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Source: *The Review of Financial Studies*, 1990, Vol. 3, No. 1, National Bureau of Economic Research Conference: Stock Market Volatility and the Crash, Dorado Beach, March 16-18, 1989 (1990), pp. 37-71

Published by: Oxford University Press. Sponsor: The Society for Financial Studies.

Stable URL: https://www.jstor.org/stable/2961956

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The procedure for opening stocks on the NYSE appears to affect price volatility. An analytical framework for assessing the magnitude of the structurally induced volatility is presented. The ratio of variance of open-to-open returns to close-to-close returns is shown to be consistently greater than one for NYSE common stocks during the period 1982 through 1986. The greater volatility at the open is not attributable to the way in which public information is released since both the open-to-open return and the close-to-close return span the same period of time. Instead, the greater volatility appears to be attributable to private information revealed in trading and to temporary price deviations induced by specialist and other traders. The implied cost of immediacy at the open is significantly higher than at the close. Other empirical evidence in this article documents the volume of trading at the open, the time delays between the exchange opening and the first transaction in a stock, the difference in daytime volatility versus overnight volatility, and the extent to which volatility is related to trading volume.

The stock market crash of 1987 has focused increased attention on the effect of market structure on the

This research was supported by The Research Foundation of the Institute of Chartered Financial Analysts. Stoll acknowledges the support of the Financial Markets Research Center and the Dean's Fund for Faculty Research

The Review of Financial Studies 1990 Volume 3, number 1, pp. 37–71

behavior of securities prices. Recommendations such as trading halts, the elimination of program trading, and trading bans of derivative instruments have been put forth.[1] One suggestion that has received considerable attention calls for "circuit breakers" that halt trading if markets become excessively disrupted. However, a trading halt is reasonable only if the procedure for reopening trading leads to prices that more closely reflect true security value. In this study, the procedure for opening stocks on the New York Stock Exchange (NYSE) is examined. The opening of trading on the NYSE provides an excellent laboratory for investigating the effect of a particular market structure on price volatility.

The importance of market structure has been long recognized in the finance literature. Cohen, Maier, Schwartz, and Whitcomb (1978) model the effect of trading arrangements on price patterns. Goldman and Beja (1979) and Hasbrouck and Ho (1987) posit a lagged adjustment model, resulting in part from market structure, for the short-term behavior of prices. Kyle (1985), Admati and Pfleiderer (1988), and Foster and Viswanathan (1988) model the interaction of liquidity traders and informed traders in a dynamic setting and derive propositions about the short-run behavior of prices and volume. A large body of research, including the recent articles by Roll (1984), Hasbrouck (1987), and Stoll (1989), examines the effect of the bid–ask spread on the short-run behavior of prices. French and Roll (1986) show that return volatility is much larger when the market is open than when it is closed. Harris (1986) provides evidence of weekly and intraday patterns in prices. Amihud and Mendelson (1987) and Wood, McInish, and Ord (1985) show that volatility is greater at market openings than at other times of the day. McInish and Wood (1989) show that bid–ask spreads are larger at the beginning of the day than later in the day. The role of market structure in the expiration-day effects of index futures and options is examined in Stoll (1987) and Stoll and Whaley (1987, 1990). In a postcrash study, Blume, MacKinlay, and Terker (1989) show that order imbalances on October 19 and 20 resulted in temporary price changes.

The article is organized as follows: In Section 1, the structural factors that affect price volatility are discussed. In particular, the nature

at the Owen Graduate School of Management, Vanderbilt University. Whaley acknowledges the support of the Unisys Fund at the Fuqua School of Business, Duke University. Athena Lee provided computer work, and helpful comments were received at presentations of the article at Rutgers University, Vanderbilt University, the NBER Conference on Stock Market Volatility in Puerto Rico, and the Imperfections in Financial Markets Conference at Minaki, Ontario. The authors also thank Fischer Black, Michael Brennan, Larry Fisher, Larry Harris, Alan White, and an anonymous referee for their comments. Address reprint requests to Prof. Stoll, Owen Graduate School of Management, Vanderbilt University, Nashville, TN 37203.

[1] For an analysis of policy issues arising out of the crash, see Stoll and Whaley (1988).

of opening transactions on the NYSE is described and contrasted with the nature of transactions during the rest of the trading day. In Section 2, a simple model of stock returns is developed. This model partitions return volatility into a component attributable to new information and a component attributable to trading shocks. Section 3 contains a description of the data used in our empirical analysis—daily opening and closing prices and volumes for all NYSE common stocks for 1982 through 1986. This sample of information is perhaps the most comprehensive used in any market structure study to date. Section 4 presents descriptive statistics on the timing of and trading volume at the opening and closing transactions of the day. In Section 5, the ratio of the return variance calculated from open-to-open returns to the return variance calculated from close-to-close returns is computed for each stock in each month during the five-year sample period. The average variance ratio exceeds one, which implies that volatility at the open exceeds volatility at the close. In Section 6, the serial dependence of returns around the open and around the close is examined and is used to infer the extent to which the cost of supplying immediacy is a source of volatility. Section 7 contains an investigation of the relative magnitudes of daytime versus overnight return volatility. The relation between price volatility and trading shocks at the open is examined in Section 8, and the extent to which price reversals are related to trading volume is examined in Section 9. Section 10 contains the summary and conclusions of the study.

1. Determinants of the Opening Price

The opening of the NYSE has many of the characteristics of a call auction market. All market orders that have accumulated overnight, limit orders to buy at or above the opening price, and limit orders to sell at or below the opening price are executed at a single price—the opening price. The specialist is the "auctioneer" who accumulates orders and determines the opening price with the assistance of the opening automated reporting system (OARS). Thus, most of the trades at the open are directly between investors, although the specialist may participate at the open to offset order imbalances. During the rest of the day, orders are executed in the sequence in which they arrive. Except for block transactions that are prearranged in upstairs trading rooms, intraday trading usually requires the participation of the specialist on one side of the transaction.[2]

The specialist's participation at the open makes price determination different from the classic Walrasian auction, in which a disinterested

[2] Stoll (1985) estimates that the specialist participates in 90 percent of the nonblock shares traded on the NYSE as either dealer for his own account or broker for the limit order book.

auctioneer determines the market-clearing price. The specialist observes the order imbalance and then has the opportunity to trade for his own account as a dealer. If the specialist's role as dealer is important at the open, price patterns around the open should be like price patterns around other transactions in which the specialist acts as dealer. In other words, the price patterns around the open should exhibit the price reversals that are normally observed in dealer markets as prices move between bid and ask levels. If the open is a classic auction in which all investors can participate, imbalances would be zero and the opening price would more closely reflect the true price of the security.

The price determination process at the open can be illustrated using the demand–supply framework of Figure 1. In Figure 1, the excess demand curve is the piecewise linear function *DD*. The vertical line segment reflects the excess demand of public market orders to buy over public market orders to sell. The imbalance of market orders (at any price) is Q_{mt}. The downward sloping segment is the excess demand of limit orders to buy over limit orders to sell. The price of the stock implied by the current public information set, which we refer to as the "true" price, is P_t^*. The total imbalance at P_t^* is Q_t^*. In a perfectly functioning auction market with a disinterested auctioneer, the imbalance in Figure 1 would cause a trial clearing price above P_t^* to be announced and new orders to be solicited. New prices would be called out until a new true price at which the imbalance is zero and no trader wishes to revise his order is determined. To the extent that imbalances convey information, the true price might change during the auction.

Openings on the NYSE do not follow such a procedure. Instead, the specialist observes the imbalance and can offset the imbalance on his own account. The only requirement is that all market orders be executed. Figure 1 illustrates how the opening price would be determined under that procedure. The line labeled *S* is the specialist's supply function. It reflects the costs (e.g., inventory-holding costs and transaction costs) incurred by the specialist and other traders in supplying immediacy—the service of taking an offsetting position to enable other traders to trade immediately.[3] If the specialist is a monopolist at the open, he prices off the marginal demand, *DD'*, to set an opening price P_t and sells Q_t shares for his own account. The specialist's problem at other times of the day is quite similar to that at the open. However, at the open, he can see the imbalance and he has information on who is trading before deciding the price at which

[3] Demsetz (1968) first describes the dealer's role as providing "immediacy" in the marketplace. Stoll (1978) provides a model of the dealer's cost function.

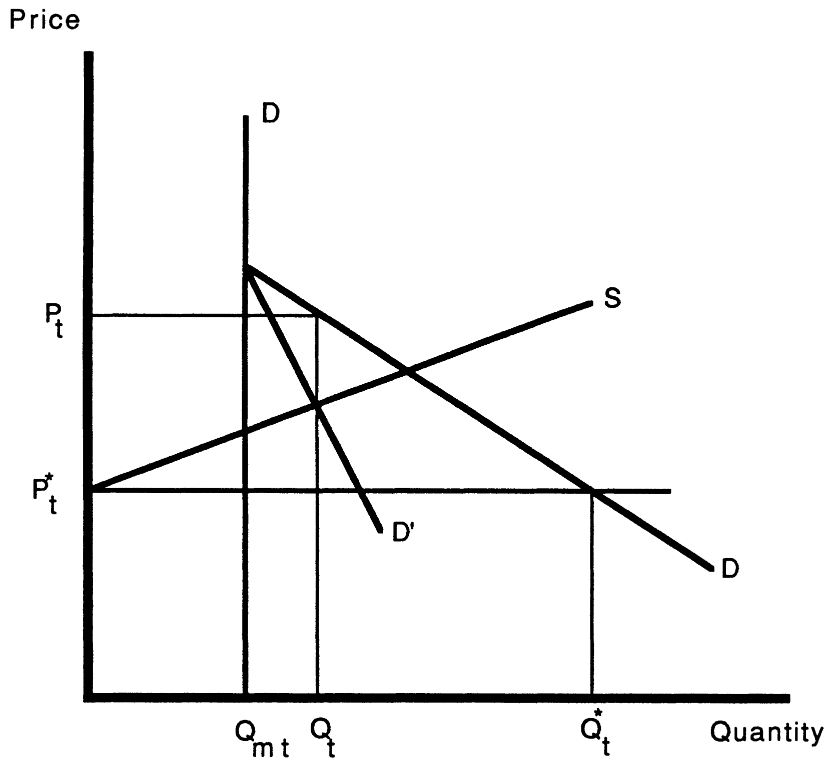

Figure 1.
Excess demand at the opening (DD), marginal revenue (DD′), and specialist supply of shares (S)

he will trade. During the rest of the day, the specialist posts bid and ask prices without knowing the size of the next trade, who the trader is, or whether it will be a purchase or sale.[4]

Volatility of prices is caused by (1) new public information, (2) trading pressures of investors, and (3) the manner in which immediacy is supplied to offset these trading pressures. In terms of Figure 1, public information changes P^*_t without causing excess demand because all investors shift their demands to reflect the new information. The analysis of this article abstracts from the effect of public information on volatility and focuses on the latter two considerations.

[4] How much better off the specialist is at the open relative to the rest of the day is not evident. In principle, the specialist can set bid and ask prices that take account of any contingency (transaction size, trader identification, etc.); however, in practice this is impossible. As a result, the ex post pricing made possible by opening procedures offers considerable advantage over the ex ante procedure required during the rest of the day.

Trading pressures emanate from information traders and liquidity traders. Information traders trade on the basis of private information, while liquidity traders trade because of cash flow needs. The "noise" introduced by liquidity traders allows information traders to disguise themselves and capitalize on their information. Suppliers of immediacy lose to information traders and profit enough from the liquidity traders to stay in business. The ability of information traders to disguise themselves and the cost of supplying immediacy depend on market structure.[5] In this article, we examine one structural arrangement for dealing with trading pressures and providing immediacy—the opening.

Several structural factors can contribute to increased volatility of prices at the open under current procedures:

- *Lack of disclosure and inability to revise orders.* If imbalances prior to the opening are not publicly disclosed, traders (other than the specialist) cannot assess the probable price change and hence the desirability of placing an opening order or of revising an existing order.[6] As a result, imbalances and price changes may be larger than they should be. Unless the orders submitted by traders are very complex, a "one-shot" auction such as the specialist provides cannot result in a price with which all traders are satisfied. A one-shot auction can also induce trading strategies that increase volatility. For example, investors might place larger orders than they would otherwise in order to avoid being rationed out.[7]
- *Specialist monopoly power.* In principle, the specialist can offset an imbalance and limit the price effect; however, he has no incentive to do so. Instead, as Figure 1 illustrates, the specialist has an incentive to induce a price effect that compensates him for the service of immediacy and produces a monopoly profit.

On the other hand, several structural factors can contribute to decreased volatility at the open:

- *Disclosure requirements.* Opening price volatility may be reduced if imbalances are disclosed and investors are given the opportunity to revise orders before an opening price is determined. Full disclosure and sufficient opportunity to revise orders could totally eliminate

[5] The interaction between informed and liquidity traders was first discussed in Bagehot (1971). More recent papers include Kyle (1985), Easley and O'Hara (1987), Admati and Pfleiderer (1988), and Foster and Viswanathan (1988). For a model of volume and volatility in the presence of information and liquidity traders, see Chopra (1989).

[6] The ability to revise orders can lead to "gaming" as traders submit fake orders that they later rescind. To limit this behavior, revisions might be subject to a fee or limited to price improvements (i.e., purchases at higher prices or sales at lower prices).

[7] See Ho, Schwartz, and Whitcomb (1985).

sources of instability arising from the structure of trading arrangements. Under current rules, a certain amount of disclosure is required, and order revision is sometimes allowed. For example, if the specialist plans to change the opening price by more than a specified amount from the preceding day's close, he is required to disclose the likely opening price change to dealers in other markets. Also, if the order imbalance is too large for the specialist to meet at reasonable prices, the specialist sometimes delays the opening. In such cases, the specialist communicates the magnitude of the imbalance to the "crowd" and solicits additional orders.

- *Oversight.* The specialist is subject to general regulatory oversight, and the quality of his markets is evaluated by the exchange. In delayed openings, the specialist is subject to direct oversight from a floor governor.
- *The crowd.* Floor traders at the specialist post, competing with the specialist, could limit the extent to which order imbalances push the opening price away from the true equilibrium price. Under current procedures, the crowd competes directly at the open only if the specialist discloses the opening imbalance. The crowd competes indirectly by policing the opening and standing ready to trade with the public immediately after the opening.

The above arguments about volatility at the open lead to the following two competing hypotheses:

- H_0: Structural price volatility at the open is less than at other times of the day. This result would be expected if the opening procedure followed the classic Walrasian market. In such a market, the opening price would fall between the bid and ask prices that the specialist would set.
- H_A: Structural price volatility at the open is greater than at other times of the day. This result would be expected in a one-shot auction in which the specialist has greater monopoly power than at other times of the day and establishes prices that vary by more than the normal bid–ask spread.

2. Return Analysis

In the last section, arguments in support of both lower and higher price volatility at the open than at other times during the day were presented. In this section, we specify how volatility is measured and how it may be partitioned into components in order to address the merits of the competing arguments.

The framework of Figure 1 can be restated in terms of stock returns. In Figure 1, P_t^* represents the true price of the security at time t and

P_t, the transaction price. Deviation of P_t from P_t^* reflects the net effect of the public's excess demand and the specialist's costs and monopoly power. If we model this transaction shock as a proportion of stock price, the transaction price may be written

$$P_t = P_t^* U_t \tag{1}$$

where U_t is the transaction shock. This relation may be restated in terms of logarithmic rates of return,

$$r_t = e_t + (u_t - u_{t-1}) \tag{2}$$

where $r_t = \ln P_t - \ln P_{t-1}$, $e_t = \ln P_t^* - \ln P_{t-1}^*$, and $u_t = \ln U_t$.

The variable e_t reflects new public information that changes the true price of the security. Markets are assumed to be informationally efficient so that e_t is serially independent.[8] The price shock u_t reflects the structural factors of interest. First, the price shock may reflect the trading imbalance caused by the demands or supplies of traders with private information. Second, the price shock also may be due to trading imbalances caused by the fortuitous nonsynchronization in the arrival of liquidity traders. Third, the price shock may reflect the higher fee charged by suppliers of liquidity, such as the specialist. In other words, u_t represents the net effect of information trading, liquidity trading, and the specialist's response.

Using the return relation (2), the variance of observed return may be written

$$\sigma^2(r_t) = \sigma^2(e_t) + \sigma^2(u_t - u_{t-1}) + 2\,\mathrm{cov}(e_t, u_t - u_{t-1}) \tag{3}$$

where u_t is the transaction shock at time t and e_t is the information that arrives at times up to and including time t. The second term in Equation (3) is the effect of trading shocks independent of a contemporaneous information shock, and the third term is the effect of any interaction between trading shocks and information. In a well-functioning opening auction, the disclosure of imbalances and trial market clearings would keep the volatility attributable to these factors [i.e., $\sigma^2(u_t - u_{t-1})$ and $\mathrm{cov}(e_t, u_t - u_{t-1})$] to a minimum, and the observed return volatility would be largely attributable to the volatility induced by new public information [i.e., $\sigma^2(e_t)$]. Trading shocks arising from liquidity traders would tend to be diversified away; and, to the extent any aggregate trading shock remained, a well-functioning auction market would provide a mechanism for attracting additional offsetting orders. Trading shocks arising from information trading would tend

[8] Serial dependence in returns is not necessarily inconsistent with efficiency since expected returns may be conditional on factors that are serially dependent. However, over the very short time horizon used in this analysis, such serial dependence is hard to imagine.

to be eliminated as the disclosure of imbalances revealed private information to the entire market.

2.1 Isolating trading shock effects

To assess the magnitude of the volatility at the open, a benchmark volatility is needed. While volatility based on returns spanning any 24-hour period beginning at a time other than at the open is acceptable, closing prices are used in this analysis. The reasons for this are that, other than at the open, market activity tends to be greatest at the close and volatility calculations in the published literature are almost always based on closing prices.[9]

To isolate the influence of trading shocks from the influence of new public information the variance-of-return relation (3) is used to represent the variance of the open-to-open return $\sigma^2(r_{o,t})$ and to represent the variance of the close-to-close return $\sigma^2(r_{c,t})$. The ratio of the variances may be written

$$\frac{\sigma^2(r_{o,t})}{\sigma^2(r_{c,t})} = \frac{\begin{array}{c}\sigma^2(e_{o,t}) + \sigma^2(u_{o,t} - u_{o,t-1}) \\ + 2\operatorname{cov}(e_{o,t}, u_{o,t} - u_{o,t-1})\end{array}}{\begin{array}{c}\sigma^2(e_{c,t}) + \sigma^2(u_{c,t} - u_{c,t-1}) \\ + 2\operatorname{cov}(e_{c,t}, u_{c,t} - u_{c,t-1})\end{array}} \tag{4}$$

where $u_{o,t}$ ($u_{c,t}$) is the transaction shock at the open (close) on day t, and $e_{o,t}$ ($e_{c,t}$) is the information that arrives after the open (close) on day $t-1$ and on or before the open (close) on day t. Over a long time series, the variance of the new information variable based on opening prices equals the variance based on closing prices [i.e., $\sigma^2(e_{o,t}) = \sigma^2(e_{c,t})$]. Therefore, a variance ratio different from one must be due to the influence of trading shocks at the open vis-à-vis the close, that is, due to differences in the magnitudes of the second and third terms in the numerator and denominator of Equation (4), respectively.

2.2 Isolating bid–ask effects

Open-to-open and close-to-close returns may be partitioned differently in order to gather additional insight about return volatility. The logarithmic open-to-open returns may be expressed as the sum of the overnight return $r_{n,t}$ and the return during the preceding day $r_{d,t-1}$,

$$r_{o,t} \equiv r_{d,t-1} + r_{n,t}$$

and the logarithmic close-to-close return may be expressed as the sum of the overnight return $r_{n,t}$ and the return on the following day $r_{d,t}$,

[9] An exception to this statement is a study by Richardson and Smith (1988) that analyzes the volatility and serial correlation of hourly prices for the 30 Dow Jones stocks.

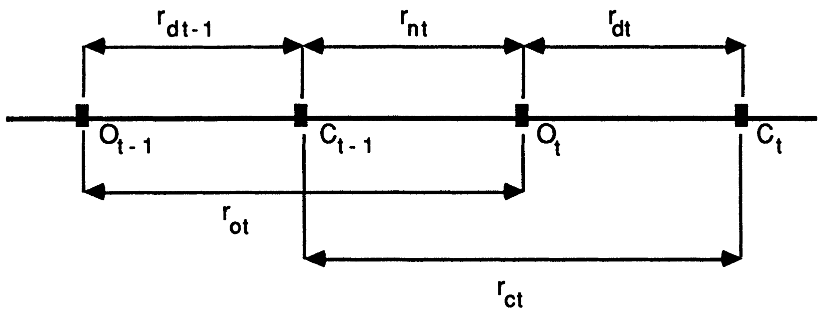

Figure 2.
Intervals over which returns are calculated
O_t = opening price on day t; C_t = closing price on day t.

$$r_{c,t} \equiv r_{n,t} + r_{d,t}$$

(See Figure 2.) Using these return definitions, the variance ratio may be written

$$\frac{\sigma^2(r_{o,t})}{\sigma^2(r_{c,t})} = \frac{\sigma^2(r_{d,t-1}) + \sigma^2(r_{n,t}) + 2\ \mathrm{cov}(r_{d,t-1}, r_{n,t})}{\sigma^2(r_{d,t}) + \sigma^2(r_{n,t}) + 2\ \mathrm{cov}(r_{d,t}, r_{n,t})} \tag{5}$$

Over a long time series, $\sigma^2(r_{d,t-1}) = \sigma^2(r_{d,t})$, so the sum of the first and second terms in the numerator is approximately the same as the sum of the first and second terms in the denominator. A variance ratio $[\sigma^2(r_{o,t})/\sigma^2(r_{c,t})]$ different from one, therefore, implies that $\mathrm{cov}(r_{d,t-1}, r_{n,t})$ and $\mathrm{cov}(r_{n,t}, r_{d,t})$ are not equal. A variance ratio greater than one, for example, implies $\mathrm{cov}(r_{d,t-1}, r_{n,t}) > \mathrm{cov}(r_{n,t}, r_{d,t})$.

While the relative magnitude of the serial covariance expressions are important in understanding why the ratio (5) is different from one, the levels of the covariances can be used to infer if the cost of immediacy imposed by the specialist is a source of volatility at the opening. During the trading day, negative serial dependence in returns is caused by movement between bid and ask prices levels, as shown in Roll (1984) and Stoll (1989). While no bid–ask spread exists at the open, a similar transaction cost is imposed when the specialist backs away from active orders. The implied spread at the open vis-à-vis the implied spread at the close should therefore reflect the difference in the cost of immediacy at the two different points in the day.[10]

[10] If the volatility is induced by traders with private information rather than by suppliers of immediacy, the serial covariance in returns will be zero. Glosten and Harris (1988), Stoll (1989), and Hasbrouck (1988) distinguish empirically these two sources of volatility. Positive serial dependence implies a lagged adjustment of market prices to information as in Goldman and Beja (1979) and Hasbrouck and Ho (1987).

2.3 Daytime and nighttime volatility

The computation of daytime and overnight returns also allows us to investigate directly whether volatility is different in periods when the market is open than it is when the market is closed. Since the market is closed for 18 hours and is open for 6, it seems reasonable to expect overnight volatility to be about 3 times higher than daytime volatility. French and Roll (1986) investigate the variance of returns in trading–nontrading periods by comparing the variance of one-day close-to-close returns with two- and three-day close-to-close returns spanning holidays and weekends and conclude that nontrading period volatility is lower. Here, with the use of opening and closing prices, we can measure trading–nontrading returns more precisely.

3. Data

The sample used in this study is the most comprehensive of any published market microstructure study to date. The data source is the Francis Emory Fitch, Inc. ("Fitch") transaction file. It contains time-stamped records of all transactions on the New York Stock Exchange. From the Fitch file, the following information is compiled for each NYSE common stock in each day during the five-year period 1982–1986: the time, price, and volume[11] of the opening transaction; the time, price, and volume[12] of the closing transaction; and the total share volume for the day. The Center for Research in Security Prices (CRSP) daily master file is used to adjust for cash dividends, stock splits, and stock dividends in calculating returns from the Fitch price data.

Four exclusionary criteria were applied. Individual stocks were eliminated from the sample for the entire year if the stock traded in fewer than 100 days during the year or if the stock traded at a share price of less than $3 at any time during the year. In addition, individual stocks were eliminated from the sample in a particular month if the stock had fewer than 15 price observations during the month, and any daily return in the month greater (less) than 50 (−50) percent was eliminated.

4. Characteristics of Openings and Closings

Since relatively little is known about the characteristics of the opening and the closing transactions of the day, we report the distribution of

[11] The Fitch data report transaction times by minute. The opening volume is defined as the sum of all shares traded at the opening price and during the minute of the opening. More than one opening transaction record sometimes appears on the Fitch tape.

[12] The closing volume is defined as the number of shares traded in the last transaction.

the times until the first transaction in individual stocks and the distribution of the times between the final transactions in individual stocks and the closing of the exchange. We also present evidence on the proportion of daily trading occurring at the opening transaction.

4.1 Timing

Descriptive statistics on the timing of opening and closing transactions are contained in Table 1. It is interesting to note that considerable time elapses before stocks actually begin trading in a given day. In 1986, for example, the average number of minutes between the official opening of the exchange and the opening transaction in a stock was 15.48 minutes. It is also interesting to note that trading typically stops well before the exchange closes. An average of 19.94 minutes elapsed between the last trade and the close of the market in 1986. Between 1982 and 1986, the average time to open declined by 5.27 minutes, and the average time from the last trade to the close declined by 9.01 minutes. Both of these changes reflect, in part, the increase in stock market activity from the beginning of the sample period to the end.

Table 1 also shows that cross-sectional differences in no-trade intervals are related to the average daily dollar trading volume of trading of individual stocks.[13] In 1986, for example, the stocks in the lowest daily dollar volume decile, on average, did not trade until over one hour after the exchange had opened. For less active stocks, the opening transaction is less likely to represent an auction since relatively few orders have accumulated overnight. Instead, for less active stocks, the opening transaction is likely to represent the execution of an order submitted after the exchange opening.

As dollar volume increases, the average time until the first transaction declines—to a low of 4.15 minutes in decile nine. The opening transaction in higher-volume stocks is likely to reflect an opening auction of orders that have accumulated overnight, but the announcement of the opening price can take time because the specialist opens in sequence the stocks for which he is responsible. The opening of certain stocks can be officially delayed because large imbalances have accumulated overnight. In a delayed opening, the specialist follows disclosure procedures for attracting offsetting orders and is monitored by a floor governor. The increase in the average time to opening for the largest volume decile (to 4.98 minutes in 1986) reflects delayed openings. The average time between the last trade and the close of the market decreases monotonically with volume to less than a minute for the highest-volume stocks.

[13] In Table 1, stocks are ranked within each month by average daily dollar trading volume in the month and clustered into deciles (and quintiles) each month during the sample period.

Table 1
Time to opening and time between last trade and market close by year and dollar volume decile for NYSE common stocks during the period 1982–1986

	1982	1983	1984	1985	1986
Average number of minutes from open to first trade[1]					
All stock days	20.75	15.56	17.29	15.97	15.48
By daily dollar volume decile					
Smallest	82.91	62.34	70.34	68.59	67.40
2	35.37	23.37	28.25	26.49	25.78
3	21.99	14.92	18.64	16.32	16.09
4	15.40	10.86	13.41	11.89	11.49
5	11.58	9.13	10.46	9.28	8.77
6	9.30	7.92	8.54	7.24	6.71
7	8.02	7.06	6.93	5.85	5.46
8	7.23	6.46	5.77	4.99	4.45
9	6.85	6.31	5.09	4.41	4.15
Largest	8.79	7.23	5.44	4.95	4.98
Average number of minutes from last trade to close[1]					
All stock days	28.95	23.60	26.55	22.44	19.94
By daily dollar volume decile					
Smallest	103.07	87.51	90.20	84.91	83.71
2	54.76	42.49	47.71	41.68	38.30
3	38.13	29.38	34.39	28.63	25.08
4	27.88	22.15	26.07	21.25	17.56
5	20.66	16.90	20.46	15.99	12.79
6	15.64	13.25	15.88	12.23	9.14
7	12.25	10.18	12.22	8.82	6.39
8	8.98	7.43	8.96	6.05	4.02
9	5.68	4.80	5.49	3.80	2.21
Largest	2.46	1.91	2.08	1.41	0.78
Number of stock days[2]	339,720	365,469	340,094	333,757	348,907

[1] The times are based on the trade times indicated on the Fitch data tapes and the following NYSE hours: 10:00 A.M. to 4:00 P.M. (EST) from September 1, 1982 through September 27, 1985; and 9:30 A.M. to 4:00 P.M. from September 30, 1985, to December 31, 1986.

[2] The sample of stocks is restricted to common stocks trading at least 100 days in the year and never trading below $3.00.

The results in Table 1 can be used to infer the extent to which trading in a stock index portfolio, such as the S&P 500, lags the stock market open and ends before the stock market close. S&P 500 stocks are generally high-dollar-volume stocks. Since each decile contains approximately 140 stocks, most of the S&P 500 stocks are likely to be contained in the largest four deciles. The average time to open does not vary much across these deciles. It was between 4.15 and 5.46 minutes in 1986. Considerably more variation across the largest four deciles arises at the close—between 0.78 and 6.39 minutes in 1986.

Variations across days of the week in the timing of trading were also examined but are not presented.[14] During 1986, the average time to open was smallest on Tuesday at 14.21 minutes and largest on Friday at 16.87 minutes. Average time to close is smallest on Friday at 19.04 minutes.

[14] Detailed results are available from the authors.

Table 2
Volume at the opening as a proportion of daily volume, by year and dollar volume decile, for NYSE common stocks during the period 1982–1986

	1982	1983	1984	1985	1986
Average daily dollar volume (× 1000)	1,349	2,012	2,007	2,604	3,725
Average proportion of volume at open[1]					
All stock days	0.1537	0.1381	0.1396	0.1268	0.1059
By daily dollar volume decile					
Smallest	0.4544	0.3691	0.4006	0.3688	0.3276
2	0.2209	0.1849	0.1962	0.1769	0.1498
3	0.1679	0.1478	0.1543	0.1392	0.1152
4	0.1389	0.1292	0.1308	0.1182	0.0946
5	0.1221	0.1159	0.1143	0.1025	0.0804
6	0.1082	0.1041	0.0997	0.0897	0.0670
7	0.0946	0.0944	0.0876	0.0794	0.0621
8	0.0851	0.0846	0.0773	0.0705	0.0557
9	0.0734	0.0776	0.0697	0.0635	0.0527
Largest	0.0720	0.0736	0.0654	0.0593	0.0533
Number of stock days[2]	339,720	365,469	340,094	333,757	348,907

[1] Opening dollar volume is defined as the value of all trades at the first price occurring at the same time.

[2] The sample of stocks is restricted to common stocks trading at least 100 days in the year and never trading below $3.00.

4.2 Volume at the opening

In this study, opening share volume is defined as the number of shares traded in the first transaction.[15] Both opening share volume and total share volume are computed for each stock on each day. Table 2 summarizes the average proportions of total daily volume accounted for by the opening trades during 1982–1986.

In the period 1982 through 1986, daily dollar volume nearly tripled, and opening volume as a fraction of daily volume fell from an average of 15.37 percent to an average of 10.59 percent. Variation in the proportion of the daily volume that occurs at the open across dollar volume deciles is large. In 1986, for example, the proportion is about 32 percent for the smallest daily volume decile and 5.3 percent for the largest dollar volume decile. A larger proportion of daily trading volume appears to take place at the open for less active stocks.

Although opening volume is a smaller proportion of total daily volume in high-volume stocks than in low-volume stocks, the rate of trading over the interval up to the opening trade is greater for high-volume stocks. Since there are 390 minutes in the trading day,[16] the 1986 opening volume in the largest-volume decile amounts to 20.79 (0.0533 × 390) minutes worth of trading. Because the time to open

[15] When more than one transaction is reported at the opening price, the volume of trading at the same price in the minute after the first transaction is aggregated.

[16] Beginning on September 30, 1985, the NYSE opened 30 minutes earlier. Prior to that time the exchange hours were 10 A.M. to 4 P.M. (EST).

averages 4.98 minutes for the largest stocks, opening volume is 4.17 times normal volume. In the case of the lowest-volume stocks, opening volume accounts for about 127.76 (0.3276 × 390) minutes of trading. Because the time to open takes about 67.40 minutes, opening volume is 1.9 times normal volume in the lowest-volume stocks. In other words, relative to the average rate of trading during the day, opening volume is at a greater rate for large than for small stocks; and this finding reflects the fact that small stocks are less likely to accumulate orders overnight.

Variations in opening volume by day of the week also were examined, although detailed results are not presented here. The average daily dollar volume is fairly uniform across the days of the week, with the exception of Monday, when volume is lower. The proportion of volume accounted for by the opening trade, however, is virtually identical across days—about 11 percent of the total daily volume in 1986.

5. Volatility at the Opening

We now turn to our first analysis of return volatility. In spirit, this section is similar to Amihud and Mendelson (1987) in the sense that we are examining open-to-open and close-to-close return volatilities. The most significant difference is that our data are much more comprehensive. While Amihud and Mendelson use returns for the 30 Dow Jones Industrial Average (DJIA) stocks during the period February 18, 1982, through February 18, 1983, we use all common stocks on the NYSE during the five-year period 1982–1986.

The analysis of return volatility begins with the computation of return variances. Return variances are calculated for each stock in each month during the period 1982–1986. The ratio of the return variances for each stock in each month is computed, and then the ratios are averaged across stocks in each month and then across the 60 months of the sample period. The results are shown in Table 3.

The average open-to-open/close-to-close variance ratio of 1.1329 reported in Table 3 indicates that open-to-open variance is about 12 percent higher than close-to-close variance on average. The average variance ratio also is calculated for the stocks within each daily dollar volume quintile. The average ratio for the stocks in the most active quintile is 1.1734. This compares with the value of 1.2 reported by Amihud and Mendelson (1987) for their sample of firms.

The second row of Table 3 reports the standard error of the variance ratio across the 60 months. These standard errors indicate that the variance ratio is significantly different from one. Under the null hypothesis, the probability of observing the ratio, 1.1329, is less than

Table 3
Average ratios of variances of open-to-open returns ($r_{o,t}$) relative to close-to-close returns ($r_{c,t}$) for NYSE common stocks during the period 1982–1986, and average difference in variances

	All stocks	By daily dollar volume quintile Smallest	2	3	4	Largest
Average variance ratio	1.1329	1.1180	1.1158	1.1200	1.1375	1.1734
Standard error of ratio[1]	0.0060	0.0062	0.0051	0.0066	0.0125	0.0156
Average standard deviation[2]	0.6226	0.5043	0.4248	0.4166	0.6119	0.5788
Average difference of variances (× 10,000)	0.3937	0.2070	0.2913	0.3762	0.4798	0.6142
Standard error of difference[1]	0.0471	0.0352	0.0359	0.0598	0.0666	0.0845
Average number of firms each month	1374	274	275	275	275	275
Sample size	60	60	60	60	60	60
Average dollar volume (× 1000)	2334	69	235	621	1753	8997

Variance ratios are calculated for each stock in each month, and are then averaged across all stocks in the sample and all stocks within each dollar trading volume quintile. Finally, the average monthly ratios are averaged across the 60 months in the five-year sample period. The average difference between the monthly average variance of open-to-open returns and the monthly average variance of close-to-close returns is also reported.

[1] The standard error is based on the distribution of the 60 monthly average values.

[2] In each month, the standard deviation of the variance ratio is calculated across the stocks. The average standard deviation reported in the table is the average of the monthly cross-sectional standard deviations of the variance ratios.

one-tenth of 1 percent. Furthermore, the volatility ratio for high-volume stocks significantly exceeds the volatility ratio for low-volume stocks. Since high-volume stocks are more likely to be opened by an auction procedure, these results suggest that the opening auction procedure is associated with increased volatility. Because the average variance ratio is upward biased by virtue of Jensen's inequality,[17] we also report the average difference in variances in the fourth row of Table 3. The null hypothesis that the open-to-open return variance equals the close-to-close return variance is also rejected.

6. Serial Dependence in Returns

The variance ratio results indicate that structural price volatility at the open is greater than at the close. The greater volatility of open-to-open returns indicates that trading shocks have a greater influence at the open than at the close. In this section, the first-order serial correlations in returns surrounding the open are examined.

6.1 Reversals

The greater volatility of open-to-open returns than close-to-close returns implies that the correlation between the daytime and follow-

[17] The extent of the bias is reflected in the ratios of average variances that correspond to the average variance ratios reported in the first row of Table 3. These are 1.0834, 1.0426, 1.0596, 1.0761, 1.1041, and 1.1428.

Table 4
Average serial correlations of returns in adjacent periods for NYSE common stocks during the period 1982–1986

	All stocks	By daily dollar volume quintile: Smallest	2	3	4	Largest
$\rho(r_n, r_d)$						
Average	−.0531	−.1224	−.0672	−.0396	−.0266	−.0098
Standard error[1]	.0033	.0035	.0043	.0040	.0040	.0063
Average standard deviation[2]	.2566	.2662	.2610	.2542	.2467	.2339
$\rho(r_{d-1}, r_n)$						
Average	.0202	−.0947	−.0144	.0298	.0574	.1225
Standard error[1]	.0064	.0047	.0059	.0068	.0072	.0105
Average standard deviation[2]	.2725	.2628	.2637	.2624	.2626	.2557
$\rho(r_{o-1}, r_o)$						
Average	−.0480	−.1130	−.0510	−.0271	−.0229	−.0263
Standard error[1]	.0033	.0035	.0041	.0035	.0038	.0068
Average standard deviation[2]	.2312	.2478	.2356	.2300	.2174	.2053
$\rho(r_{c-1}, r_c)$						
Average	−.0138	−.0936	−.0268	.0021	.0159	.0334
Standard error[1]	.0039	.0044	.0043	.0042	.0043	.0055
Average standard deviation[2]	.2336	.2470	.2368	.2280	.2204	.2095
Average number of firms each month	1,374	274	275	275	275	275
Sample size	60	60	60	60	60	60
Average dollar volume (× 1000)	2334	69	235	621	1753	8997

Serial correlations are calculated for each stock in each month and are then averaged across all stocks in the sample and all stocks within each dollar trading volume quintile. Finally, the average serial correlations are averaged across the 60 months in the five-year sample period.

[1] The standard error is based on the distribution of the 60 monthly average serial correlation estimates.

[2] In each month, the standard deviation of the serial correlation is calculated across the stocks. The average standard deviation reported in the table is the average of the monthly cross-sectional standard deviations of the serial correlations.

ing overnight return, $\rho(r_{d,t-1}, r_{n,t})$, exceeds the correlation between the overnight and following daytime return, $\rho(r_{n,t}, r_{d,t})$.[18] That implication is confirmed by the average serial correlations reported in the first two panels of Table 4. The results in the table show that $\rho(r_{d,t-1}, r_{n,t}) > \rho(r_{n,t}, r_{d,t})$ for all stocks and in each volume category.

The results in the last two panels of Table 4 show that the serial correlation in open-to-open returns, $\rho(r_{o,t-1}, r_{o,t})$, is negative in all volume categories, whereas the serial correlation in close-to-close returns, $\rho(r_{c,t-1}, r_{c,t})$, is negative only in the two smallest-volume quintiles and is positive in the other volume quintiles. This result means that open-to-open returns are more likely to be reversed than are close-to-close returns. Indeed, in close-to-close returns, there is evidence of price continuations among high-volume stocks. Price reversals are typical in dealer markets as a result of price movements between the bid and the ask [see Roll (1984) and Stoll (1989)]. Con-

[18] Serial correlations rather than serial covariances are reported to standardize across stocks.

trary to the null hypothesis, openings accentuate price reversals relative to those observed in closing prices.

The serial correlation in open-to-open returns depends in part on the serial correlation between the overnight return and the return the following day, $\rho(r_{n,t}, r_{d,t})$.[19] That correlation averages -0.0531 and is significantly different from zero. The negative correlation is much more pronounced for low-volume stocks than for high-volume stocks, however. The correlation in close-to-close returns depends in part on the serial correlation between the daytime return and the return the following night, $\rho(r_{d,t-1}, r_{n,t})$.[20] That correlation averages 0.0202 over all stocks. It is negative for the two lowest-volume categories and positive for the three highest-volume categories.

The serial correlation results for the components of the 24-hour return indicate that the overnight return tends to be reversed by the following daytime return. This is an indication of a temporary price deviation at the opening. On the other hand, the daytime return is much less likely to be reversed by the return in the following night. This suggests that the closing price is less likely to reflect a temporary deviation. Indeed, the positive serial dependence between the daytime return and the following overnight return observed in the high-volume stocks is evidence of a price continuation. Price continuations after the close and price reversals after the opening are consistent with a market in which public buying or selling pressure carries over from the close to the following opening.[21] Providers of immediacy, such as the specialist, are compensated by price reversals during the trading day following the opening. Additional insight into these issues is provided later in the article where we analyze the effect of the volume of trading on volatility and reversals.

6.2 Implied bid–ask spreads

Price reversals reflect the compensation of suppliers of immediacy for taking the other side of transactions initiated by active traders. In a dealer market, reversals reflect movements between bid and ask prices. In an auction market, similar reversals are observed even though no bid–ask spread is quoted because suppliers of immediacy back

[19] Since $r_{o,t} \equiv r_{d,t-1} + r_{n,t}$, the first-order serial covariance in open-to-open returns may be written as $\text{cov}(r_{d,t-2}, r_{d,t-1}) + \text{cov}(r_{d,t-1}, r_{n,t}) + \text{cov}(r_{n,t-1}, r_{d,t-1}) + \text{cov}(r_{n,t-1}, r_{n,t})$. The only term in the summation involving returns in adjacent time periods is the serial covariance between the overnight return and the return the following day, $\text{cov}(r_{n,t-1}, r_{d,t-1})$.

[20] Since $r_{c,t} \equiv r_{n,t} + r_{d,t}$, the serial covariance in close-to-close returns may be written as $\text{cov}(r_{n,t-1}, r_{n,t}) + \text{cov}(r_{n,t-1}, r_{d,t}) + \text{cov}(r_{d,t-1}, r_{n,t}) + \text{cov}(r_{d,t-1}, r_{d,t})$. The only term in the summation involving returns in adjacent time periods is the serial covariance between the daytime return and the return the following night, $\text{cov}(r_{d,t-1}, r_{n,t})$.

[21] One explanation for price continuations suggested by William Spitz is the pecking-order theory of research recommendations, which implies that favored clients receive recommendations before the general public.

away from active traders.[22] Under the assumption of market efficiency and certain other assumptions about dealer behavior, Roll (1984) shows that the bid–ask spread is given by $S = 2\sqrt{-\text{cov}}$, where cov is the first-order serial covariance of returns. While Stoll (1989) and others show that Roll's procedure underestimates the quoted bid–ask spread, the procedure conveys the relative magnitude of transaction costs.

Roll's procedure is used to calculate the bid–ask spreads implied by the serial covariances of returns between the overnight return and the return the following day, between the daytime return and the return the following night, between successive open-to-open returns, and between successive close-to-close returns. Serial covariances are calculated for each stock in each month and then are averaged across stocks in each dollar volume quintile in each month.[23] The average serial covariances for each quintile in each month are used to compute the implied spreads, and then the monthly spreads are averaged across the 60 months of the sample to generate the results reported in Table 5.

The different return series yield startlingly different implied spreads. The implied spread based on closing prices—the data used by Roll—is small (0.0971 percent) when averaged over all stocks in the period 1982–1986 and is negative for the most active quintile of stocks (−0.5505). A negative spread is unreasonable and simply reflects the fact that the underlying serial covariance is estimated to be positive. Roll (1984) also found a small average spread of 0.298 percent in the period 1963–1982 and a larger number of stocks with negative implied spreads. A positive serial dependence is also present between the daytime return and the following overnight return. The spread implied by this series of returns is negative for every trading volume category except the lowest. The evidence implies that the "momentum" of prices during the day is carried over to the next morning's open.

On the other hand, the implied spread based on open-to-open returns yields a significant positive spread for all volume categories. Over all stocks, the spread implied by open-to-open returns is 0.8983 percent, or 50 cents on a $55 stock. This number is statistically and economically significant.[24] It is particularly significant economically in view of the fact that the Roll procedure underestimates the quoted

[22] Stoll and Haller (1989) show, for example, that prices tend to reverse in the German stock market, which is an auction market.

[23] Harris (1989) recommends cross-sectional averaging prior to calculating the Roll implied spread in order to reduce errors in the covariance estimates.

[24] McInish and Wood (1989) find that the quoted spread is higher in the first 15 minutes of the trading day than later in the trading day, although the difference is not as great as that between the implied spreads based on open-to-open returns and close-to-close returns.

Table 5
Average implied bid–ask spreads for all stocks and for stocks classified by daily dollar volume quintile in all months during the period 1982–1986

Dollar volume quintile		Implied bid–ask spreads (%)			
		(r_n, r_d)	$r_{d-1}, r_n)$	(r_o, r_{o-1})	(r_c, r_{c-1})
Smallest	Average spread	1.0626	0.7942	1.3327	1.0339
	Standard error[1]	0.0176	0.0477	0.0323	0.0641
	Proportion positive[2]	0.6825	0.6423	0.6752	0.6436
2	Average spread	0.7044	−0.0292	0.8217	0.2624
	Standard error[1]	0.0313	0.0801	0.0719	0.0968
	Proportion positive[2]	0.6073	0.5200	0.5855	0.5381
3	Average spread	0.4375	−0.4997	0.5836	−0.1812
	Standard error[1]	0.0465	0.0770	0.0774	0.0969
	Proportion positive[2]	0.5600	0.4545	0.5418	0.4873
4	Average spread	0.2290	−0.6996	0.4895	−0.3858
	Standard error[1]	0.0631	0.0636	0.0939	0.0935
	Proportion positive[2]	0.5418	0.4073	0.5345	0.4582
Largest	Average spread	0.2102	−0.9066	0.6006	−0.5505
	Standard error[1]	0.0653	0.0593	0.1176	0.0884
	Proportion positive[2]	0.5200	0.3164	0.5455	0.4291
All stocks	Average spread	0.6602	−0.2943	0.8983	0.0971
	Standard error[1]	0.0245	0.0784	0.0536	0.0884
	Proportion positive[2]	0.5822	0.4680	0.5764	0.5131

Spreads are calculated according to Roll's (1984) model as $2\sqrt{-\text{cov}}$. For the sequence of returns listed at the top of each column, the serial covariances for stocks in each month are averaged across all stocks in each month in each volume category. The implied spread is calculated from the average serial covariance in that month, and average values over the 60 months in the data set are reported in the table. If the average serial covariance is positive, we take the square root of the absolute value of the covariance and reattach the negative sign.

[1] The standard error is based on the distribution of the 60 monthly average implied spread estimates.

[2] The proportion positive is the average number of stocks with positive spreads divided by average number of stocks in the volume category. Each volume category contains an average of 275 stocks except the smallest, which contains 274.

spread. A significant positive spread also is implied by the serial covariance between the overnight return and the return the following day. Over all stocks, the spread is 0.6602 percent. Furthermore, it is positive for all volume categories and declines from the smallest-volume category (1.0626 percent) to the largest-volume category (0.2102 percent). These results imply that prices established at the open tend to be reversed during the rest of the day, and they are consistent with the view that the volatility of open-to-open returns is due in part to temporary price deviations necessary to compensate providers of liquidity at the open. To the extent the specialist is an important provider of liquidity at the open, he benefits from the price reversals.

7. Daytime versus Overnight Volatility

Oldfield and Rogalski (1980, p. 734) report that the variance of daytime (open-to-close) returns is 4.26 times higher than the variance

Table 6
Average ratios of variances of open-to-close returns ($r_{d,t}$) relative to close-to-open returns ($r_{n,t}$) for NYSE common stocks during the period 1982–1986

	All stocks	By daily dollar volume quintile Smallest	2	3	4	Largest
Average ratio	5.3968	2.9109	4.5491	5.7564	6.6784	7.0856
Standard error[1]	0.1272	0.0725	0.1117	0.1533	0.1861	0.2055
Average standard deviation[2]	5.9024	2.3520	3.4411	4.5968	6.0921	7.6733
Average number of firms each month	1374	274	275	275	275	275
Sample size	60	60	60	60	60	60
Average dollar volume (× 1000)	2334	69	235	621	1753	8997

Variance ratios are calculated for each stock in each month and are then averaged across all stocks in the sample and all stocks within each dollar trading volume quintile. Finally, the average monthly ratios are averaged across the 60 months in the five-year sample period.

[1] The standard error is based on the distribution of the 60 monthly average ratios.

[2] In each month, the standard deviation of the variance ratio is calculated across the stocks. The average standard deviation reported in the table is the average of the monthly cross-sectional standard deviations of the variance ratios.

of overnight (previous close-to-open) returns for a sample of five firms during the 39-month period October 1, 1974, through December 31, 1977. Since trading occurs over six hours and nontrading occurs over 18 hours, the per-hour ratio of variances implied by this number is 12.78. French and Roll (1986, p. 9) use daily closing prices of NYSE and AMEX stocks during the 20-year period 1963–1982 and the fact that exchanges are closed on weekends and holidays to infer that the per-hour ratio of variances in trading versus nontrading periods is 13.2. Clearly, there appears to be an interesting phenomenon at work, and the data used in this study allow us to provide more comprehensive and complete documentary evidence of the trading–nontrading volatility effect.

Table 6 shows the average variance ratios of daytime returns to overnight returns for NYSE stocks during the sample period January 1982 through December 1986. The average of the monthly ratios is approximately 5.40, which implies an average per-hour ratio of daytime to overnight variances of 16.20. This number is higher than the values reported in the other two studies and may reflect, in part, the greater trading activity in recent years.

Also evident in Table 6 is a strong positive association between the average variance ratio and the daily dollar volume quintile. It is known that the return variance of a stock is smaller the larger the volume of trading in the stock, but Table 6 shows that the ratio of the daytime to the overnight variance is larger the larger the volume of trading in the stock.[25] In other words, a stock in the lowest-volume quintile

[25] French and Roll (1986) do not find any association between the variance ratio and the equity value of the firm.

has a larger daytime and a larger overnight variance of returns than a stock in the highest-volume quintile, but for the low-volume stock the overnight return variance is relatively higher than the daytime return variance. Two factors explain this relation. First, since the overnight return variance is heavily influenced by the variance of the opening price, the volume pattern in Table 6 implies that opening procedures have a greater impact on the volatility of low-volume stocks than they do on the volatility of high-volume stocks. Second, since low-volume stocks are slow to open, their opening prices (and thus their overnight volatility) tend to reflect marketwide volatility that is already incorporated in the daytime returns of more active stocks.

8. Trading Volume and Price Volatility

The evidence to this point reveals several empirical regularities. First, the average ratio of the variance of open-to-open returns to the variance of close-to-close returns is greater than one and increases with the daily dollar volume trading activity. On the basis of this evidence, the null hypothesis that trading shocks are smaller at the open than at the close is rejected. Second, the serial dependence in open-to-open returns and between the overnight and following daytime return is negative in all volume categories, and it is less negative in high-volume stocks than in low-volume stocks. This evidence implies that the suppliers of liquidity, who are compensated by price reversals, are responsible, at least in part, for the higher volatility of the opening. This compensation is greater in low-volume stocks than in high-volume stocks. Third, the serial dependence in close-to-close returns and between the daytime return and the following overnight return, while negative in the two smallest-volume categories, is positive in the remaining three-volume categories. This positive correlation suggests the presence of price momentum between the closing price and the next morning's open. In this section, we examine the relation between volatility and trading shocks at the opening, at the close, and during the day. This analysis gives further insight into the source of the first empirical regularity—the greater volatility of open-to-open returns than of close-to-close returns. In the next section, the extent to which price reversals are related to volume and price delays is examined. This will provide insight into the sources of serial dependence in returns.

The relation between return in a stock and trading shocks is expressed by Equation (2):

$$r_t = e_t + (u_t - u_{t-1}) \tag{2}$$

As shown in Figure 1, the values of u_t and u_{t-1} depend on order imbalances at the beginning point and ending point of the return interval. The direction and magnitude of imbalances in orders are not directly observable; however, knowledge of the direction of imbalances is not necessary in assessing their effect on volatility.[26] Only the magnitude of the imbalance is required. A natural proxy for the order imbalance is the abnormal volume of shares traded. In U.S. markets, abnormally high trading volume is usually an indication of a trading imbalance since efficient procedures for bringing in the other side of a trade on short notice do not exist.

In addition to the presence of high volume at the open, another indication of an order imbalance is a delay in opening a stock. In the actively traded stocks, such delays typically occur as the specialist seeks to round up the other side of the imbalance. In less actively traded stocks, a delayed open may simply mean the absence of any orders. Because of this fact, the analysis is carried out for stocks classified into dollar volume deciles.

While Equation (2) is most natural when applied to successive transactions, some returns, such as the daytime return, are defined over a time interval encompassing many transactions. An interesting issue to investigate is the extent to which throughput volume (i.e., volume between the open and the close as opposed to volume at the open or at the close) is related to return volatility. If trading volume is due to liquidity trading, price effects would reflect the cost of supplying immediacy. In such a world, price changes would tend to be fully reversed, in which case throughput volume would not be related to return volatility. On the other hand, if volume were due to information trading, throughput volume would be related to return volatility because price changes would not tend to be reversed.

8.1 Overnight and daytime volatility

Our first investigation involves regressing the volatility of overnight and daytime returns on proxies for trading shocks. In these regressions, volatility is measured by the absolute value of the return.[27] Trading shocks are proxied by standardized volume or standardized time delay. Each observation for a stock is standardized by subtracting the mean for the stock in the month and dividing by the monthly standard deviation.[28]

[26] Hasbrouck (1988) and Blume, MacKinlay, and Terker (1989) sign the imbalance on the basis of the sign of the price change.

[27] An alternative proxy for return volatility is the square of return.

[28] In running the regressions, we exclude stock-days in which splits or stock dividends occurred since we use share volume as a variable. We could use dollar volume, but on exdays that might induce spurious correlation with our dependent variable.

In the first regression, the absolute value of the overnight return is regressed on D_t, a dummy variable taking the value one on Monday and zero on other days; $v_{c,t-1}$, standardized share volume at the close on day $t-1$; $v_{o,t}$, standardized share volume at the open on day t; and τ_t, standardized proportion of the trading day elapsed before the first trade occurs, that is,

$$|r_{n,t}| = a_0 + a_1 D_t + a_2 v_{c,t-1} + a_3 v_{o,t} + a_4 \tau_t + \epsilon_t \tag{6}$$

Under the null hypothesis that order imbalances do not affect volatility, the coefficients a_2, a_3, and a_4 should equal zero. The coefficient a_1 is zero under the null hypothesis that a close-to-open return spanning a weekend has the same volatility as an overnight return not spanning a weekend. In the second regression, the absolute value of the daytime return is regressed on the Monday dummy; on standardized end-point volumes, $v_{o,t}$ and $v_{c,t}$; on standardized throughput volume defined as standardized daily share volume not including the standardized end-point volumes, w_t; and on the standardized delay at the open, τ_t, that is,

$$|r_{d,t}| = a_0 + a_1 D_t + a_2 v_{o,t} + a_3 v_{c,t} + a_4 w_t + a_5 \tau_t + \epsilon_t \tag{7}$$

The coefficients in Equation (7) have the same interpretation as those in Equation (6) except for the coefficient on throughput volume, a_4. Under the null hypothesis that imbalances do not have price effects, a_4 is zero; but a_4 is also zero if imbalances have price effects that are reversed during the day. A nonzero value of a_4 implies the presence of informed traders who convey information by trading.

Regressions (6) and (7) are performed on daily data for individual stocks classified each month into 10 groups according to average daily dollar volume of trading in the month, and the results are reported in Table 7. The monthly dollar volume of each stock also is included as an independent variable in the regressions in order to provide an additional control. The coefficient values are not reported for this variable.

The first panel of Table 7 focuses on the overnight return that ends with the opening price, and the second panel focuses on the daytime return that ends with the closing price. As one might expect, the overnight return ending with the Monday opening price is more volatile than are other overnight returns during the week—0.129 percent more in the case of the highest-dollar-volume stocks. However, as others have noted, this difference in volatility is not proportional to the greater time elapsed. The daytime return on Monday also exhibits slightly higher volatility than on other days, but the effect is small and of marginal statistical significance given the large number of observations.

Table 7
Results of time-series, cross-sectional regressions of overnight return volatility $|r_{n,t}|$ and daytime return volatility $|r_{d,t}|$ on trading volume and delayed openings for NYSE common stocks during the period 1982–1986

	Smallest	2	3	8	9	Largest
	$|r_{n,t}| = a_0 + a_1 D_t + a_2 v_{c,t-1} + a_3 v_{o,t} + a_4 \tau_t + \epsilon_t$					
$\hat{a}_0$	1.0826	0.8798	0.8159	0.6673	0.6046	0.5158
	(201.51)[1]	(152.68)	(144.56)	(130.88)	(140.83)	(171.23)
$\hat{a}_1$	0.0486	0.0628	0.0552	0.0727	0.0880	0.1295
	(7.63)	(11.71)	(11.09)	(14.82)	(19.63)	(24.70)
$\hat{a}_2$	0.0052	0.0017	0.0013	−0.0019	0.0009	−0.0049
	(2.01)	(0.79)	(0.67)	(−0.97)	(0.49)	(−2.31)
$\hat{a}_3$	0.1308	0.1490	0.1488	0.1755	0.1733	0.1921
	(50.77)	(68.88)	(74.19)	(86.41)	(90.34)	(78.19)
$\hat{a}_4$	−0.0302	−0.0172	−0.0047	0.1418	0.1784	0.2352
	(−11.73)	(−7.93)	(−2.33)	(69.89)	(93.12)	(95.96)
$\bar{R}^2$	0.0267	0.0317	0.0347	0.0894	0.1328	0.1569
Number of observations	162,789	169,215	170,044	170,647	170,686	170,104
	$|r_{d,t}| = a_0 + a_1 D_t + a_2 v_{o,t} + a_3 v_{c,t} + a_4 w_t + a_5 \tau_t + \epsilon_t$					
$\hat{a}_0$	1.0557	1.1812	1.2089	1.3597	1.3722	1.2938
	(134.54)	(121.79)	(118.88)	(159.12)	(178.62)	(289.02)
$\hat{a}_1$	0.0260	0.0306	0.0381	0.0340	0.0521	0.0750
	(2.79)	(3.39)	(4.25)	(4.12)	(6.48)	(9.61)
$\hat{a}_2$	0.3451	0.3387	0.3217	0.2821	0.2878	0.2798
	(71.59)	(73.93)	(71.10)	(66.78)	(68.89)	(65.73)
$\hat{a}_3$	0.4750	0.4275	0.4049	0.3494	0.3632	0.4045
	(98.86)	(90.10)	(85.41)	(78.18)	(82.90)	(93.73)
$\hat{a}_4$	0.4657	0.4145	0.3817	0.3190	0.3275	0.3637
	(106.17)	(102.86)	(97.00)	(90.98)	(94.77)	(104.94)
$\hat{a}_5$	−0.1037	−0.0675	−0.0570	−0.0085	−0.0132	−0.0134
	(−26.86)	(−18.32)	(−15.67)	(−2.51)	(−3.85)	(−3.68)
$\bar{R}^2$	0.0911	0.0723	0.0627	0.0510	0.0566	0.0675
Number of observations	162,789	169,215	170,044	170,647	170,686	170,104

Stocks are classified into 10 groups based on average monthly dollar volume of trading. Regression results for stocks falling into the three lowest-volume and three highest-volume groups are reported in this table.

The notation used in this table is as follows: $D_t = 1$ of day t is a Monday, 0 otherwise; $r_{n,t} \equiv$ close-to-open return in percent; $r_{d,t} \equiv$ open-to-close return in percent; $v_{o,t} \equiv$ opening standardized share volume on day t; $v_{c,t} \equiv$ closing standardized share volume on day t; $v_t \equiv$ total standardized share volume for day t; $\tau_t \equiv$ standardized minutes until first trade in day t as a proportion of total minutes of trading in day t; and $w_t \equiv v_t - v_{o,t} - v_{c,t}$. Standardized variables are computed by subtracting the stock's mean value in the month and dividing by the standard deviation for the month.

[1] The values in parentheses are t-ratios.

Overnight volatility is strongly related to abnormal volume at the open, $v_{o,t}$, with t-values exceeding 50 in all volume categories. In the largest-volume category, a one-standard-deviation increase in opening volume is related to an increase in volatility of 0.192 percent. The effect of an increase in time to opening, τ_t, has a different interpretation depending on the volume category of the stock. Among high-volume stocks an increase in the time to opening is likely to reflect difficulty in opening the stock. As a result a delay in opening has a strong positive association with overnight volatility. Among high-volume stocks a one-standard-deviation increase in the time to open is associated with an increase of 0.235 percent in overnight volatility. Among low-volume stocks, an increase in time to opening signifies inactivity and is associated with reduced volatility.

Daytime volatility is also strongly related to opening volume, and the coefficient is somewhat larger than in the overnight volatility regression. This implies that trading pressures at the open have lasting effects on volatility. Interestingly, the opening time delay, after accounting for opening volume, is not associated with increased volatility during the rest of the day. This implies that delayed openings are successful in establishing fair prices.[29] Throughput volume during the day, w_t, and closing volume, v_{ct}, also are significantly related to daytime volatility; and the magnitudes of all the volume coefficients are about the same in the daytime regression. The significance of the throughput volume, in particular, suggests the existence of price effects that are not reversed and implies the presence of information trading.

The results in Table 7 provide additional support for the proposition that market structure affects volatility. The influence of trading volume at the open is quite strong.[30] This effect implies an inability or unwillingness to find offsetting volume that would mitigate opening price volatility. The earlier finding that price changes at the open tend to be reversed, at least in part, implies that the volatility at openings is due in part to the presence of liquidity trading and the need to compensate providers of immediacy. The relation between volume and volatility is also strong during the remainder of the day. The fact that throughput volume has an association comparable in magnitude to the effect of end-point volume implies that an important source of structural volatility is information trading.

8.2 Open-to-open and close-to-close volatility

Having examined daytime and overnight volatility, we now investigate the difference between volatility based on the open-to-open return and volatility based on the close-to-close return. More specifically, we regress the difference in absolute value of open-to-open return and absolute value of close-to-close return of the preceding day (i.e., $|r_{o,t}| - |r_{c,t-1}|$) on end-point volume, throughput volume, and opening delays, that is,

$$\begin{aligned} |r_{o,t}| - |r_{c,t-1}| = a_0 &+ a_1 D_t + a_2 v_{c,t-2} + a_3 v_{o,t-1} + a_4 v_{c,t-1} \\ &+ a_5 v_{o,t} + a_6 w_{t-1} + a_7 \tau_t + a_8 \tau_{t-1} + \epsilon_t \end{aligned} \tag{8}$$

[29] In the low-volume categories, time delay is associated with reduced volatility during the rest of the day, but this simply reflects inactivity in those stocks.

[30] Other studies find a relation between volume and volatility, but they do not examine volume at the open and close as compared with volume at other times of the day. See Karpoff (1987) for a survey of the evidence.

Table 8
Results of time-series, cross-sectional regressions of the difference between open-to-open return volatility $|r_{o,t}|$ and close-to-close return volatility from the previous day $|r_{c,t-1}|$ on trading volume and delayed openings for NYSE common stocks during the period 1982–1986

$$|r_{o,t}| - |r_{c,t-1}| = a_0 + a_1 D_t + a_2 v_{c,t-2} + a_3 v_{o,t-1} + a_4 v_{c,t-1} + a_5 v_{o,t} + a_6 w_{t-1} + a_7 \tau_t + a_8 \tau_{t-1} + \epsilon_t$$

	Smallest	2	3	8	9	Largest
$\hat{a}_0$	−0.0383	−0.0238	−0.0144	−0.0020	0.0278	0.0217
	(−3.43)[1]	(−1.75)	(−1.07)	(−0.16)	(2.91)	(3.63)
$\hat{a}_1$	0.0739	0.0714	0.0719	0.1005	0.0682	0.0913
	(5.58)	(5.62)	(6.02)	(8.62)	(6.86)	(8.76)
$\hat{a}_2$	−0.0079	−0.0029	−0.0164	−0.0121	−0.0108	−0.0060
	(−1.47)	(−0.57)	(−3.40)	(−2.57)	(−2.69)	(−1.44)
$\hat{a}_3$	−0.0713	−0.0641	−0.0706	−0.0905	−0.0937	−0.1291
	(−10.37)	(−9.92)	(−11.70)	(−15.12)	(−18.08)	(−22.63)
$\hat{a}_4$	−0.0585	−0.0419	−0.0455	−0.0535	−0.0628	−0.1086
	(−8.52)	(−6.26)	(−7.17)	(−8.41)	(−11.52)	(−18.65)
$\hat{a}_5$	0.1306	0.1265	0.1255	0.1319	0.1358	0.1441
	(24.34)	(24.65)	(26.01)	(27.19)	(31.70)	(29.22)
$\hat{a}_6$	−0.0404	−0.0315	−0.0331	−0.0342	−0.0433	−0.0823
	(−6.45)	(−5.53)	(−6.29)	(−6.86)	(−10.05)	(−17.59)
$\hat{a}_7$	0.0011	−0.0014	0.0205	0.1346	0.1618	0.2085
	(0.20)	(−0.27)	(4.26)	(27.91)	(38.05)	(42.76)
$\hat{a}_8$	−0.0197	−0.0085	−0.0186	−0.0604	−0.0765	−0.1003
	(−3.58)	(−1.64)	(−3.84)	(−12.51)	(−17.98)	(−20.58)
$\bar{R}^2$	0.0047	0.0044	0.0052	0.0147	0.0263	0.0387
Number of observations	162,789	169,215	170,044	170,647	170,686	170,104

Stocks are classified into 10 groups based on average monthly dollar volume of trading. Regression results for stocks falling into the three lowest-volume and three highest-volume groups are reported in this table.

The notation used in this table is as follows: $D_t = 1$ if day t is a Monday, 0 otherwise; $r_{n,t} \equiv$ close-to-open return in percent; $r_{d,t} \equiv$ open-to-close return in percent; $v_{o,t} \equiv$ opening standardized share volume on day t; $v_{c,t} \equiv$ closing standardized share volume on date t; $v_t \equiv$ total standardized share volume for day t; $\tau_t \equiv$ standardized minutes until first trade in day t as a proportion of total minutes of trading in day t; and $w_t \equiv v_t - v_{o,t} - v_{c,t}$. Standardized variables are computed by subtracting the stock's mean value in the month and dividing by the standard deviation for the month.

[1] The values in parentheses are t-ratios.

The results are shown in Table 8.

The results in Table 8 are consistent with those in Table 7. Variables that increase overnight volatility—opening volume and time delay at the open—increase the volatility of open-to-open returns as compared with close-to-close returns. Variables that increase daytime volatility—daytime volume and closing volume—decrease the volatility of open-to-open returns as compared with close-to-close returns. The fact that lagged values of opening volume and of time delay enter with a negative sign indicates that changes in these variables are related to increased volatility.

Table 9 shows results of a comparable regression for the difference between absolute daytime and absolute overnight returns. These results are also directly consistent with the results in Table 7. While normal daytime volatility exceeds normal overnight volatility as reflected in the intercept term, abnormally high volume during day t or at the close of day t substantially raises daytime relative to overnight volatility. Abnormal opening volume increases both overnight and daytime volatility and has a smaller net effect on the difference. The difference in volatilities is reduced by abnormal opening delays. In the high-volume stocks such delays are related to increases in overnight volatility without increasing daytime volatility.

On the basis of the regression results, we strongly reject the hypothesis that order imbalances, as proxied by volume and delays in opening, are not related to volatility. Overnight volatility is strongly related to opening volume and delays in opening a stock. Daytime volatility is strongly related to volume at the open, at the close, and during the day. The difference between open-to-open volatility and close-to-close volatility reflects the same factors. Increases in opening volume and in time delays at the open increase open-to-open volatility relative to close-to-close volatility. Larger daytime volumes decrease open-to-open volatility relative to close-to-close volatility. The fact that throughput volume during the day is significantly related to volatility during the day means that price changes during the day are not fully reversed, and this in turn implies that volume is at least in part associated with information trading.

9. Transaction Volume and Price Reversals

The empirical results of the previous section do not identify whether the observed association between trading shocks and volatility arises from the greater costs of providing immediacy to liquidity traders when volume is high or solely from the presence of information trading. In this section, tests are performed to help distinguish these sources of volatility. Providers of immediacy, such as the specialist, are compensated by price reversals. The specialist tends to be passive and buys when others are selling and sells when others are buying. If the specialist is to make money, prices must recover after they have fallen, and they must fall after they have risen. In this section, we investigate whether the reversals documented earlier are related to volume of trading and opening delays.

The first-order serial dependence between the overnight return, $r_{n,t}$, and the daytime return, $r_{d,t}$, can be measured using the regression equation,

$$r_{d,t} = a_o + \alpha r_{n,t} + \epsilon_t \tag{9}$$

The results in the first panel of Table 4 indicate that the estimated value of α is negative, which means that reversals tend to occur. We

Table 9
Results of time-series, cross-sectional regressions of the difference between daytime return volatility $|r_{d,t}|$ and return volatility on the following night $|r_{n,t}|$ on trading volume and delayed openings for NYSE common stocks during the period 1982–1986

$$|r_{d,t}| - |r_{n,t}| = a_0 + a_1 D_t + a_2 v_{c,t-1} + a_3 v_{o,t} + a_4 v_{c,t} + a_5 w_t + a_6 \tau_t + \epsilon_t$$

	Smallest	2	3	8	9	Largest
$\hat{a}_0$	−0.0269	0.3013	0.3931	0.6935	0.7690	0.7806
	(−3.08)[1]	(28.91)	(36.48)	(73.52)	(92.35)	(153.14)
$\hat{a}_1$	−0.0225	−0.0324	−0.0175	−0.0449	−0.0436	−0.0676
	(−2.18)	(−3.34)	(−1.85)	(−4.93)	(−5.01)	(−7.60)
$\hat{a}_2$	0.0026	0.0027	−0.0015	0.0056	−0.0020	0.0066
	(0.63)	(0.70)	(−0.40)	(1.53)	(−0.58)	(1.85)
$\hat{a}_3$	0.2038	0.1752	0.1605	0.0713	0.0784	0.0445
	(38.04)	(35.57)	(33.46)	(15.28)	(17.29)	(9.17)
$\hat{a}_4$	0.4684	0.4159	0.3929	0.3013	0.3110	0.3300
	(87.75)	(81.54)	(78.21)	(61.07)	(65.47)	(67.15)
$\hat{a}_5$	0.4508	0.3939	0.3638	0.2696	0.2748	0.2948
	(92.51)	(90.92)	(87.23)	(69.60)	(73.30)	(74.67)
$\hat{a}_6$	−0.0764	−0.0532	−0.0540	−0.1494	−0.1900	−0.2452
	(−17.81)	(−13.43)	(−14.02)	(−36.78)	(−51.13)	(−59.09)
$\bar{R}^2$	0.0781	0.0605	0.0548	0.0474	0.0589	0.0789
Number of observations	162,789	169,215	170,044	170,647	170,686	170,104

Stocks are classified into 10 groups based on average monthly dollar volume of trading. Regression results for stocks falling into the three lowest-volume and three highest-volume groups are reported in this table.

The notation used in this table is as follows: $D_t = 1$ if day t is a Monday, 0 otherwise; $r_{n,t} \equiv$ close-to-open return in percent; $r_{d,t} \equiv$ open-to-close return in percent; $v_{o,t} \equiv$ opening standardized share volume on day t; $v_{c,t} \equiv$ closing standardized share volume on day t; $v_t \equiv$ total standardized share volume for day t; $\tau_t \equiv$ standardized minutes until first trade in day t as a proportion of total minutes of trading in day t; and $w_t \equiv v_t - v_{o,t} - v_{c,t}$. Standardized variables are computed by subtracting the stock's mean value in the month and dividing by the standard deviation for the month.

[1] The values in parentheses are t-ratios.

now investigate whether the magnitude of the reversal as measured by α is related to end-point volume, throughput volume, and opening delays. The following linear form is assumed:

$$\alpha = a_1 + a_2 D_t + a_3 v_{c,t-1} + a_4 v_{o,t} + a_5 v_{c,t} + a_6 w_t + a_7 \tau_t \quad (10)$$

Substituting for α in Equation (9) gives a regression equation with multiplicative independent variables, the results for which are shown in Table 10.

Consistent with the first panel of Table 4, the coefficient a_1 is significantly negative in all volume categories. This result indicates that providers of immediacy are being compensated. The fact that the absolute magnitude of the coefficient decreases as dollar trading volume increases probably reflects the smoothing effect of the large number of transactions in high-volume stocks. In low-volume stocks, we are more likely to observe successive transactions. In high-volume stocks, the daytime return spans many transactions, which attenuates

Table 10
Results of time-series, cross-sectional regressions of daytime return on following overnight return, trading volume, and delayed openings for NYSE common stocks during the period 1982–1986

$$r_{d,t} = a_0 + a_1 r_{n,t} + a_2 r_{n,t} D_t + a_3 r_{n,t} v_{c,t-1} + a_4 r_{n,t} v_{o,t} + a_5 r_{n,t} v_{c,t} + a_6 r_{n,t} w_t + a_7 r_{n,t} \tau_t + \epsilon_t$$

	Smallest	2	3	8	9	Largest
$\hat{a}_0$	−0.0120	−0.0305	−0.0681	−0.0068	−0.0063	0.0327
	(−1.21)[1]	(−2.38)	(−5.00)	(−0.57)	(−0.59)	(5.34)
$\hat{a}_1$	−0.2286	−0.2132	−0.1977	−0.0639	−0.0369	−0.0538
	(−57.24)	(−45.03)	(−38.30)	(−9.84)	(−5.52)	(−7.97)
$\hat{a}_2$	0.0061	0.0115	0.0502	0.0010	−0.0418	−0.0702
	(0.70)	(1.15)	(4.61)	(0.09)	(−3.74)	(−7.47)
$\hat{a}_3$	−0.0003	0.0083	0.0212	0.0007	0.0004	−0.0088
	(−0.07)	(2.01)	(4.67)	(0.14)	(0.08)	(−2.09)
$\hat{a}_4$	0.0830	0.1156	0.1122	0.0310	0.0179	0.0239
	(22.56)	(30.67)	(28.01)	(7.79)	(3.89)	(5.70)
$\hat{a}_5$	0.0933	0.1187	0.1339	0.1290	0.1294	0.0958
	(20.79)	(22.49)	(22.99)	(22.02)	(21.71)	(18.74)
$\hat{a}_6$	0.0987	0.1472	0.1552	0.1080	0.1186	0.0978
	(25.24)	(34.23)	(34.27)	(24.03)	(26.01)	(22.89)
$\hat{a}_7$	0.0556	0.0329	0.0215	−0.0007	0.0201	0.0086
	(15.34)	(8.13)	(4.85)	(−0.18)	(5.09)	(2.30)
$\bar{R}^2$	0.0284	0.0205	0.0163	0.0052	0.0056	0.0051
Number of observations	162,789	169,215	170,044	170,647	170,686	170,104

Stocks are classified into 10 groups based on average monthly dollar volume of trading. Regression results for stocks falling into the three lowest-volume and three highest-volume groups are reported in this table.

The notation used in this table is as follows: $D_t = 1$ if day t is a Monday, 0 otherwise; $r_{n,t} \equiv$ close-to-open return in percent; $r_{d,t} \equiv$ open-to-close return in percent; $v_{o,t} \equiv$ opening standardized share volume on day t; $v_{c,t} \equiv$ closing standardized share volume on day t; $v_t \equiv$ total standardized share volume for day t; $\tau_t \equiv$ standardized minutes until first trade in day t as a proportion of total minutes of trading in day t; and $w_t \equiv v_t - v_{o,t} - v_{c,t}$. Standardized variables are computed by subtracting the stock's mean value in the month and dividing by the standard deviation for the month.

[1] The values in parentheses are t-ratios.

the transaction-by-transaction reversals observed in the low-volume category.[31]

If high volume at the open or delayed openings were to accentuate reversals, the signs of a_4 and a_7 would be negative, but such is not the case. Instead, high volume at the open is associated with a price continuation.[32] When the overnight return is positive on large opening volume, the subsequent daytime return also tends to be positive, holding constant volume during the rest of the day. On the other hand, when the overnight return is positive on low volume at the open (i.e., standardized opening volume is negative), the subsequent daytime return tends to be negative, holding constant volume during

[31] Stoll and Whaley (1990) find for S&P 500 and non-S&P 500 stocks nearly identical serial correlation coefficients of −0.238 and −0.183, respectively, when the overnight return is regressed on the return in the last half-hour on the preceding day for a sample of 11 days.

[32] The significant positive coefficients for multiplicative variables that include volume on day t may also reflect the association of return (not absolute return) and volume that has been observed by others. See Mulherin and Gerety (1989).

the rest of the day. Similarly, below-average volume during the rest of the day is associated with a reversal of the overnight return. These results imply that successive periods of high volume are associated with price continuations, whereas alternating high- and low-volume periods are associated with price reversals. A period of low volume appears to give the specialist the opportunity to reverse a position. The average pattern of volume is for volume at the open to be negatively correlated with volume for the rest of the day,[33] which is consistent with price reversals around the open.

Table 11 is similar to Table 10, but it examines the serial correlation between the overnight return and the preceding day's return. In the three largest-volume categories, the important role of volume in reversals is evident. When opening volume, closing volume, or throughput volume on day $t - 1$ is high, the opening price on day t tends to reverse the return on day $t - 1$ (holding constant opening volume and opening delay on day t). In the absence of above-normal volume on day $t - 1$, the opening price tends to continue the preceding day's trend (a_1 is positive), particularly if opening volume and delay in opening are above normal. If opening volume is below normal, the tendency to reverse the preceding day's return is accentuated. In Table 4 we noted a tendency for price continuations between the daytime and following overnight return among large stocks. The results in Table 11 help explain this tendency and indicate that continuations depend importantly on the pattern of volume. In the low-volume category, the role of volume in reversals is less evident, and the tendency to reversals is reflected in the intercept term.

The results in Tables 10 and 11 give insight into the sources of volatility at the open. Prices determined at the open when opening volume is above normal do not tend to be reversed (Table 10), although they are followed by greater volatility (Table 7). Prices determined at the open when opening volume is below normal tend to be reversed (Table 10). Prices determined during the day when volume during the day is above normal tend to be reversed at the next day's open, particularly if opening volume on the next day is below normal (Table 11). These results are consistent with a market mechanism in which the specialist liquidates positions at low-volume openings. At such times, he may have more discretion in establishing a favorable price. In addition, it may be difficult to liquidate a position when opening volume is high because such occasions result in price continuations that force the specialist's inventory in the same direction as on the previous day.

[33] In other words, volume tends to be shifted. In a study of the Japanese stock market, Barclay, Litzenberger, and Warner (1988) also find that Saturday trading simply shifts volume from the rest of the week.

Table 11
Results of regressions of overnight return on preceding daytime return, trading volume, and delayed openings for NYSE common stocks during the period 1982–1986

$$r_{n,t} = a_0 + a_1 r_{d,t-1} + a_2 r_{d,t-1} D_t + a_3 r_{d,t-1} v_{o,t-1} + a_4 r_{d,t-1} v_{c,t-1} + a_5 r_{d,t-1} v_{o,t} + a_6 r_{d,t-1} w_{t-1} + a_7 r_{d,t-1} \tau_{t-1} + a_8 r_{d,t-1} \tau_t + \epsilon_t$$

	Smallest	2	3	8	9	Largest
$\hat{a}_0$	−0.0973	−0.0508	−0.0144	0.0009	0.0067	0.0258
	(−13.90)[1]	(−6.68)	(−1.93)	(0.14)	(1.25)	(7.46)
$\hat{a}_1$	−0.1046	−0.0499	−0.0255	0.0319	0.0455	0.0621
	(−51.09)	(−29.59)	(−16.40)	(21.18)	(31.87)	(38.18)
$\hat{a}_2$	−0.0154	−0.0190	−0.0276	−0.0182	−0.0227	−0.0337
	(−3.62)	(−5.28)	(−8.18)	(−5.50)	(−7.17)	(−9.46)
$\hat{a}_3$	0.0176	0.0184	0.0116	−0.0071	−0.0143	−0.0307
	(8.94)	(11.65)	(7.74)	(−4.71)	(−9.64)	(−17.49)
$\hat{a}_4$	0.0137	0.0063	0.0006	−0.0215	−0.0337	−0.0546
	(7.76)	(3.87)	(0.38)	(−13.59)	(−22.71)	(−33.87)
$\hat{a}_5$	0.0480	0.0531	0.0579	0.0393	0.0379	0.0472
	(29.73)	(43.05)	(51.13)	(33.92)	(32.89)	(33.08)
$\hat{a}_6$	0.0208	0.0122	0.0084	−0.0064	−0.0197	−0.0379
	(13.00)	(9.44)	(6.91)	(−5.41)	(−17.15)	(−28.35)
$\hat{a}_7$	−0.0112	−0.0049	−0.0044	0.0007	0.0044	−0.0001
	(−5.30)	(−3.07)	(−3.02)	(0.54)	(3.29)	(−0.08)
$\hat{a}_8$	−0.0160	−0.0081	0.0048	0.0485	0.0601	0.0678
	(−8.29)	(−4.98)	(3.18)	(37.37)	(48.58)	(45.12)
$\bar{R}^2$	0.0249	0.0168	0.0179	0.0325	0.0521	0.0680
Number of observations	162,789	169,215	170,044	170,647	170,686	170,104

Stocks are classified into 10 groups based on average monthly dollar volume of trading. Regression results for stocks falling into the three lowest-volume and three highest-volume groups are reported in this table.

The notation used in this table is as follows: $D_t = 1$ if day t is a Monday, 0 otherwise; $r_{n,t} \equiv$ close-to-open return in percent; $r_{d,t} \equiv$ open-to-close return in percent; $v_{o,t} \equiv$ opening standardized share volume on day t; $v_{c,t} \equiv$ closing standardized share volume on day t; $v_t \equiv$ total standardized share volume for day t; $\tau_t \equiv$ standardized minutes until first trade in day t as a proportion of total minutes of trading in day t; and $w_t \equiv v_t - v_{o,t} - v_{c,t}$. Standardized variables are computed by subtracting the stock's mean value in the month and dividing by the standard deviation for the month.

[1] The values in parentheses are t-ratios.

10. Summary and Conclusions

This article investigates the structure of the market at the open on the NYSE. An analytical framework for assessing the magnitude of the structurally induced price volatility is devised and then applied to price data for all NYSE common stocks during the period 1982–1986.

The article begins by describing the timing of opening and closing trades in individual stocks. In 1986, for example, the average delay between exchange open and the first trade of the day was 15.48 minutes, and the average time between the last trade and the exchange close was 19.94 minutes. The volume of trading at the open is shown to be substantial, accounting for about 19.5 minutes of trading in the highest-volume decile and about 128 minutes of trading in the lowest-volume decile. The most striking feature of these descriptive statistics is the relative infrequency of trading in many stocks.

The ratio of open-to-open return variance to close-to-close return variance is significantly greater than one for the sample of stocks used in this study. The greater volatility at the open cannot be due to the way in which public information is released since both the open-to-open return and the close-to-close return span the same period of time. The greater volatility at the open results either from the presence of private information revealed in trading or from the fortuitous nonsynchronization of liquidity trading that results in price effects and enables the suppliers of immediacy to earn revenues.

Negative serial correlation of overnight and daytime returns implies that prices tend to reverse around the open. This is an indication that suppliers of immediacy are extracting a premium for their services. The average implied spread across all stocks in the period 1982–1986 is 0.8983 percent if based on open-to-open returns, whereas it is only 0.0971 percent if based on close-to-close returns. This evidence means that prices have a greater tendency to reverse around the open than around the close. Modifications in market structures may be able to eliminate such volatility.

The evidence of negative serial dependence is not inconsistent with the presence of informed trading since prices are not fully reversed. Some component of price changes is likely to be related to the presence of private information revealed through trading. Indeed, in the large-volume stocks, positive serial dependence is observed.

Over the entire sample, daytime volatility is 5.4 times as large as overnight volatility. Most of this difference appears to be due to differences in the amount of public information released during the day as opposed to during the night. The ratio is smallest for lowest-volume stocks because low-volume stocks have greater overnight volatility.

The article investigates in detail the extent to which volatility of the overnight return and of the daytime return are related to volume of trading and delays in opening a stock. High volume at the open accentuates overnight return volatility, and high volume during the rest of the day accentuates daytime volatility. The fact that volatility of the daytime return, which spans many transactions, is related to volume during the day is evidence that volume has permanent effects on prices and in turn implies that private information is revealed through trading.

Among high-volume stocks, delayed openings accentuate overnight return volatility, as one might expect. Interestingly, volatility during the rest of the day is not greater than normal, holding constant other factors such as volume. This suggests that the price determined in delayed openings is "correct." Among low-volume stocks, a delay in opening means that volume is less than normal; and, as a result, daytime volatility is lower the longer the time to the first transaction.

The relation between price reversals and volume is also investigated. The opening price is more likely to reverse the price change of the preceding day if the volume on the prior day was above normal and if the opening volume is below normal. One interpretation of this finding is that openings on high volume are less under the control of the specialist than openings on low volume. Overnight returns on above-normal opening volume are more likely to be reversed during the rest of the day if daytime volume is below normal.

Demand-side factors play an important role in the pattern of prices. High volume tends to be associated with price continuations; that is, an overnight return based on high opening volume is likely to be of the same sign as the preceding day's daytime return. An overnight return on high opening volume tends not to be reversed during the rest of the day if volume during the rest of the day continues above normal.

The effect of stock market structure on the short-run volatility of stock prices is complex, and it is difficult to separate the volatility induced by demand-side factors from the volatility induced by the way stocks are opened. Nevertheless, documented behaviors such as greater volatility around the open, the effect of trading volume on volatility, and the greater return to suppliers of immediacy at the open make it desirable to investigate improvements in the structure of trading.

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