{AHLow}\,j}}{107}$	$\left(\overline{\text{Ratio}}_{\text{AHHigh}\,j} - \overline{\text{Ratio}}_{\text{AHLow}\,j}\right) < 0$		$\left(\overline{\text{Ratio}}_{\text{AHHigh}\,j} - \overline{\text{Ratio}}_{\text{AHLow}\,j}\right) > 0$	
		N	N_Significant	N	N_Significant
38.80732	35.79618	49	15	58	13

PANEL C: Effects of News Difference

$\frac{\sum_{j=1}^{107} \overline{\text{Ratio}}_{\text{NewsDiffHigh}\,j}}{107}$	$\frac{\sum_{j=1}^{107} \overline{\text{Ratio}}_{\text{NewsDiffLow}\,j}}{107}$	$\left(\overline{\text{Ratio}}_{\text{NewsDiffHigh}\,j} - \overline{\text{Ratio}}_{\text{NewsDiffLow}\,j}\right) < 0$		$\left(\overline{\text{Ratio}}_{\text{NewsDiffHigh}\,j} - \overline{\text{Ratio}}_{\text{NewsDiffLow}\,j}\right) > 0$	
		N	N_Significant	N	N_Significant
38.19366	33.03446	30	2	77	36

Figure 1. Hypothesized Volatility Effects of Extended-Hours Trading
This diagram shows the expected effects of extended-hours trading volume (V_{ClOp}) on close-to-open and open-to-close return variances for the private information and noise hypotheses.

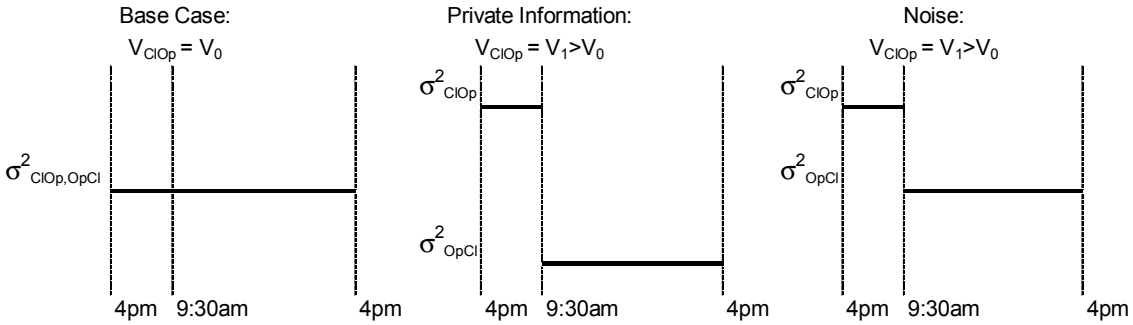


Figure 2. Intraday Distribution of Trading Volume
This graph demonstrates the dynamics of the number of trades and dollar volume over extended-hours and regular trading session subintervals.

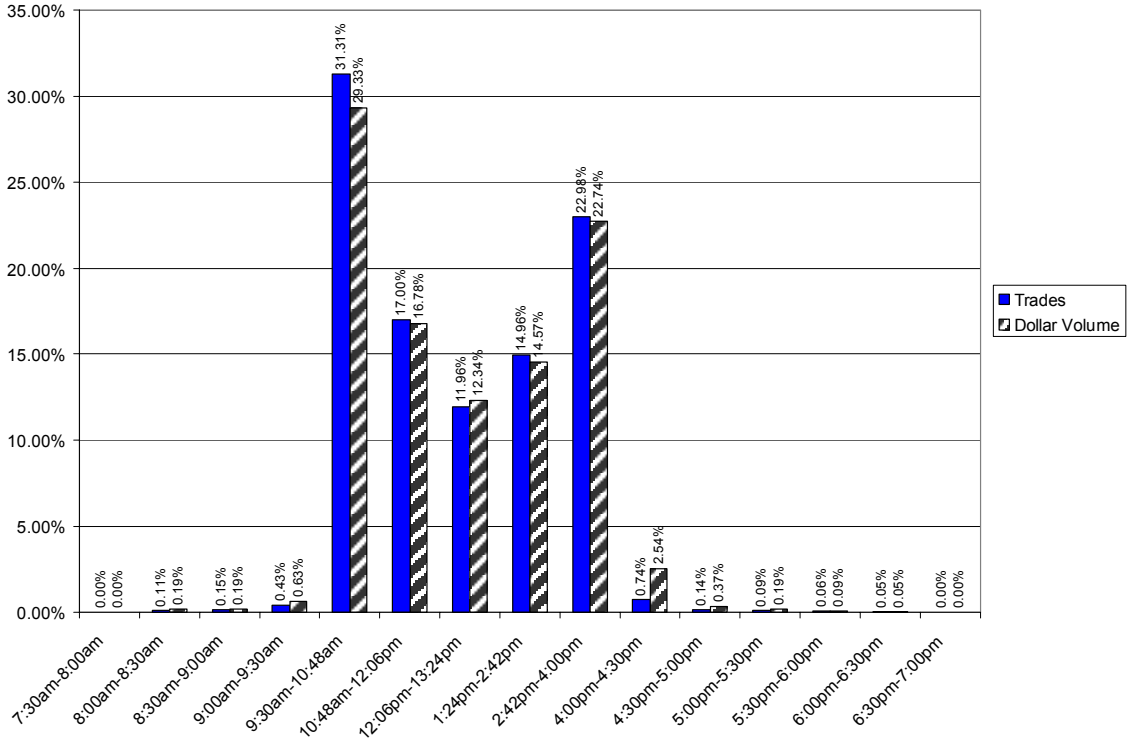
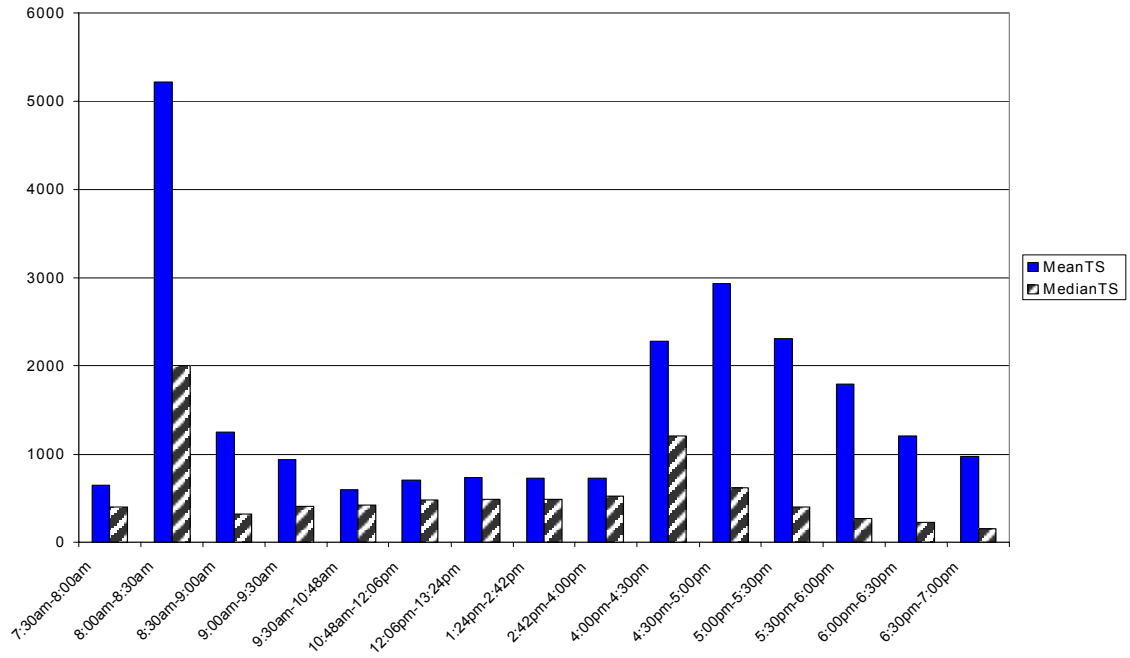


Figure 3. Intraday Distribution of Trade Size
Panels 1 and 2 present the intraday distributions of mean and median trade size. TS is trade size measured in number of shares per trade, DTS is the dollar size of trade.

PANEL 1



PANEL 2

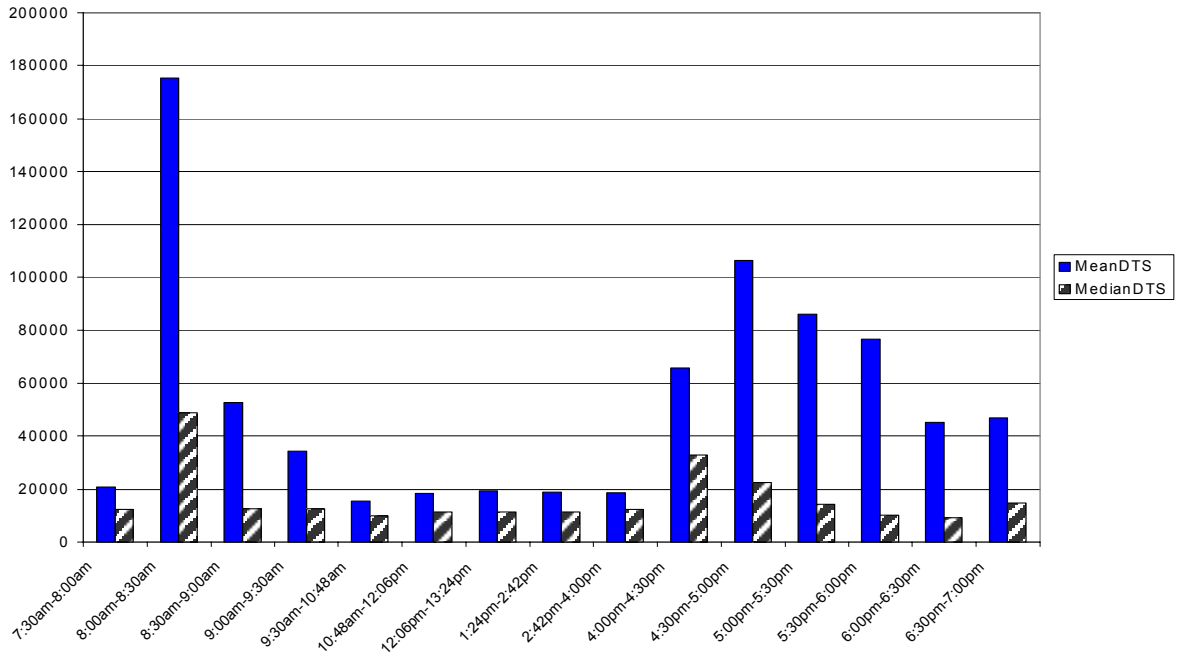


Figure 4. Distribution of News Releases over Trading and Non-trading Hours by Weekday

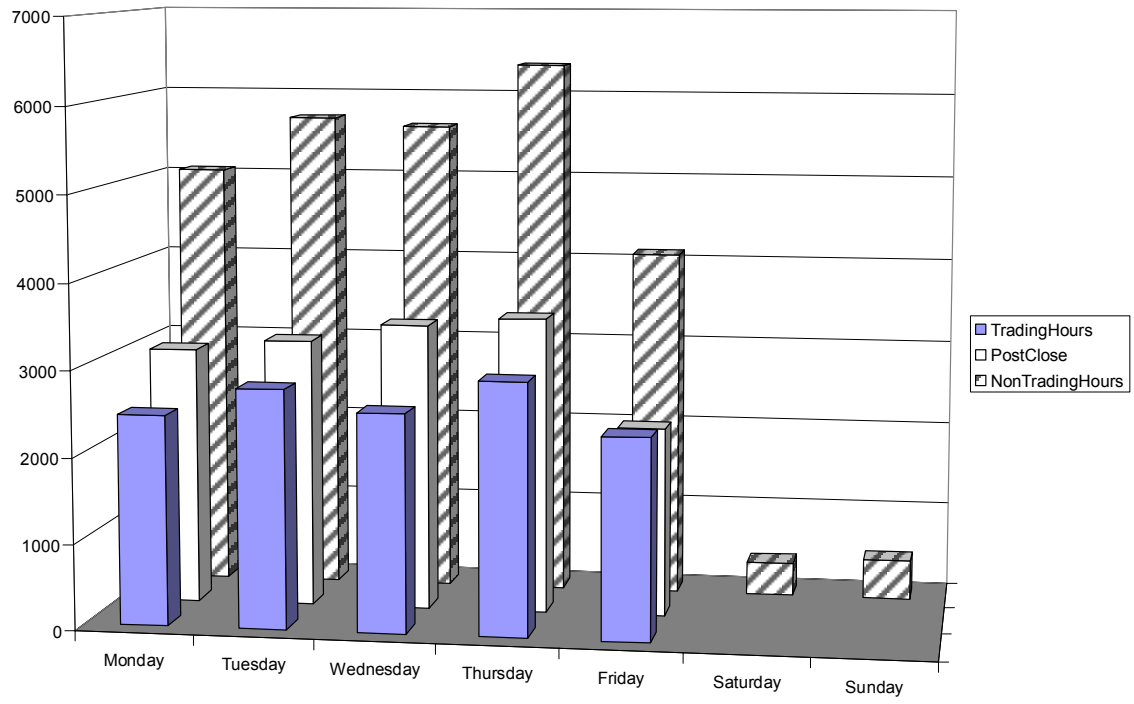
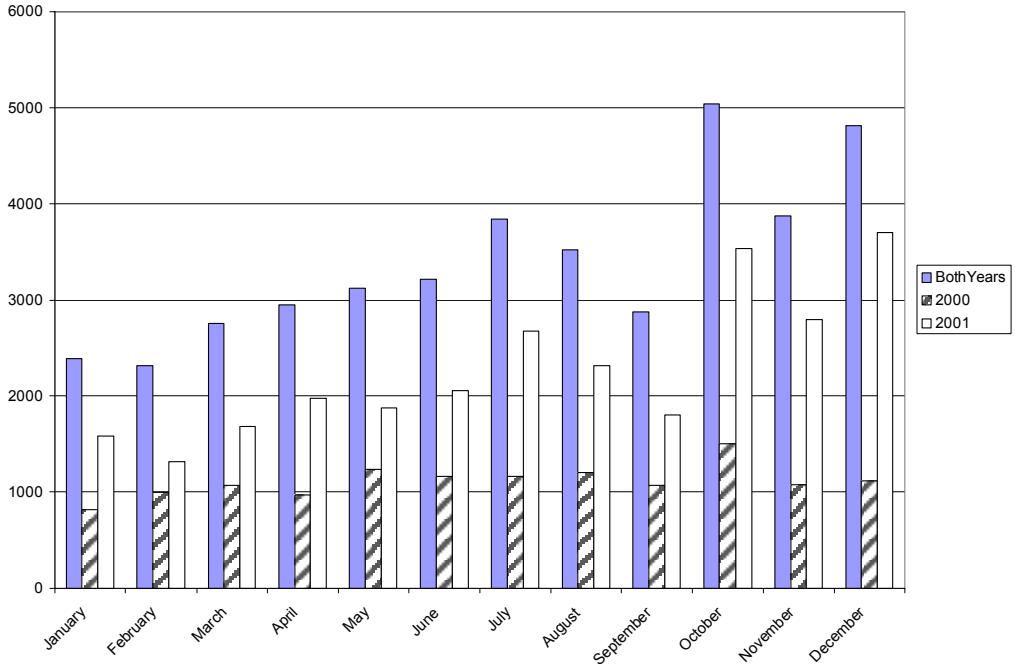


Figure 5. Monthly and Weekday Seasonalities in Public News Flow

PANEL 1



PANEL 2

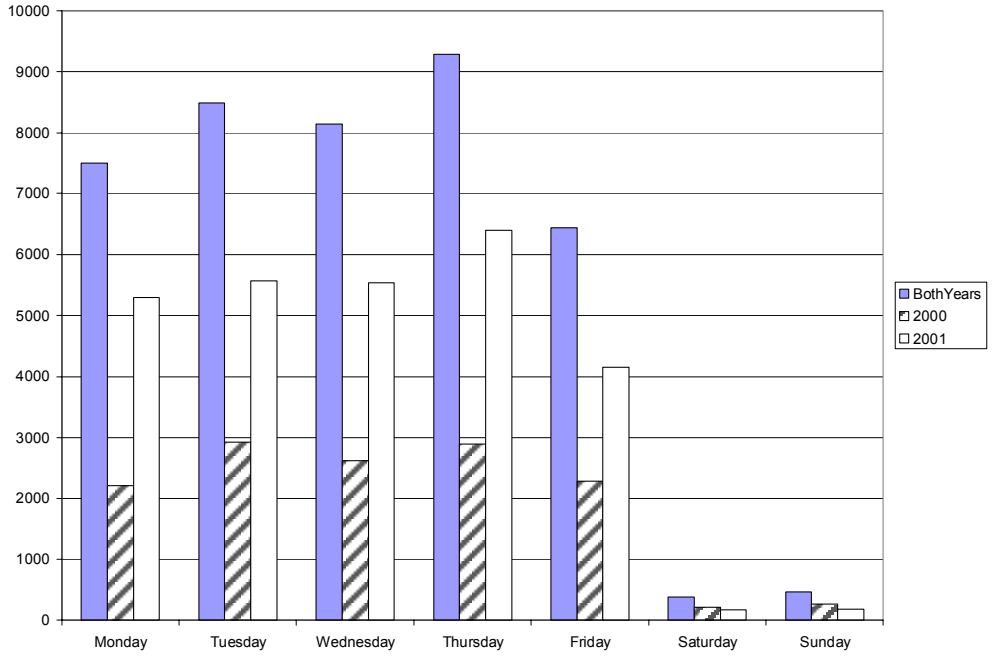
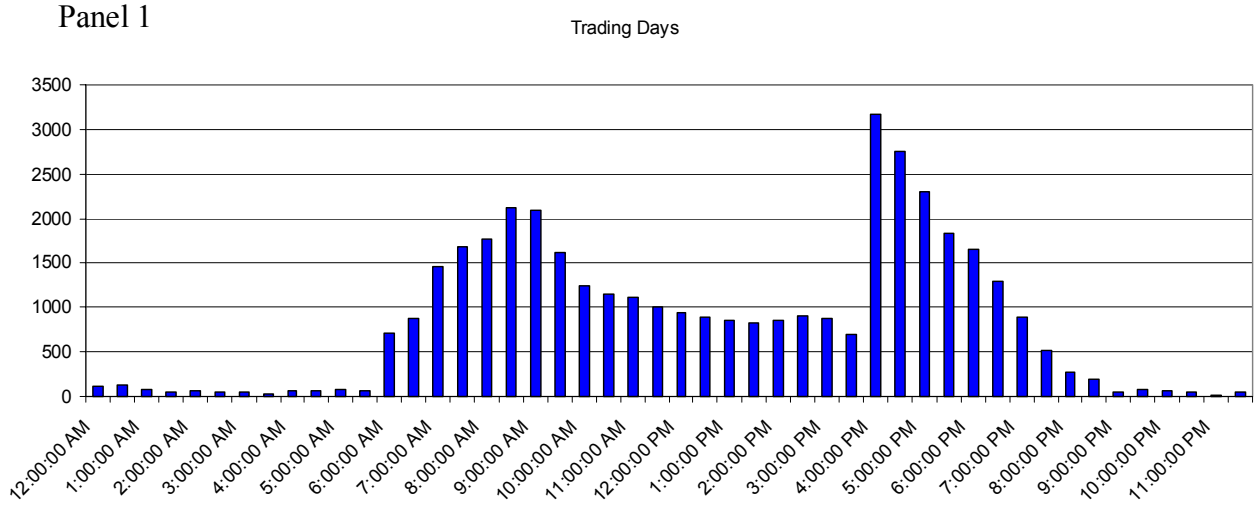


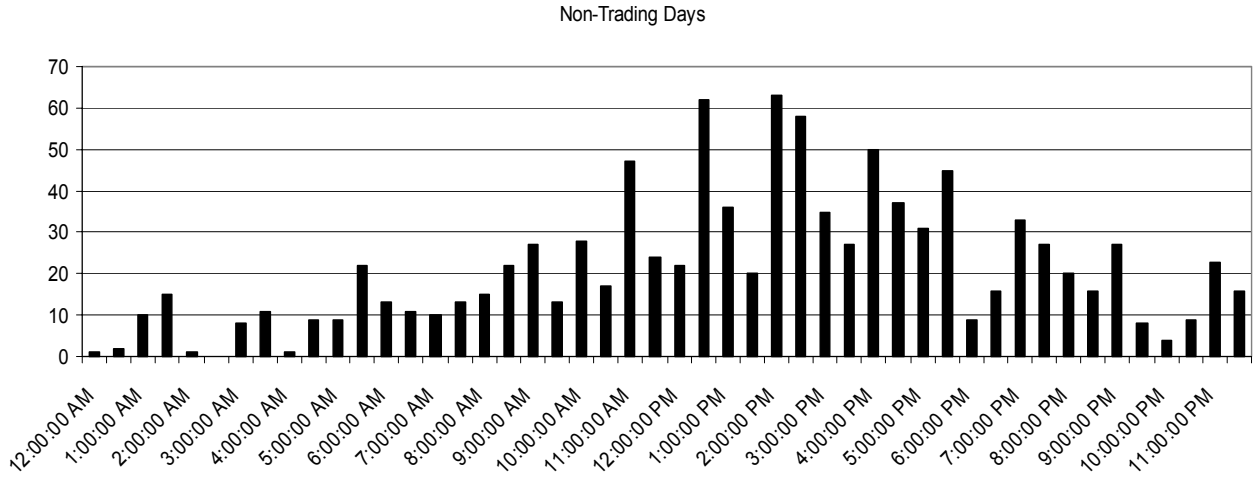
Figure 6. Intraday Flow of Public Information

Panel 1 presents the number of news releases in 30-minute intraday increments for all trading days during the 2000-2001 period; Panel 2 displays the releases for all nontrading days in the sample; Panel 3 plots the intraday releases for five trading days with shortened regular trading sessions (1 p.m. close).

Panel 1



Panel 2



Panel 3

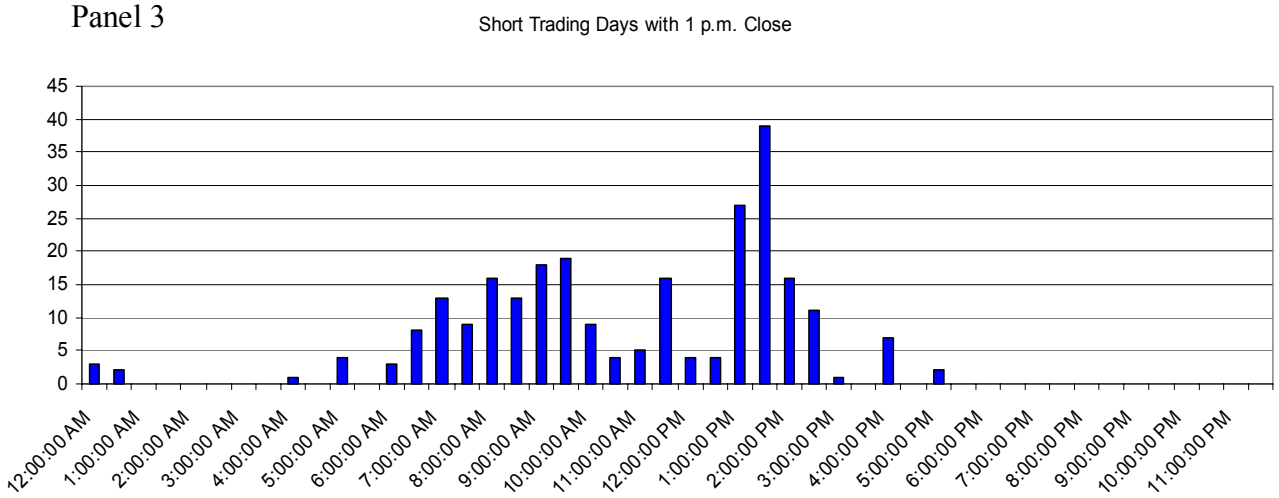
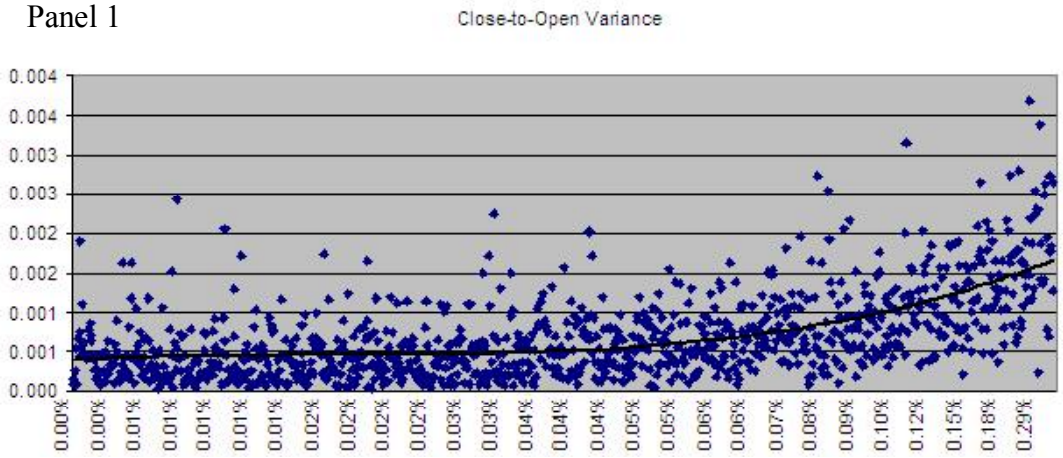


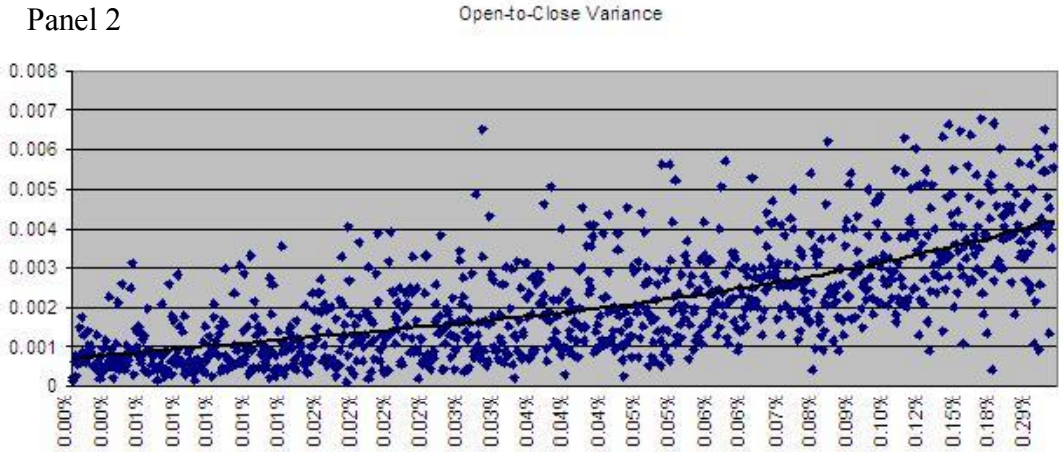
Figure 7. Variance Effects of Extended-Hours Dollar Volume

The plots exhibit close-to-open, open-to-close, and close-to-close return variances as functions of the extended-hours trading dollar volume expressed as a percentage of firm capitalization. Solid lines represent 3-rd order polynomial trend lines. Abscissa scale not maintained.

Panel 1



Panel 2



Panel 3

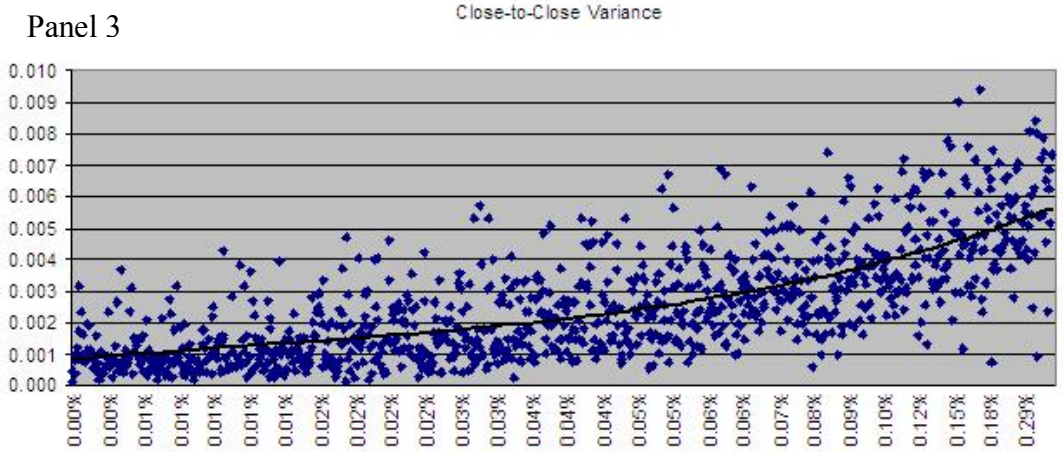


Figure 8. Effects of Extended-Hours Volume on the Variance Ratio
This plot presents the ratio of open-to-close variances to close-to-open variances on a per-hour basis as a function of extended-hours dollar volume scaled by firm size. Abscissa scale not maintained. Solid line represents 3-rd order polynomial trend.