THE JOURNAL OF FINANCE • VOL. LIX, NO. 2 • APRIL 2004

Liquidity Externalities and Adverse Selection: Evidence from Trading after Hours

MICHAEL J. BARCLAY and TERRENCE HENDERSHOTT*

ABSTRACT

This paper examines liquidity externalities by analyzing trading costs after hours. There is less than 1/20 as many trades per unit time after hours as during the trading day. The reduced trading activity results in substantially higher trading costs: quoted and effective spreads are three to four times larger than during the trading day. The higher spreads reflect greater adverse selection and order persistence, but not higher dealer profits. Because liquidity provision remains competitive after hours, the greater adverse selection and higher trading costs provide a direct measure of the magnitude of the liquidity externalities generated during the trading day.

UNDERSTANDING NETWORK EFFECTS and liquidity externalities is one of the most important outstanding issues in market design (Madhavan (2000)) and market regulation (Macey and O'Hara (1999)). Liquidity externalities arise from bringing traders together in space and time to reduce search and trading costs. Bringing traders together creates liquidity externalities because the additional traders arriving in the marketplace reduce trading costs for all investors. To date, attention has focused almost exclusively on spatial network effects by examining the trading of securities in different markets at the same time (Lee (1993), Hasbrouck (1995), and others). In contrast, this paper studies the effects of temporal consolidation of trades by analyzing trading during and outside of exchange trading hours.

A well-known liquidity externality arises from asymmetric information. Rational informed traders break up their orders across markets and over time. This provides incentives for liquidity traders to consolidate their trades geographically (Garbade and Silber (1979), Mendelson (1982, 1987), Pagano (1989a, 1989b)) and intertemporally (Admati and Pfleiderer (1988) and Foster and Viswanathan (1990)). It has been difficult to document the importance of these liquidity externalities, however. Unless there are barriers that restrict the flow of orders from one trading venue to another, in equilibrium, contemporaneous

*Barclay and Hendershott are from the Simon School of Business, University of Rochester and Haas School of Business, University of California at Berkeley. We thank Tim McCormick for providing data and helpful comments. We also thank Rick Green (the editor); Joel Hasbrouck; Rich Lyons; an anonymous referee; and seminar participants at the Review of Financial Studies Conference on Investments in Imperfect Capital Markets, the University of California at Berkeley, the University of North Carolina, and the Economic Research group at Nasdaq for their helpful comments. Hendershott gratefully acknowledges support from the National Science Foundation. Any errors are our own.

trading costs must be equal across venues. Therefore, it is not surprising that existing studies have found little variation in trading costs for a given security in different markets. Intertemporal variation in the amount of informed and uninformed trading within the trading day (Admati and Pfleiderer (1988), Wood, McInish, and Ord (1985), Madhavan, Richardson, and Roomas (1997)) and across trading days (Foster and Viswanathan (1993)) is also relatively small.

In contrast, endogenous shifts in the trading process at the open and the close result in large differences in the amount of both informed and uninformed trading after hours (Barclay and Hendershott (2003)). Hence, studying market activity and trading costs after hours provides an excellent laboratory to examine liquidity externalities and the endogenous temporal choices of traders demanding and supplying liquidity. Our results also provide insights about the difficulties associated with starting and growing markets with relatively little activity, market stability, and potential market failure.

Advances in telecommunications and computing have led to the creation and growing use of alternative trading systems such as electronic communications networks (ECNs). Because these systems link investors directly with one another, they eliminate the need for a dealer to intermediate the trades. As long as the electronic trading systems are turned on, trades can occur at any time of day or night. Nevertheless, trading after hours remains thin with less than 1/20 as many trades per unit time than during the trading day. The large differences in the amount of trading after hours and during the trading day should allow us to measure the importance of liquidity externalities on trading costs.

This paper examines trading costs after hours using proprietary data from the National Association of Securities Dealers (NASD), including all after-hours trades and quotes from March through December 2000.[1,2] Throughout our sample period, the Nasdaq Quotation and Trade Dissemination Services operated from 8:00 a.m. until 6:30 p.m. We divide this time interval into three distinct periods: the preopen (from 8:00 to 9:30 a.m.), the trading day (9:30 a.m. to 4:00 p.m.), and the postclose (from 4:00 to 6:30 p.m.).

As suggested by the theory of liquidity externalities, quoted and effective spreads are substantially higher after hours than during the trading day. Quoted and effective spreads are more than three times larger during the postclose and more than four times larger during the preopen than during the trading day. To determine why spreads are larger after hours than during the trading day, we decompose the effective spread into its adverse-selection and fixed (including dealer profits) components. We find that the adverse-selection component of the spread is more than four times larger during the preopen than during the trading day, and more than twice as large during the postclose

[1] Nasdaq did not retain after-hours quotes by market participant prior to mid February 2000.

[2] Related papers study market participants' trading and quoting behavior after hours. Most papers focus on preopening price discovery through nonbinding quotes and orders in the absence of trading. Biais, Hillion, and Spatt (1999) examine learning and price discovery through nonbinding order placement prior to the opening on the Paris Bourse. Cao, Ghysels, and Hatheway (2000) and Ciccotello and Hatheway (2000) investigate price discovery through nonbinding market-maker quotes prior to the Nasdaq opening. Davies (2003) analyzes the impact of preopen orders submitted by registered traders on the Toronto Stock Exchange.

as during the trading day. Because effective spreads are wider after hours than during the trading day, this translates into an adverse-selection cost measured in dollars that is 15 times larger during the preopen and seven times larger during the postclose than during the trading day.

Adverse-selection costs are highest early in the morning and decrease as the open approaches. Adverse selection is relatively constant during the trading day (but slightly lower near the open and the close), and increases again immediately after the close. The difference in adverse-selection costs between the trading day and after hours is increasing in trade size and mirrors the changes in the level of trading activity. These patterns suggest that the liquidity externalities primarily reflect reduced adverse-selection costs.

While spreads are wide after hours, knowledge of subsequent price movements allows demanders of liquidity during the preopen to receive better prices, on average, than would be available if they waited until the open. Demanders of liquidity in the postclose also receive better prices than would be available at the open, but the difference is smaller than during preopen. This suggests that liquidity demands motivate a larger fraction of the trades in the postclose than during the preopen.

Although negotiating a transaction price is a zero sum game—a better price for liquidity demanders comes at the expense of liquidity suppliers—we find that trading after hours benefits both demanders and suppliers of liquidity. The average demander of liquidity after hours pays more than the opening quote midpoint, but less than the full opening bid–ask spread. Thus, as noted above the demander of liquidity receives a better price than would be available at the open, yet the supplier of liquidity still earns a small profit.

The fixed component of the spread represents a smaller fraction of the bid–ask spread after hours than during the trading day. Because spreads are much smaller during the day, however, the fixed component in dollars is slightly larger after hours than during the day.[3] The fact that the fixed component of the spread remains roughly constant after hours, while the effective spread increases by a factor of three or four indicates that the higher trading costs after hours are caused by greater adverse selection and not by a lack of competition in liquidity provision. These results again suggest that the liquidity externalities primarily reflect reduced adverse-selection costs.

Our results show how a market can function with relatively little trading activity. Suppliers of liquidity remain competitive after hours and earn only a normal rate of profit. However, the lower trading activity degrades the liquidity externalities and results in substantially higher trading costs. Our results also suggest discretionary uninformed traders have no incentive to move their trades outside of the normal trading day. Thus, the current equilibrium with heavy trading during exchange trading hours and relatively little trading after hours is likely to persist unless there are significant structural and/or institutional changes in the market that facilitate trading after hours. This persistent,

[3] Lower trading volume after hours increases the per share opportunity cost of intermediation due to the opportunity cost of the dealers' time. This will increase the fixed component of the spread without increasing the true profitability of providing liquidity.

low-volume equilibrium highlights the difficulties in establishing and growing new markets.

Section I of the paper describes our data and provides descriptive statistics for our sample. Section II compares trading costs after hours to those during trading days. Section III decomposes the spread and investigates why trading costs are higher after hours. Section IV examines the time series relation between trading costs in the different periods. Section V concludes.

I. Data and Descriptive Statistics

Two data sets are used for our analysis. The first contains all after-hours trades and quotes for Nasdaq-listed stocks from March through December 2000 (212 trading days), and was obtained directly from Nasdaq.[4] For each after-hours trade, we have the ticker symbol, report and execution date and time, share volume, price, and source indicator (e.g., SOES or SelectNet). For each after-hours inside quote change during times when the Nasdaq trade and quote dissemination systems are operating (8:00 a.m. to 6:30 p.m.), we have the ticker symbol, report date and time, and bid and ask prices. If there is more than one quote change in a given second, we use the last quote change for that second.

At the close, all market-maker quotes are cleared. If market makers choose to post quotes after the close, these quotes are binding. In our sample period, Knight Securities was the only market maker with significant postclose quoting activity. The other active market participants after the close were ECNs (Instinet and Island had the most quote updates) and the Midwest stock exchange. During the preopen, market makers can post quotes, but these quotes are not binding and the inside quotes are often crossed (Cao, Ghysels, and Hatheway (2000)).[5] To construct a series of binding inside quotes, we use only ECN quotes during the preopen.

The second data set is the Nastraq database compiled by the NASD. For the same time period, Nastraq data are used to obtain trades and quotes during the trading day (9:30 a.m. to 4:00 p.m.).[6] We examine the top 200 Nasdaq stocks, ranked by dollar trading volume, for each month during the sample period. Our sample of the 200 highest dollar-volume Nasdaq stocks contains 274 million trades during the day and five million trades after hours, with a similar number of inside quote changes. Using the Lee and Ready (1991) algorithm, trades are classified as buyer initiated if the trade price is greater than the quote midpoint,

[4] We would like to thank Tim McCormick at Nasdaq for providing these data and for facilitating our understanding of them and of after-hours trading in general.

[5] From 9:20 a.m. until the open, the "trade or move" rule is in effect. This rule requires that if the quotes become crossed, then a trade must occur or the quotes must be revised. Because participants can revise their quotes without trading, the market-maker quotes are not firm.

[6] We attempt to filter out large data errors in both data sets by eliminating trades and quotes with large price changes that are immediately reversed. We also exclude trades with nonstandard delivery options.

and seller initiated if the trade price is less than the quote midpoint.[7] Trades executed at the midpoint are classified with the tick rule; midpoint trades on an up-tick are classified as buyer initiated and midpoint trades on a downtick are classified as seller initiated.

Panel A of Table I provides descriptive statistics for our sample of the 200 highest dollar-volume Nasdaq stocks and for quartiles ranked by dollar trading volume. Panel B of Table I shows the average percentage of trading volume and number of trades that occur in our three time periods: the preopen (8:00 to 9:30 a.m.), the trading day (9:30 a.m. to 4:00 p.m.), and the postclose (4:00 to 6:30 p.m.). Although the percentage of trading after hours is relatively constant across quartiles, the percentage of trading volume in the preopen is larger for stocks in the higher volume quartiles, and the percentage of trading volume in the postclose is larger for stocks in the lower volume quartiles.

The average number of trades during the day is extremely high for the highest volume quartile. There are approximately 16,000 trades per day, or approximately 0.7 trades per second for stocks in this quartile. The highest volume stocks have more than one trade per second. Stocks in the highest volume quartile are also active after hours, averaging more than 100 trades per day in both the preopen and the postclose. Stocks in the lowest quartile are much less active after hours. In each of the dollar-volume quartiles, there are approximately 50 times as many trades during the day as after hours.

Panel C of Table I presents the average percentage of trading volume and number of trades by trade size. We define the trade-size categories as small (1,000 shares or less), medium (more than 1,000 but less than 10,000 shares), and large (10,000 shares or more). During the preopen and trading day periods, about 50 percent of the total trading volume occurs in small trades. The average trade size in the postclose is much larger. Only 18 percent of the total postclose trading volume occurs in small trades and more than 50 percent of the total volume occurs in large trades. While large trades are relatively more prevalent after hours than during the day, the lower total number of trades after hours results in relatively few large after-hours trades per day. On average each stock in our sample has less than one large trade per day in the preopen and less than two large trades per day in the postclose.

Figure 1 shows the average number of trades and the average dollar trading volume per stock for each minute from 8:00 a.m. to 6:30 p.m. for the 50 stocks in the highest dollar-volume quartile.[8] The average number of trades and dollar trading volume are calculated for each stock and each minute, and then

[7] Trades are matched with quotes using execution times and the following algorithm that has been found by Nasdaq economic research to perform well for the Nasdaq market. SelectNet and SOES are electronic trading systems run by Nasdaq. Because the execution times for these trades are very reliable, we match the trade with the inside quote 1 second before the trade execution time. For all other trades, we match the trade with the inside quote 3 seconds before the trade execution time.

[8] We focus on the top 50 stocks because minute-by-minute observations for the lower volume stocks follow a similar pattern, but are much noisier after hours because there are many fewer after-hours trades for these stocks (Table I).

Table I

Descriptive Statistics, Percentage Trading Volume, and Number of Trades by Dollar-Volume Quartile and Trade Size

Panel A reports the average price per share, daily dollar trading volume, standard deviation of daily stock returns, market capitalization, and the number of market makers. Panels B and C report the percentage of total trading volume and the average number of trades per day in the preopen, postclose, and trading day periods by dollar-volume quartile (Panel B) and by trade size (Panel C). In all panels, statistics are calculated for each stock and then averaged across stocks. Sample: the 200 highest dollar-volume Nasdaq stocks from March through December 2000.

Panel A: Descriptive Statistics by Dollar-Volume Quartile

Volume Quartile	Share Price	Daily Trading Volume ($ millions)	Std. Dev. of Daily Returns	Market Cap ($ billions)	Number of Market Makers
Highest	94.83	792.97	6.61%	47.64	62.18
2	65.46	166.63	7.23%	7.83	45.99
3	50.62	76.28	7.43%	4.42	41.81
Lowest	52.08	47.30	7.41%	2.83	33.59
All	65.75	270.79	7.17%	15.68	45.89

Panel B: Percentage of Trading Volume and Average Number of Trades per Day by Dollar-Volume Quartile

	Percentage of $ Trading Volume			Average Number of Trades/Day		
Volume Quartile	Trading Day	Pre-Open	Post-Close	Trading Day	Pre-Open	Post-Close
Highest	96.3	1.0	2.7	16,439	144	170
2	96.2	0.8	3.0	5,024	36	48
3	95.9	0.8	3.3	2,832	22	31
Lowest	96.0	0.6	3.3	1,569	10	15
All	96.1	0.8	3.1	6,466	53	66

Panel C: Percentage of Trading Volume and Average Number of Trades per Day by Trade Size

	Percentage of $ Trading Volume			Average Number of Trades/Day		
Trade Size	Trading Day	Pre-Open	Post-Close	Trading Day	Pre-Open	Post-Close
Small	52.3	50.7	18.5	6,050.8	48.9	55.4
Medium	28.0	23.0	27.6	371.8	4.0	8.7
Large	19.7	27.0	54.0	43.5	0.3	1.9

averaged across stocks. Figure 1 graphs the log (base 10) of this average. The number of trades and the dollar trading volume increase rapidly as the open approaches. During the trading day, the number of trades and trading volume exhibit the familiar U-shape pattern (Chan, Christie, and Schultz (1995) and others). The number of trades then falls dramatically in the first minute after the close. Trading activity continues to decrease until 6:30 p.m. when Nasdaq trade and quote reporting systems go offline.

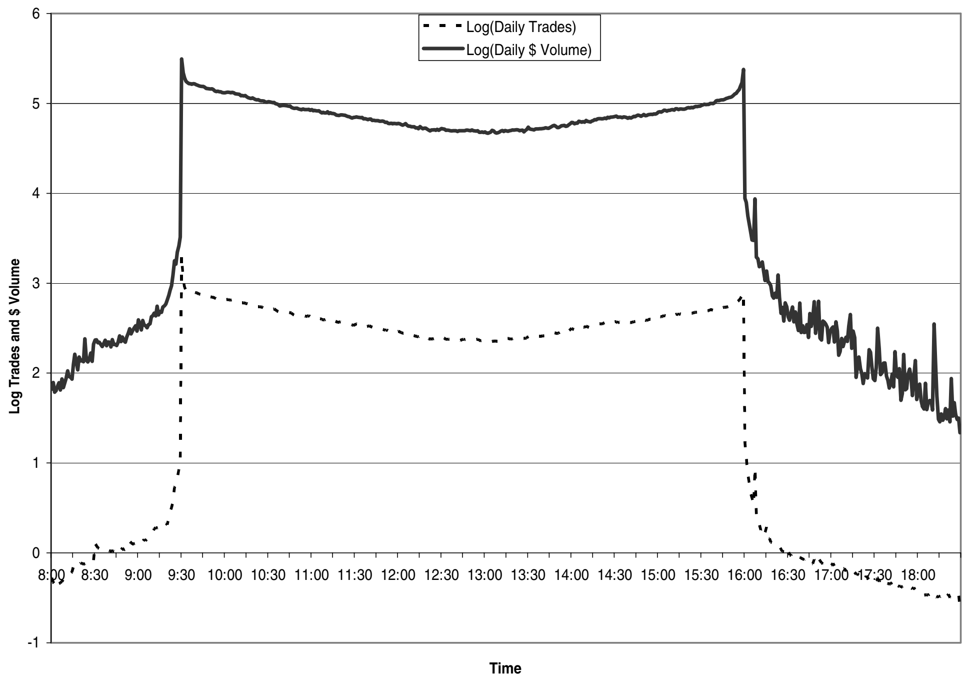

Figure 1. Daily number of trades and dollar trading volume. The average daily number of trades and dollar trading volume for each 1-minute period from 8:00 a.m. to 6:30 p.m. is calculated for each stock and then averaged across stocks for the 50 highest-dollar-volume Nasdaq stocks from March through December 2000. The logarithms of these averages are graphed.

Institutional investors sometimes prearrange to trade Nasdaq stocks after the close to ensure they receive the closing price.[9] Roughly 45 percent of the medium and large trades during the postclose occur at the closing price, and 60 percent are at or within the closing quotes. These fractions decline somewhat further from the close, but less so for the medium and large trades than for the small trades. While "trading at close" may represent a substantial fraction of postclose volume, it represents a much smaller fraction of postclose trades. Medium and large trades, which likely contain virtually all of this institutional "trading at close" activity, represent over 80 percent of the postclose trading volume, but only 15 percent of postclose trades.

II. Trading Costs after Hours and during the Trading Day

If the liquidity externalities are roughly proportional to the amount of trading volume, then trading costs should follow an inverse relation with the trading activity documented in Figure 1. Figure 2 shows the average percentage

[9] See Blume and Edelen (2002), for example, for a discussion of the trading strategies of index funds as they attempt to track an index like the S&P 500.

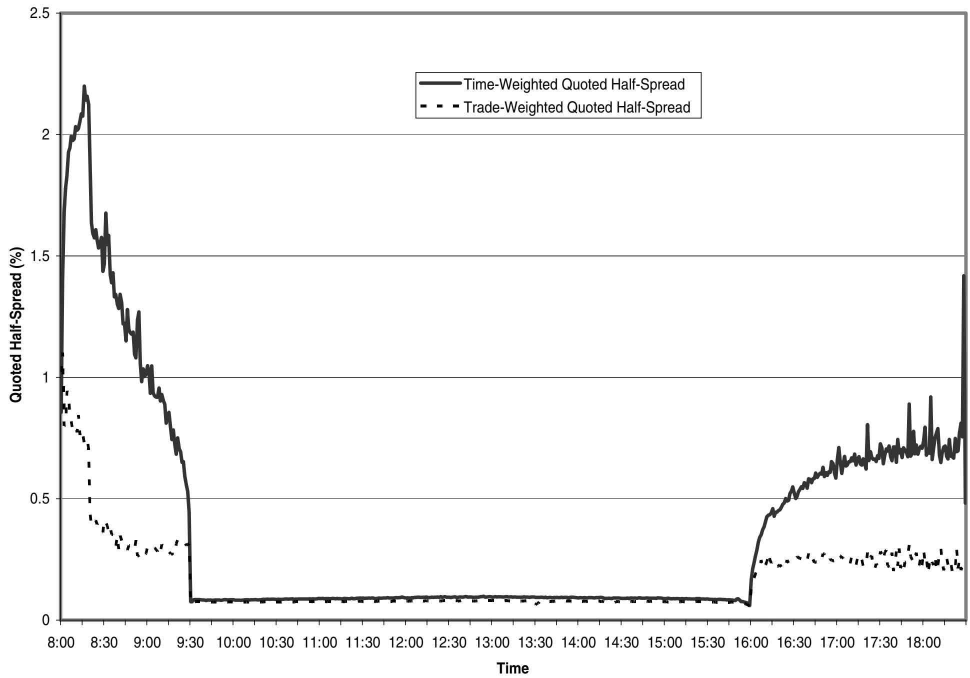

Figure 2. Time-weighted and trade-weighted percentage quoted half spreads. Time-weighted and trade-weighted percentage quoted half spreads are calculated each minute from 8:00 a.m. to 6:30 p.m. for the 50 highest dollar-volume Nasdaq stocks from March through December 2000. The average spread is calculated for each stock and each minute, and then averaged across stocks.

time-weighted and trade-weighted quoted half spreads for each minute from 8:00 a.m. to 6:30 p.m. for the 50 stocks in the highest dollar-volume quartile. The average time-weighted quoted half-spread increases from about 1 percent at 8:00 a.m. to more than 2 percent at 8:15 a.m. This increase in the average quoted spread simply reflects that fact that quoting begins earlier in the day for more active stocks with smaller spreads.[10] The average time-weighted quoted half-spread then declines steadily for the remainder of the preopen and drops significantly at the open from 30 basis points 1 minute before the open to 7 basis points at the open. The spread remains roughly constant throughout the trading day with a small decline just before the close. After the close, the time-weighted quoted half-spread immediately doubles and then increases steadily to about 75 basis points by 6:30 p.m.

The trade-weighted quoted half-spread is much smaller after hours than the time-weighted quoted half-spread, presumably because trades are more likely

[10] This conclusion is verified by the positive correlation between the time of the first quote and the spread at the time of the first quote. However, the first binding quote appears by 8:15 a.m. almost every day for the highest-volume stocks.

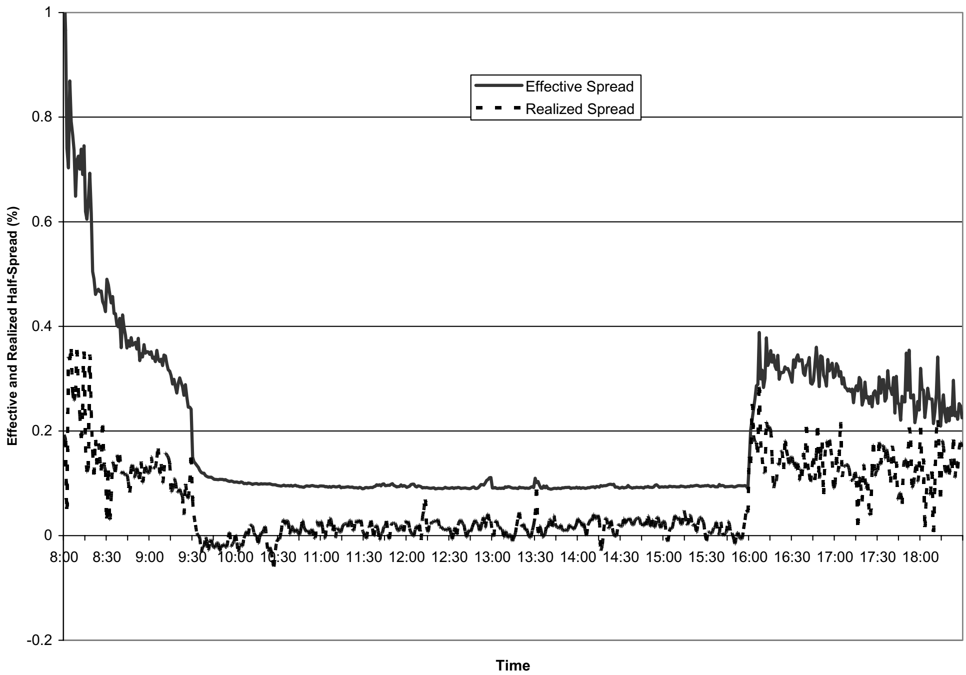

Figure 3. Percentage effective and realized percentage half spreads. The percentage effective and realized half spreads are calculated each minute from 8:00 a.m. to 6:30 p.m. for the 50 highest-dollar-volume Nasdaq stocks from March to December 2000. The percentage effective spread is the absolute difference between the transaction price and the quote midpoint at the time of the trade divided by the quote midpoint at the time of the trade. The percentage realized half-spread is the signed (positive for buyer-initiated and negative for seller-initiated trades) difference between the trade price and the quote midpoint 5 minutes after the trade divided by the quote midpoint at the time of the trade. The average effective and realized half -spreads are calculated for each stock and each minute, and then averaged across stocks.

to occur after hours when good prices are available. The trade-weighted quoted half-spread declines gradually from 8:00 until 8:15 a.m., and then drops sharply at 8:15 a.m. and again at the open. Because of the high frequency trading during the trading day, trade-weighted and time-weighted quoted half spreads are nearly identical. After the close, the trade-weighted quoted half-spread increases for about the first 10 minutes and then remains roughly constant until 6:30 p.m.

Figure 3 shows the average percentage effective and realized half spreads for each minute from 8:00 a.m. to 6:30 p.m. for stocks in the highest dollar-volume quartile. The effective half-spread is defined as the absolute difference between the trade price and the quote midpoint at the time of the trade. The realized half-spread is defined as the signed (positive for buyer-initiated trades and negative for seller-initiated trades) difference between the trade price and the quote midpoint 5 minutes after the trade.

The effective half spreads shown in Figure 3 display a pattern similar to the trade-weighted quoted half spreads shown in Figure 2. The effective half-spread declines steadily from more than one percent at 8:00 a.m. to about 15 basis points at the open, with sharp declines at 8:15 a.m. and again at the open. The effective half-spread remains steady at 9 to 10 basis points for most of the trading day and then drops slightly just before the close. The effective half-spread then triples in the first few minutes after the close, and remains at that level for about an hour before declining again slightly.

The average realized half-spread shown in Figure 3 is more volatile than the average effective half-spread. The realized half-spread is greatest from 8:00 to 8:15 a.m., and then declines to about 12 basis points and remains there until the open. In the first minute after the open, the realized half-spread and the effective half-spread are about the same. However, the realized half-spread quickly declines, becoming slightly negative for the first half-hour of the trading day before rising to one basis point for the rest of the trading day. After the close, the realized half-spread increases immediately to almost 15 basis points, and remains at about that level until 6:30 p.m.

The difference between the effective spread and the realized spread is equal to the signed difference between the quote midpoint 5 minutes after the trade and the quote midpoint at the time of the trade. This difference is sometimes called the price impact of the trade and has been used as a measure of the trade's information content. This difference is much greater after hours than during the trading day, suggesting that there may be more adverse selection after hours than during the trading day. We explore this issue in more detail below.[11]

The changes in effective and realized spreads and price impacts are consistent with liquidity externalities causing the changes in trading costs after hours. Lower trading activity after the close results in higher trading costs, which discourages discretionary liquidity trading. This raises adverse selection costs, which, in turn, widens spreads further and further decreases liquidity trading. Thus, as you move away from the close, the effective spread and price impact of a trade increase. The process reverses itself in the preopen as trading costs and price impacts fall as the open approaches.

Realized spreads are significantly larger after hours than during the trading day. The realized half-spread is an ex post measure of the spread-related trading costs net of the price impact of the trade. Hence, the higher average realized spreads after hours imply that investors who trade after hours are willing to pay a premium (net of the price impact of their trades) to trade outside of the normal trading day. Investors may be willing to pay a premium to trade after hours to satisfy liquidity demands that cannot wait until the trading day, or to

[11] Because the limit order book is much thinner after hours than during the trading day, an alternate explanation for this phenomenon is that trades generate a larger temporary price impact after hours by removing limit orders that are on the inside. A vector autoregression (VAR) (Hasbrouck (1991)) confirms that the differential price impact is explained primarily by the greater information content of the trades and is not due to temporary microstructure effects.

Table II

Effective and Realized Half Spreads by Dollar-Volume Quartile

The effective and realized half spreads are calculated for the trading day, preopen, and postclose for the 200 highest-dollar-volume Nasdaq stocks from March to December 2000. Cross-sectional means are reported with standard deviations below in parentheses. The effective half-spread is the absolute difference between the transaction price and the quote midpoint at the time of the trade. The effective half spread at the open (Panel C) is the average effective half-spread for the first 2 minutes after the open. The realized half-spread is the signed (positive for buyer-initiated and negative for seller-initiated trades) difference between the trade price and the quote midpoint 5 minutes after the trade. The realized half-spread at the open is the signed difference between the trade price and the quote midpoint at the open. After-hours values that differ from the trading day at a 0.01 level are denoted with a *. After-hours values that differ from the other after-hours period at a 0.01 level are denoted with a †.

Panel A: Effective Half-Spread by Dollar-Volume Quartile

	Effective Half-Spread ($)			Effective Half-Spread (%)		
Volume Quartile	Trading Day	Pre-Open	Post-Close	Trading Day	Pre-Open	Post-Close
Highest	0.078	0.277†*	0.216†*	0.097	0.334†*	0.264†*
	(0.03)	(0.16)	(0.11)	(0.02)	(0.12)	(0.08)
2	0.088	0.366†*	0.288†*	0.152	0.590†*	0.470†*
	(0.04)	(0.20)	(0.16)	(0.03)	(0.12)	(0.09)
3	0.090	0.397*	0.331*	0.201	0.797†*	0.669†*
	(0.05)	(0.25)	(0.20)	(0.05)	(0.18)	(0.17)
Lowest	0.109	0.506*	0.455*	0.226	0.989†*	0.883†*
	(0.05)	(0.27)	(0.22)	(0.04)	(0.23)	(0.20)
All	0.091	0.387†*	0.322†*	0.169	0.677†*	0.572†*
	(0.05)	(0.24)	(0.20)	(0.06)	(0.29)	(0.27)

Panel B: Realized Half-Spread by Dollar-Volume Quartile

	Realized Half-Spread ($)			Realized Half-Spread (%)		
Volume Quartile	Trading Day	Pre-Open	Post-Close	Trading Day	Pre-Open	Post-Close
Highest	0.007	0.092*	0.110*	0.011	0.117*	0.137*
	(0.01)	(0.05)	(0.06)	(0.01)	(0.05)	(0.06)
2	0.011	0.131*	0.156*	0.024	0.218†*	0.254†*
	(0.01)	(0.07)	(0.09)	(0.02)	(0.06)	(0.08)
3	0.012	0.174*	0.184*	0.040	0.345*	0.379*
	(0.01)	(0.12)	(0.12)	(0.04)	(0.11)	(0.12)
Lowest	0.017	0.243*	0.254*	0.041	0.481*	0.495*
	(0.01)	(0.15)	(0.13)	(0.03)	(0.15)	(0.14)
All	0.012	0.160*	0.176*	0.029	0.290*	0.316*
	(0.01)	(0.12)	(0.12)	(0.03)	(0.17)	(0.17)

profit from short lived private information.[12] We begin to address these issues with a more thorough examination of effective and realized spreads in Table II.

[12] Because the realized spread is measured net of any price changes that occur within 5 minutes after the trade, the private information would have to be reflected in prices more than 5 minutes after the trade, but before the open.

Table II—*Continued*

Panel C: Realized and Effective Half-Spreads at the Open by Dollar-Volume Quartile

Volume Quartile	Effective Spread ($) at the Open	Realized Spread ($) Pre-Open to the Open	Realized Spread ($) Post-Close to the Open	Effective Spread (%) at the Open	Realized Spread (%) Pre-Open to the Open	Realized Spread (%) Post-Close to the Open
Highest	0.093	0.047*	0.073	0.113	0.067*	0.094
	(0.05)	(0.04)	(0.11)	(0.03)	(0.04)	(0.12)
2	0.097	0.020†*	0.072†	0.164	0.001*	0.082*
	(0.05)	(0.15)	(0.11)	(0.04)	(0.48)	(0.31)
3	0.097	0.035*	0.055*	0.210	0.107*	0.099*
	(0.06)	(0.05)	(0.09)	(0.06)	(0.13)	(0.22)
Lowest	0.114	0.026†*	0.071†*	0.236	0.079†*	0.167†*
	(0.05)	(0.07)	(0.10)	(0.05)	(0.13)	(0.18)
All	0.100	0.032†*	0.068†*	0.181	0.064†*	0.110†*
	(0.05)	(0.09)	(0.10)	(0.07)	(0.26)	(0.22)

Table II provides the effective (Panel A) and realized (Panel B) half spreads (in dollars and percent) by time period and dollar-volume quartile. For the highest-volume quartile, the average effective half-spread is 3.5 times larger in the preopen than during the trading day. This difference increases to a factor of 4.5 for the lowest-volume quartile. The difference of 20 to 30 cents (25 to 75 basis points) between the preopen and trading-day effective spreads is both statistically and economically significant. After the close, the average effective spreads are again significantly larger than during the trading day, and the difference again increases for the lower volume quartiles. Finally, effective spreads are about 10 percent to 25 percent larger during the preopen than during the postclose. For the percentage effective spread, this difference is statistically significant for all volume quartiles; for the dollar effective spread, this difference is statistically significant over all and for the higher volume quartiles.

Realized half spreads (Table II, Panel B) are 10 to 20 cents (10 to 45 basis points) higher in the preopen than during the trading day and, as observed for the effective spreads, the difference increases for the lower volume quartiles. Realized spreads are slightly larger in the postclose than in the preopen, although these differences generally are not statistically significant.

The higher effective and realized spreads after hours raise the question of why traders do not wait for the lower trading costs observed during the trading day. Panel C of Table II provides the effective half-spread during the first 2 minutes after the open and the realized half-spread for after-hours trades measured in relation to the quote midpoint at the open.[13] Comparing the effective spread at the open with the realized spread measured in relation to the opening quote midpoint provides a direct comparison of the price that a trader received

[13] Comparing effective spreads at 10 a.m. with realized spreads for after-hours trades measured in relation to the 10 a.m. price does not affect the qualitative results.

after hours with the price he would expect to receive by waiting until the open. The average effective half-spread at the open is significantly larger than the realized half-spread (measured in relation to the quote midpoint at the open) for after-hours trades. This difference demonstrates that liquidity demanders after hours receive better prices, on average, than they would receive if they wait until the open. The positive realized spreads in this panel, however, demonstrate that liquidity providers do not incur losses on these trades. In fact, comparing the realized spreads after hours (in Panel C) with realized spreads during the trading day (in Panel B) indicates that liquidity provision may be slightly more profitable during the preopen than during the trading day.

The higher realized spreads during the preopen raise the question of whether part of the increase in effective spreads after hours is caused by a reduction in competition among liquidity suppliers and not by a reduction in liquidity externalities. However, realized spreads measured in relation to the quote midpoint 5 minutes after the trade are not directly comparable after hours and during the trading day. In 5 minutes during the trading day, a liquidity supplier has many opportunities to reverse a trade and lock in any profits. The lower trading volume after hours implies that it is much more difficult to reverse a trade in the same time frame after hours. The fact that realized spreads measured in relation to the opening quote midpoint are much smaller than realized spreads measured in relation to the quote midpoint 5 minutes after the trade suggests that the realized spread might overstate the profitability of supplying liquidity after hours because of the greater persistence in the direction of trades and price changes after hours. The spread decomposition in Section III helps to disentangle these effects by showing that there is little difference in the profitability of liquidity provision during the trading day and after hours, which supports the conclusion that the higher effective spreads after hours are caused by greater adverse selection and reduced liquidity externalities, and not by a lack of competition among liquidity suppliers.

Comparing the effective and realized spreads in Table II shows that the average price impact of a trade is higher after hours than during the trading day, and higher in the preopen than during the postclose.[14] This suggests that trades may be more informed after hours than during the trading day, and that there may be more liquidity-motivated trading during the postclose than during the preopen. For trades in the preopen, higher trading costs measured at the time of the trade, but lower trading costs measured in relation to the open, reflect

[14] For trades in the preopen, realized spreads measured 30 minutes after the trade (not reported) and realized spreads measured in relation to the opening price (Panel C, Table II) show larger price impacts than realized spreads measured 5 minutes after the trade. This indicates that the price impact is not reversed by the open, and is unlikely to be caused by the thin after-hours limit-order book. For trades in the postclose, realized spreads measured 30 minutes after the trade (not reported) also show larger price impacts than realized spreads measured 5 minutes after the trade, but realized spreads measured in relation to the next day's opening price show smaller price impacts. This indicates that there may be some price reversals for trades after the close. However, postclose realized spreads measured in relation to the next day's opening price have large standard deviations.

rational choices by traders with short-lived information. Traders are better off paying higher spreads before the open than waiting for lower spreads after the open because prices move, on average, in the direction of their trades. This is also true in the postclose, but the cost advantage of trading in the postclose is smaller than during the preopen.

The average trade size is larger after hours than during the trading day (Table I). To control for the different trade sizes, Table III reports the average effective and realized half spreads (in dollars and percent) by time period and trade size. Because both effective and realized spreads increase with trade size in our sample, the increase in after-hours trading costs is slightly overstated in Table II. Table III shows that this overstatement is small, however.

Figures 2 and 3 and Tables II and III demonstrate that the ex ante costs of trading are much higher outside of the normal trading day. The wide spreads

Table III

Effective and Realized Half Spreads by Trade Size

The effective and realized half spreads are calculated for the trading day, preopen, and postclose for the 200 highest-dollar-volume Nasdaq stocks from March to December 2000 for small (≤1,000 shares), medium (1,001 to 9,999 shares), and large (≥10,000 shares) trades. Cross-sectional means are reported with standard deviations below in parentheses. The effective spread is the absolute difference between the trade price and the quote midpoint at the time of the trade. The realized half-spread is the signed (positive for buyer-initiated and negative for seller-initiated trades) difference between the trade price and the quote midpoint 5 minutes after the trade. After-hours values that differ from the trading day at a 0.01 level are denoted with a *. After-hours values that differ from the other after-hours period at a 0.01 level are denoted with a †.

Panel A: Effective Half-Spread by Trade Size

	Effective Half-Spread ($)			Effective Half-Spread (%)		
Trade Size	Trading Day	Pre-Open	Post-Close	Trading Day	Pre-Open	Post-Close
Small (−1,000)	0.090	0.388†*	0.306†*	0.166	0.678†*	0.542†*
	(0.04)	(0.24)	(0.19)	(0.06)	(0.30)	(0.26)
Medium (1,001–9,999)	0.112	0.361*	0.398*	0.209	0.663*	0.681*
	(0.07)	(0.26)	(0.24)	(0.07)	(0.31)	(0.29)
Large (10,000+)	0.167	0.619†*	0.451†*	0.321	1.073†*	0.769†*
	(0.10)	(0.50)	(0.26)	(0.10)	(0.58)	(0.25)

Panel B: Realized Half-Spread by Trade Size

	Realized Half-Spread ($)			Realized Half-Spread (%)		
Trade Size	Trading Day	Pre-Open	Post-Close	Trading Day	Pre-Open	Post-Close
Small (−1,000)	0.003	0.090*	0.094*	0.020	0.289*	0.288*
	(0.01)	(0.05)	(0.06)	(0.03)	(0.17)	(0.16)
Medium (1,001–9,999)	0.088	0.120†*	0.216†*	0.134	0.303†*	0.418†*
	(0.07)	(0.11)	(0.13)	(0.06)	(0.22)	(0.17)
Large (10,000+)	0.242	0.508†*	0.383†*	0.388	0.761†*	0.559†*
	(0.15)	(0.44)	(0.25)	(0.12)	(0.73)	(0.19)

after hours may deter discretionary liquidity traders from demanding liquidity at these times. These wide spreads, however, may also represent a potential profit opportunity from liquidity provision. The potential profits from providing liquidity after hours depend critically on the amount of adverse selection in these trades. Although we have provided some preliminary information suggesting that adverse selection is severe after hours, we now turn to a more formal analysis of this issue.

III. Adverse Selection, Order Processing Costs and Dealer Profits, and Order Persistence: Decomposing the Effective Spread

Although the higher trading costs after hours are consistent with greater adverse selection and a loss of liquidity externalities after hours, other possible explanations, for example, reduced competition for liquidity provision, necessitate a more comprehensive analysis of the characteristics of after-hours trades. The most direct approach is to decompose the bid–ask spread into its various components.

It is generally recognized that the bid–ask spread is comprised of at least three components, adverse selection, inventory costs, and a fixed component including the dealers' profit. Among these three components, the inventory component has been the most difficult to measure. Amihud and Mendelson (1980) and others predict that liquidity suppliers will adjust their quotes to induce order reversals (buy orders followed by sell orders, or vice versa) to help manage their inventories. In these models, the quote revisions caused by a trade include both adverse-selection and inventory costs. Because the inventory models predict that the probability of a trade reversal is greater than one half, several empirical studies have attempted to use the probability of a trade reversal to separate the inventory component from the adverse-selection component of the spread. Unfortunately, the data display a high probability of order persistence (buys followed by buys or sells followed by sells) rather than order reversals, which makes estimation of the inventory and adverse-selection components of the spread problematic. For example, Huang and Stoll (1997) initially estimate a negative adverse-selection component of the spread for 19 of the 20 stocks in their sample. Huang and Stoll sidestep this problem by "bunching" trades and assuming that all trades that occur at the same price without an intervening quote revision are really one larger order that was broken up. Although Huang and Stoll acknowledge that bunching trades in this way over corrects the problem, it does allow them to estimate positive adverse-selection effects in a three-way spread decomposition. In the current trading environment, the trade bunching assumption seems less appealing. For the high-volume Nasdaq stocks, with more than one trade per second involving more than 60 market makers, it is difficult to justify the assumption that bunched trades originate from a single order.

Instead, we use the effective spread decomposition found in Lin, Sanger, and Booth (1995), which is based on the model in Huang and Stoll (1994). The Lin–Sanger–Booth (LSB) decomposition has several advantages in our setting.

First, the LSB model does not require the probability of a reversal to be greater than 1/2 in order to provide sensible estimates of the adverse-selection component of the spread. Instead, LSB estimate an "order persistence" component of the spread, which we discuss in more detail below. Given the relative lack of evidence of short-run inventory effects (Hasbrouck (1988), Madhavan and Smidt (1991), and Hasbrouck and Sofianos (1993)), it seems advantageous to estimate a model that does not rely on inventory induced trade reversals.[15] Second, the LSB model does not require a constant effective spread. In our data, the effective spread is not constant after hours, and is significantly larger after hours than during the trading day (Figure 3).

Madhavan, Richardson, and Roomas (1997) (MRR) provide an alternate approach to decomposing the spread when orders are persistent. As discussed below, their model provides essentially the same estimate of the adverse-selection component of the spread as LSB. The difference between the models arises in the fixed component of the spread. MRR attribute the nonadverse-selection component of the spread to market makers' cost per share of providing liquidity, fixed, inventory, and risk bearing costs, along with dealers' profits. By comparison the three-way LSB decomposition allows the fixed and dealer profit component to be estimated separately.

Before estimating the spread decomposition, we briefly review the underlying model (a more detailed discussion is available in LSB). Let A_t and B_t be the bid and ask quotes at time t, and let δ be the probability of a continuation (a sell order followed by another sell order, or vice versa). Then, conditional on a sell order at time t, a liquidity supplier's expected gross profit at $t+1$ is

$$E_t(P_{t+1}) - P_t = \delta B_{t+1} + (1-\delta)A_{t+1} - B_t, \tag{1}$$

where $E_t(P_{t+1}) = \delta B_{t+1} + (1-\delta)A_{t+1}$ is the expected future transaction price conditioned on the trade at time t, and $P_t = B_t$ is the transaction price at time t.

[15] To explore whether inventory adjustments by market makers motivate after hours trading, we perform several tests (details omitted). First, we examine the cumulative net order flow across the trading periods (similar to the time series regressions of trading costs in Section IV). If market makers passively manage their inventory through quote adjustments, net order flow should exhibit reversals, for example, heavy buying by market makers during the trading day would cause market makers to sell shares after the close. In our data, however, cumulative net order flow during the day is positively correlated with cumulative net order flow after the close, which seemingly is inconsistent with the predictions of simple inventory adjustment models. This positive correlation would occur if the slow revelation of private information had a larger effect than the passive inventory adjustments of market makers or it could be evidence of active inventory management by market makers as in Lyons (1995) and Madhavan and Sofianos (1997). Without data containing the identity of traders (which the NASD is not willing to provide), it is not possible for us to disentangle these two possibilities. Second, we examine whether or not trades within or outside of the spread have significantly different price impacts (as would be the case if the trades inside the spread represent market maker risk sharing trades that are less informative than other trades). Although trades after the close are less informed than trades before the open, we could not find a significant relation between the information content of the trade and whether it was inside the spread. Thus, we were unable to find strong evidence of inventory effects.

Let $M_t = (A_t + B_t)/2$ be the quote midpoint at time t and let $z_t = P_t - M_t$ be the effective half-spread. To reflect possible adverse information revealed by a trade at time t, quote revisions are assumed to be $B_{t+1} = B_t + \lambda z_t$ and $A_{t+1} = A_t + \lambda z_t$, where $0 < \lambda < 1$ is the portion of the spread due to adverse selection. A liquidity supplier's gross profit for a sell order at time t is then related to the effect spread by

$$\begin{aligned} E_t(P_{t+1}) - P_t &= \delta B_{t+1} + (1-\delta)A_{t+1} - P_t \\ &= \lambda z_t + (1-2\delta)(M_t - B_t) + M_t - P_t \\ &= -(1-\lambda-\theta)z_t \end{aligned} \tag{2}$$

where $\theta = 2\delta - 1$ and $(1-\lambda-\theta)z_t$ is the liquidity supplier's expected profit. A liquidity supplier's gross profit for a sell order at time t can be obtained in the same fashion and is identical.

Because λ reflects the quote revision in response to a trade as a fraction of the effective spread, and because θ reflects the extent of order persistence, these parameters can be estimated using the following regressions:

$$\begin{aligned} \Delta M_{t+1} = M_{t+1} - M_t &= \lambda z_t + e_{t+1} \\ z_{t+1} &= \theta z_t + \eta_{t+1}, \end{aligned} \tag{3}$$

where the disturbance terms e_{t+1} and η_{t+1} are assumed to be uncorrelated.

A. The Adverse-Selection Component of the Effective Spread

Estimating the adverse-selection component of the spread is the first step in determining whether the wider spreads after hours observed in Tables II and III can be explained by intertemporal liquidity externalities arising from discretionary liquidity traders trading during the day. Table IV provides the adverse-selection component of the bid–ask spread in dollars,[16] and as a fraction of the effective spread. Results are reported separately by volume quartile in Panel A, by trade size in Panel B, and by trade size for the highest volume quartile in Panel C.[17] The last row of Panel A shows that for the full sample, the fraction of the effective spread that is due to adverse selection is almost three times as large during the postclose than during the trading day (14 percent vs. 5 percent), and it is over four times larger during the preopen than during

[16] Decomposing the spread measured as a percentage of share price provides the same qualitative results.

[17] Huang and Stoll's (1997) two-way decomposition of the quoted spreads provides results similar to those in Panel A. Estimates of the adverse-selection component of the spread from the Huang and Stoll procedure are slightly higher for all time periods, but the ordering across periods remains the same. In our sample, the adverse-selection component of the spread during the trading day is smaller than that found in LSB and Huang and Stoll due to the dramatic growth in trading activity. For the high-volume stocks, the average number of trades per day is 160 in LSB's 1988 sample, 430 in Huang and Stoll's 1992 sample, and 16,439 in our 2,000 sample.

Table IV

The Adverse-Selection Component of the Effective Half-Spread by Dollar-Volume Quartile and Trade Size

The adverse-selection component of the spread is estimated for the trading day, preopen, and postclose for the 200 highest-dollar-volume Nasdaq stocks from March to December 2000 for small ($\leq$1,000 shares), medium (1,001 to 9,999 shares), and large ($\geq$10,000 shares) trades using the regression $\Delta M_{t+1} = \lambda z_t + e_{t+1}$, where ΔM_{t+1} is the change in the quote midpoint following trade t, and z_t is the effective half-spread at time t. Cross-sectional means are reported with standard deviations below in parentheses. After-hours values that differ from the trading day at a 0.01 level are denoted with a *. After-hours values that differ from the other after-hours period at a 0.01 level are denoted with a †.

	Proportion			Dollars		
	Trading Day	Pre-Open	Post-Close	Trading Day	Pre-Open	Post-Close
Panel A: Adverse-Selection Component of the Effective Half-Spread by Dollar-Volume Quartile						
Volume Quartile						
Highest	0.038	0.188†*	0.076†*	0.003	0.058†*	0.019†*
	(0.02)	(0.07)	(0.04)	(0.00)	(0.04)	(0.02)
2	0.052	0.250†*	0.150†*	0.005	0.096†*	0.048†*
	(0.02)	(0.04)	(0.05)	(0.00)	(0.06)	(0.04)
3	0.055	0.233†*	0.162†*	0.005	0.094†*	0.060†*
	(0.02)	(0.05)	(0.06)	(0.00)	(0.06)	(0.05)
Lowest	0.069	0.230†*	0.176†*	0.008	0.117†*	0.079†*
	(0.04)	(0.07)	(0.05)	(0.01)	(0.08)	(0.05)
All	0.053	0.225†*	0.141†*	0.005	0.091†*	0.052†*
	(0.03)	(0.06)	(0.07)	(0.00)	(0.07)	(0.04)
Panel B: Adverse-Selection Component of the Effective Half-Spread by Trade Size (Full Sample)						
Trade Size						
Small (−1,000)	0.060	0.231†*	0.162†*	0.006	0.093†*	0.056†*
	(0.03)	(0.06)	(0.07)	(0.00)	(0.07)	(0.05)
Medium (1,001–9,999)	0.015	0.176†*	0.093†*	0.001	0.066†*	0.041†*
	(0.02)	(0.12)	(0.06)	(0.00)	(0.08)	(0.04)
Large (10,000+)	0.002	0.088*	0.081*	0.000	0.052*	0.040*
	(0.01)	(0.24)	(0.09)	(0.00)	(0.16)	(0.05)
Panel C: Adverse-Selection Component of the Effective Half-Spread by Trade Size (Highest-Volume Quartile)						
Trade Size						
Small (−1,000)	0.042	0.194†*	0.092†*	0.003	0.060†*	0.021†*
	(0.02)	(0.07)	(0.05)	(0.00)	(0.04)	(0.02)
Medium (1,001–9,999)	0.008	0.125†*	0.038†*	0.001	0.034†*	0.013†*
	(0.02)	(0.08)	(0.03)	(0.00)	(0.03)	(0.02)
Large (10,000+)	0.002	0.043*	0.025*	0.000	0.014*	0.014*
	(0.00)	(0.15)	(0.03)	(0.00)	(0.05)	(0.02)

the trading day (22 percent vs. 5 percent). Because effective spreads are much wider after hours than during the trading day (Table II), these differences are magnified in dollar terms. The adverse-selection component of the spread is 10 times larger during the postclose than during the trading day (5 cents vs.

0.5 cents), and 18 times larger in the preopen than during the trading day (9 cents vs. 0.5 cents).[18] The fraction of the spread attributed to adverse selection is generally decreasing in trading volume.[19] Because the effective spread is also decreasing in trading volume, adverse selection decreases faster in dollar terms than as a fraction of the spread.

Because trades are larger after hours than during the trading day, in Panel B we report the adverse-selection component of the spread by time period and trade size. During the trading day, the adverse-selection component is decreasing in trade size for more than 80 percent of the stocks in each volume quartile. LSB found the opposite relation in their sample of 150 NYSE stocks in 1988. This difference may be due to the dramatic growth in volume over time, increasing the value of breaking up informed trades (Barclay and Warner (1993)). The difference may also be related to the fact that most large trades on Nasdaq are not anonymous, occurring with market makers who refuse to trade in large sizes with traders they suspect may be informed.

The inverse relation between adverse selection and trade size is also apparent after hours. The difference in adverse selection between the preopen and the postclose narrows as trade size increases and is not statistically significant for large trades. Hence, while the large trades after the close are likely a continuation of trading at the close, it appears that these trades are not significantly different in their characteristics from large trades before the open. It is not surprising that small trades account for the difference in adverse selection between the preopen and postclose because a majority of trades in the preopen are executed anonymously on an ECN, while most trades in the postclose are negotiated with market makers (Barclay and Hendershott (2003)).

Because adverse selection is decreasing in trade size more quickly during the trading day than after hours, the differences in adverse selection between the trading day and after hours increase with trade size. For small trades, the fraction of the spread due to adverse selection is two to four times larger after hours than during the trading day. For large trades, the fraction of the spread due to adverse selection is over 40 times larger after hours than during the trading day. In dollar terms, these differences are even greater. For small trades, the dollar effective spread attributed to adverse selection is seven to 15 times larger after hours than during the trading day. For large trades, the dollar

[18] Estimates of the components of the bid–ask spread rely on an underlying model that may be mis-specified. In addition, the microstructure may be significantly different after hours than during the trading day. A VAR described in Hasbrouck (1991) that is robust to delayed effects caused by inventory adjustments, discreteness of prices, lagged adjustment to new information, and lagged adjustment to trades shows that the ultimate price impact of a trade innovation as measured by the impulse response function provides the same ordering as the adverse-selection component of the spread—the average impulse response function is five times larger in the preopen, and two times larger in the post-close than during the trading day. The impulse response functions are significantly larger than the adverse-selection components of the spread, indicating a lagged price adjustment to trades that is not captured in the adverse-selection component of the spread. The VAR is estimated using differing number of lags to account for the differences in trading activity across time periods. Further details are available from the authors upon request.

[19] A similar relation between adverse selection and trading volume is found in Hasbrouck (1991) and Easley et al. (1996).

effective spread attributed to adverse selection is several hundred times larger after hours than during the trading day.

To verify that the results in Panel B are not driven by stocks in the lower volume quartiles, for which large trades after hours are rare, Panel C provides the adverse-selection component of the effective spread by trade size for the highest volume quartile. The results in Panel C are generally consistent with the results in Panel B. As in Panel B, the adverse-selection component of the spread for the highest volume stocks is higher after hours than during the trading day for every trade-size category, and this difference is increasing in trade size.

Figure 4 graphs the adverse-selection component of the spread for half-hour intervals from 8:00 a.m. to 6:30 p.m. The adverse-selection component of the spread is estimated stock by stock and then averaged across stocks. To ensure that we have sufficient data to estimate the adverse-selection component of the spread in each half-hour interval, we limit our analysis to the 50 highest volume stocks.

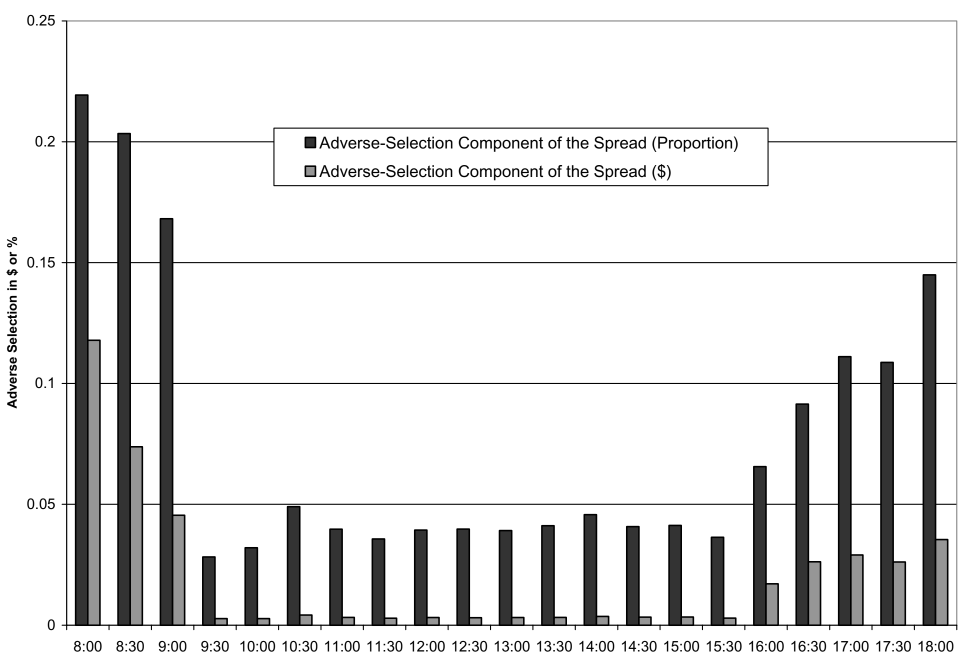

Figure 4. The adverse-selection component of the effective spread by 30-minute interval. The adverse-selection component of the effective half-spread is calculated for each 30-minute interval from 8:00 a.m. to 6:30 p.m. for the 50 highest-dollar-volume Nasdaq stocks from March to December 2000 using the regression $\Delta M_{t+1} = \lambda z_t + e_{t+1}$, where ΔM_{t+1} is the change in the quote midpoint following trade t, and z_t is the effective half-spread at time t. The cross-sectional averages are graphed. The same scale on the vertical-axis is used for the adverse-selection component of the effective spread in dollars and as a proportion of the spread.

Adverse selection decreases steadily during the preopen, and then falls by 80 percent in the first half-hour of the trading day. Adverse selection per trade is at its lowest in the first half hour of the trading day (from 9:30 a.m. to 10:00 a.m.). This may be due to the high volume of trade during this half-hour, and the large volume of retail orders that accumulate overnight and execute at the open. Adverse selection remains roughly constant throughout most of the rest of the trading day and then falls again in the last half hour before the close (from 3:30 p.m. to 4:00 p.m.). In proportional (dollar) terms, the adverse-selection component doubles (increases five times) in the first half hour after the close, and then increases by about 20 percent in each of the next two half-hour periods. The adverse-selection proportion of the spread is roughly constant from 5:00 to 6:00 p.m. before increasing again in the final half hour of the postclose.

This analysis of the adverse-selection component of the spread is consistent with the hypothesis that discretionary traders consolidating their trades during the trading day results in significantly higher adverse selection after hours. In addition, Table IV provides the average adverse selection per trade, not the adverse selection for the marginal liquidity provider. Assuming that the most sophisticated traders are currently providing liquidity, if less sophisticated traders attempt to provide liquidity after hours, they will face even greater adverse selection than shown in Table IV.

B. *The Fixed (Order Processing and Dealer Profit) Component of the Effective Spread*

Although adverse selection is higher after hours than during the trading day, adverse selection accounts for only 10 percent to 20 percent of the after-hours effective spread. Thus, the wider spreads may be large enough to provide higher profits from supplying liquidity after hours, in spite of increased adverse selection and not all of the increase in trading costs is attributable to the loss of the liquidity externalities. This directs our analysis to the fixed component of the effective spread, which includes both order-processing costs and dealer profits.[20] Order-processing costs have several components. Some of the costs (e.g., investments in technology) are truly fixed and independent of both time and the number of transactions. Other costs (e.g., clearing and settlement) are independent of time, but depend on the number of transactions. The remaining costs (e.g., the opportunity cost of the market maker) are independent of the number of transactions, but depend on time. The low after-hours trading volume will not affect the fixed or trade dependent order processing costs per trade. However, the time-dependent order-processing costs per trade are expected to increase after hours.

[20] The fixed component of the spread overstates the profitability of supplying liquidity through limit orders because it does not measure the opportunity cost of waiting for an execution. Presumably the lower frequency of trade after hours results in higher opportunity costs than during the trading day.

Just as the positive correlation in order flow makes estimating inventory costs difficult, it also complicates determining the fixed component of the spread. Spread decomposition models typically assume that there is zero or negative serial correlation in trades. LSB and MRR are exceptions. Before estimating the fixed component of the spread, it is useful to understand the relation between the two models.

MRR estimate the first-order serial correlation in trades (ρ), the adverse selection (θ_{MRR}), and the fixed costs of supplying liquidity (ϕ). Employing the common assumption that the midquote is an unbiased estimate of the true price, (1) from MRR can be written as

$$M_{t+1} = M_t + \theta_{MRR}(x_t - \rho x_{t-1}) + \varepsilon_t, \tag{4}$$

where x_t is the trade sign (+1 for a buy order and −1 for a sell order). Similarly (2) from MRR can be written as

$$P_t = M_{t+1} + \phi x_t + \xi_t. \tag{5}$$

The implied quoted half-spread from MRR is ($\theta_{MRR} + \phi$) and the proportion of the spread that is due to adverse selection is $\theta_{MRR}/(\theta_{MRR} + \phi)$. For simplicity assume that all trades take place at the quotes (a comparison of the effective and trade-weighted quoted spreads in Figures 2 and 3 suggests that). It follows from (5) and (2) that

$$E\phi x_t = P_t - M_{t+1} = P_t - (M_t + \lambda(P_t - M_t)) = (1 - \lambda)(P_t - M_t), \tag{6}$$

implying that the fixed component in MRR is equal to the sum of the fixed and order persistence components in LSB. It is also the case that if the effective spread is constant then the measures of order persistence are the same in MRR and LSB: $\theta_{LSB} = \rho$. Empirically, if MRR is estimated using (4), (5), and $x_t\, x_{t-1} = \rho x_t{}^2$, the adverse-selection component of the spread ($\theta_{MRR}/(\theta_{MRR} + \phi)$) is very close to the estimates of adverse-selection component of the spread, λ, from LSB in Table IV.

MRR do not provide means to separate the risk bearing and inventory costs from the order processing costs and profits. Equation 2 above does provide this decomposition under the assumption that profits are measured one step ahead, for example, if the next trade is a reversal, then the liquidity provider profits, otherwise the liquidity provider trades at the quote at a loss because the quotes move due to adverse selection. Therefore, the fixed component from LSB can be thought of as a lower bound where the bound is tight when trades are perfectly serially correlated.

Table V provides the LSB fixed component of the spread as a fraction of the effective spread and in dollars, by volume quartile (Panel A), trade size (Panel B), and trade size for the highest volume quartile (Panel C). Panel A shows that the fixed component accounts for slightly more than half of the effective spread

Table V

The Fixed (Order Processing and Dealer Profit) Component of the Effective Half-Spread by Dollar-Volume Quartile and Trade Size

The fixed (order processing and dealer profit) component of the effective spread is estimated for the trading day, preopen, and postclose for the 200 highest-dollar-volume Nasdaq stocks from March to December 2000 for small (≤1,000 shares), medium (1,001 to 9,999 shares), and large (≥10,000 shares) trades using the regression $\Delta P_{t+1} = -\gamma z_t + u_{t+1}$, where ΔP_{t+1} is the change in the transaction price following trade t, and z_t is the effective spread at time t. Cross-sectional means are reported with standard deviations below in parentheses. After-hours values that differ from the trading day at a 0.01 level are denoted with a *. After-hours values that differ from the other after-hours period at a 0.01 level are denoted with a †.

	Proportion			Dollars		
	Trading Day	Pre-Open	Post-Close	Trading Day	Pre-Open	Post-Close
Panel A: Fixed (Order Processing and Dealer Profit) Component of the Effective Half-Spread by Dollar-Volume Quartile						
Volume Quartile						
Highest	0.532	0.284†*	0.420†*	0.043	0.070†*	0.086†*
	(0.12)	(0.09)	(0.10)	(0.02)	(0.03)	(0.04)
2	0.531	0.180†*	0.281†*	0.047	0.055†	0.071†*
	(0.07)	(0.08)	(0.10)	(0.02)	(0.03)	(0.03)
3	0.524	0.148†*	0.202†*	0.047	0.043†	0.053†
	(0.05)	(0.09)	(0.11)	(0.03)	(0.02)	(0.03)
Lowest	0.507	0.113†*	0.150†*	0.055	0.045†*	0.057†
	(0.04)	(0.07)	(0.09)	(0.02)	(0.03)	(0.03)
All	0.524	0.181†*	0.263†*	0.048	0.053†*	0.067†*
	(0.08)	(0.11)	(0.14)	(0.02)	(0.03)	(0.04)
Panel B: Fixed (Order Processing and Dealer Profit) Component of the Effective Half-Spread by Trade Size (Full Sample)						
Trade Size						
Small (−1,000)	0.476	0.171†*	0.245†*	0.043	0.050†*	0.059†*
	(0.07)	(0.10)	(0.13)	(0.02)	(0.03)	(0.03)
Medium (1,001–9,999)	0.814	0.268*	0.282*	0.096	0.080†*	0.095†
	(0.13)	(0.20)	(0.18)	(0.06)	(0.09)	(0.08)
Large (10,000+)	0.990	0.591†*	0.435†*	0.166	0.371†*	0.189†
	(0.05)	(0.40)	(0.22)	(0.10)	(0.39)	(0.17)
Panel C: Fixed (Order Processing and Dealer Profit) Component of the Effective Half-Spread by Trade Size (Highest-Volume Quartile)						
Trade Size						
Small (−1,000)	0.487	0.267†*	0.378†*	0.038	0.065†*	0.072†*
	(0.11)	(0.09)	(0.09)	(0.02)	(0.03)	(0.03)
Medium (1,001–9,999)	0.814	0.436†*	0.496†*	0.096	0.124†*	0.152†*
	(0.17)	(0.17)	(0.16)	(0.07)	(0.12)	(0.11)
Large (10,000+)	0.984	0.778†*	0.659†*	0.195	0.484†*	0.309†*
	(0.09)	(0.43)	(0.14)	(0.13)	(0.37)	(0.24)

during the trading day, decreasing from 53 percent in the lowest volume quartile to 51 percent in highest volume quartile. Because effective spreads are inversely related to trading volume, in dollar terms, the fixed component is also inversely related to trading volume during the trading day, increasing from 4.3 cents for the highest volume quartile to 5.5 cents for the lowest volume quartile.

After hours, the fixed component represents a much smaller fraction of the spread, 18 percent in the preopen and 26 percent in the postclose, and is more sensitive to trading volume, decreasing from 28 percent and 42 percent in the highest volume quartile to 11 percent and 15 percent in the lowest volume quartile. In addition, the fixed component of the spread is lower in the preopen than in the postclose. In dollar terms, the fixed component of the spread is generally increasing in trading volume after hours.

Perhaps the most interesting result in Panel A is that although the effective spread is more than four times larger during the preopen than during the trading day, supplying liquidity in the preopen is about as profitable as during the trading day (5.3 cents vs. 4.8 cents per trade, on average). Supplying liquidity in the preopen is slightly more profitable for high-volume stocks and slightly less profitable for low-volume stocks compared with the trading day. Providing liquidity in the postclose is more profitable than providing liquidity in the preopen or the trading day, although the differences are not statistically significant in the two lowest volume quartiles.

Panel B extends the analysis in Panel A to control for trade size. The fixed component of the spread increases with trade size in all three periods. For large trades, the fixed component is 59 percent of the spread in the preopen and 99 percent of the spread during the trading day. The primary difference between the preopen and the trading day is in these large trades, where the fixed component of the spread (in dollars) is twice as large during the preopen as it is during the trading day. After controlling for trade size, the fixed component of the spread is roughly the same during the postclose and during the trading day. Thus, in Panel A, the larger average fixed component of the spread for the postclose is largely explained by the fact that trades are much larger during the postclose than during the trading day.

As with the adverse-selection component of the spread, the difference between the marginal and average profitability of supplying liquidity after hours may be large. Assuming that the most sophisticated traders are currently providing liquidity after hours, if less sophisticated investors attempt to provide liquidity through limit orders, they likely will do so at times and at prices that will generate lower profits than the averages reported in Table V. Because supplying liquidity does not appear to be more profitable after hours than during the trading day, the market appears to be in equilibrium with the low after hours activity being due to the intertemporal liquidity externalities arising from discretionary liquidity traders congregating together during the trading day.

The fixed component of the bid–ask spread is an ex ante measure of dealer profits. The realized spread is an ex post measure of these same profits. Consistent with the results in Table V, the realized half spreads in Panel C of

Table II are small after hours: 3 cents in the preopen and 9 cents in the postclose. Realized spreads in both the preopen and the postclose are larger than during the trading day.[21]

C. Order Persistence

Our data exhibit a high degree of order persistence (buy orders followed by buy orders, or vice versa). The positive serial correlation in the direction of the trades may be due to several factors including the breaking up of orders into smaller trades, or the sequential exercise of stale limit orders. The small depth at the Nasdaq inside spread encourages the breaking up of orders, and several firms now offer software that automates the process of executing trades against multiple market participants simultaneously or in rapid succession.

Table VI provides the order persistence component of the spread by volume quartile (Panel A), trade size (Panel B), and trade size for the highest volume quartile (Panel C). The left half of the table reports the order persistence component as a fraction of the effective spread, and the right half of the table provides the probability of a continuation. The probability of a continuation is very high in our sample: 71 percent during the trading day and 79 percent in the preopen and postclose.[22]

Panels B and C of Table VI show that order persistence is generally decreasing in trade size for all time periods. During the trading day, the probability of a continuation 73 percent for small trades, 58 percent for medium trades, and 50 percent for large trades. During the preopen, the probability of a continuation is 79 percent for small trades, 77 percent for medium trades, and 63 percent for large trades. During the postclose, the probability of a continuation is 79 percent for small trades, 80 percent for medium trades, and 74 percent for large trades. These patterns indicate that order persistence is more prevalent after hours than during the trading day, and more prevalent in the preopen than in the postclose.

During the trading day, the fraction of the spread due to order persistence is roughly constant across volume quartiles at 42 percent. However, the component of the spread due to order persistence is decreasing in trading volume after hours. Spreads are more sensitive to trading volume after hours than during the trading day (Table II), and the sensitivity is more pronounced for

[21] A comparison of the fixed component of the spread and the realized spread highlights the shortcomings of a two-way spread decomposition. If the fixed component of the spread is calculated as 1 minus the adverse-selection component (as in Huang and Stoll's (1997) two-way decomposition), the average fixed component is nine cents during the trading day, 30 cents in the preopen, and 28 cents in the postclose. These values for the fixed component of the spread are eight, 10, and three times larger than the respective realized spreads. The two-way spread decomposition assumes that buy and sell orders are serially uncorrelated. The LSB three-way spread decomposition incorporates the order persistence observed in the data. This produces estimated dealer profits in Table V that are much closer to the corresponding realized spreads in Table II.

[22] Order persistence may be measured with error during the trading day due to the difficulties in correctly ordering transactions in such high frequency data.

Table VI

The Order Persistence Component of the Effective Half-Spread by Dollar-Volume Quartile and Trade Size

The order-persistence component of the spread is estimated for the trading day, preopen, and postclose for the 200 highest-dollar-volume Nasdaq stocks from March to December 2000 for small ($\leq$1,000 shares), medium (1,001 to 9,999 shares), and large ($\geq$10,000 shares) trades using the regression $z_{t+1} = \theta z_t + \eta_{t+1}$, where z_t is the effective spread at time t. Cross-sectional means are reported with standard deviations below in parentheses. After-hours values that differ from the trading day at a 0.01 level are denoted with a *. After-hours values that differ from the other after-hours period at a 0.01 level are denoted with a †.

	Proportion of Effective Spread			Probability of a Continuation		
	Trading Day	Pre-Open	Post-Close	Trading Day	Pre-Open	Post-Close
Panel A: Order Persistence by Dollar-Volume Quartile						
Volume Quartile						
Highest	0.427	0.531*	0.507*	0.714	0.765*	0.753*
	(0.12)	(0.05)	(0.09)	(0.06)	(0.02)	(0.04)
2	0.411	0.576*	0.571*	0.705	0.788*	0.786*
	(0.07)	(0.07)	(0.10)	(0.04)	(0.03)	(0.05)
3	0.411	0.619*	0.634*	0.706	0.809*	0.817*
	(0.04)	(0.09)	(0.12)	(0.02)	(0.05)	(0.06)
Lowest	0.416	0.662*	0.674*	0.708	0.831*	0.837*
	(0.04)	(0.10)	(0.12)	(0.02)	(0.05)	(0.06)
All	0.416	0.597*	0.596*	0.708	0.798*	0.798*
	(0.07)	(0.09)	(0.12)	(0.04)	(0.05)	(0.06)
Panel B: Order Persistence by Trade Size (Full Sample)						
Trade Size						
Small (−1,000)	0.458	0.602*	0.593*	0.729	0.801*	0.797*
	(0.08)	(0.09)	(0.12)	(0.04)	(0.04)	(0.06)
Medium (1,001–9,999)	0.160	0.558†*	0.626†*	0.580	0.779†*	0.813†*
	(0.11)	(0.19)	(0.16)	(0.06)	(0.10)	(0.08)
Large (10,000+)	0.008	0.280†*	0.487†*	0.504	0.640†*	0.744†*
	(0.05)	(0.33)	(0.20)	(0.03)	(0.17)	(0.10)
Panel C: Order Persistence by Trade Size (Highest-Volume Quartile)						
Trade Size						
Small (−1,000)	0.469	0.542*	0.533*	0.735	0.771*	0.767*
	(0.12)	(0.05)	(0.09)	(0.06)	(0.02)	(0.04)
Medium (1,001-9,999)	0.162	0.437†*	0.470†*	0.581	0.719†*	0.735†*
	(0.14)	(0.13)	(0.14)	(0.07)	(0.06)	(0.07)
Large (10,000+)	0.018	0.178†*	0.317†*	0.509	0.589†*	0.659†*
	(0.09)	(0.29)	(0.14)	(0.05)	(0.15)	(0.07)

larger trades (Table III). This may induce informed traders to break up their orders more often, resulting in the increase in order persistence after hours, especially in the lower volume quartiles. The higher order persistence for low-volume stocks after hours does not appear to be immediately incorporated into the quotes. This causes the profitability of liquidity provision after hours to decrease in the lower volume quartiles (Table V), rather than increasing, as it does during the trading day.

IV. The Persistence of Trading Costs and Order Flow across Time Periods

When traders decide how to time their trades it is important to understand how trading costs in the three time periods are related to each other on a day-to-day basis. A simple way to capture this is to measure how past trading costs predict subsequent ones. To do this, we regress effective and realized spreads in each time period (preopen, trading day, and postclose) on the lagged spread values. Both the number of trades and the dollar trading volume were also included in these regressions, but added little explanatory power and are not reported. Let $s_{i,t}$ be the average effective or realized spread for stock i in time period t. For each stock and time period, the spread is regressed on an intercept and the spread in the preceding preopen, trading-day, and postclose periods:

$$s_{i,t} = \alpha_i + \sum_{j=1}^{3} \beta_{i,j} \times s_{i,t-j} + \varepsilon_{i,t}. \tag{7}$$

Table VII provides the average coefficient estimates and average t-statistics for these regressions. For effective spreads, the positive coefficients show that trading in each time period is related to that in the previous time periods. The average t-statistics suggest that the effective spread in the prior trading day is

Table VII

The Time Series of Trading Costs

The spread ($s_{i,t}$), both effective and realized, is calculated by time period each day (i) for the 200 highest-dollar-volume Nasdaq stocks (t) from March to December 2000. For each stock and time period, the spread is regressed on an intercept and the spread for preceding preopen, trading day, and postclose periods:

$$s_{i,t} = \alpha_i + \sum_{j=1}^{3} \beta_{i,j} \times s_{i,t-j} + \varepsilon_{i,t}.$$

Cross-sectional means are reported with average t-statistics below in parentheses.

	Effective Spread			Realized Spread		
Preceding Spread	Pre-Open (1)	Trading Day (2)	Post-Close (3)	Pre-Open (4)	Trading Day (5)	Post-Close (6)
Pre-Open	0.053	0.011	0.046	0.026	0.003	0.042
	(0.67)	(1.72)	(0.92)	(0.33)	(0.19)	(0.66)
Trading Day	1.635	0.704	2.024	0.116	0.164	0.138
	(2.13)	(15.85)	(4.00)	(0.26)	(2.47)	(0.38)
Post-Close	0.182	0.011	0.081	0.083	0.008	0.046
	(1.62)	(1.28)	(1.08)	(0.83)	(0.38)	(0.65)

most informative about trading in each time period and the closer after hours time period is more informative than the prior one.

Realized spreads are also positive related in the time series, but the relation is weaker, with only the prior trading day in the trading day regression having a significant average t-statistic. The average coefficients are also lower than those in the effective spread regressions. The weaker relation between realized spreads suggests that the relation in effective spreads is driven by the time series relation in adverse selection.

V. Summary

This paper examines intertemporal liquidity externalities as measured through trading costs both during and outside of normal exchange trading hours for the 200 highest volume Nasdaq stocks in the final 10 months of 2000. Previous academic literature focuses almost exclusively on spatial network effects by taking a cross-sectional approach and examining the same security trading at the same time in different markets. The large endogenous shifts in the trading process at the open and at the close result in large differences in trading activity that provide an excellent laboratory to examine liquidity externalities through the endogenous temporal choices of traders demanding and supplying liquidity. Beyond increasing our scholarly understanding of one of the most important outstanding issues in market design and market regulation, studying liquidity effects is of practical importance to exchanges, investors, dealers, brokers, and regulators.

Quoted and effective spreads are more than three times larger during the postclose than during the trading day, and more than four times larger during the preopen than during the trading day. Demanders of liquidity in the postclose also receive better prices, on average, than would be available at the open, but the difference is smaller than for the preopen trades, suggesting that some traders in the postclose have high liquidity demands.

Stock markets exhibit positive liquidity externalities that typically result in multiple possible equilibria. If the market currently is in an equilibrium in which discretionary liquidity traders congregate during the trading day, then adverse selection will be high after hours, and individual discretionary liquidity traders will have no incentive to move their trades outside of the normal trading day. Understanding the nature of trading costs after hours will provide useful information about the likely future growth and development of this market. Our results also provide insights about the difficulties associated with starting and growing markets with relatively little activity, market stability, and potential market failure.

We use the method developed by Lin, Sanger, and Booth (1995) to decompose the effective spread into its various components. The adverse-selection component of the spread measured in dollars is 15 times larger during the preopen and seven times larger during the postclose than during the trading day. Adverse-selection costs are highest early in the morning, decrease as the open approaches, remain relatively constant during the trading day, and increase again immediately after the close. The dollar profit per share as measured by the fixed/profit component of the spread is roughly the same during the day and after hours, suggesting incentives to provide liquidity at better prices after hours are limited and that the market is in an equilibrium in which discretionary liquidity traders intertemporally consolidate their trades during the trading day.

The magnitude of the liquidity externalities suggests that exchanges have little incentive to expand their trading hours due to competitive pressure. Despite the wide spreads, profit opportunities for dealers to provide liquidity appear limited and the high adverse selection and low trading activity make monitoring the market costly. The wide spreads should discourage investors from trading after hours unless they have very high liquidity demands or short-lived private information. Finally, the investor protections, for example, warnings of high trading costs and volatility, currently employed by brokers and regulators should be continued.

REFERENCES

Admati, Anat, and Paul Pfleiderer, 1988, A theory of intraday patterns: Volume and price variability, *Review of Financial Studies* 1, 3–40.

Amihud, Yakov, and Haim Mendelson, 1980, Dealership market: Market making with inventory, *Journal of Financial Economics* 8, 21–53.

Barclay, Michael, and Terrence Hendershott, 2003, Price discovery and trading after hours, *Review of Financial Studies* 16, 1041–1073.

Barclay, Michael, and Jerold Warner, 1993, Stealth trading and volatility: Which trades move prices? *Journal of Financial Economics* 34, 281–305.

Biais, Bruno, Pierre Hillion, and Chester Spatt, 1999, Price discovery and learning during the preopening period in the Paris Bourse, *Journal of Political Economy* 107, 1218–1248.

Blume, Marshall E., and Roger M. Edelen, 2002, On replicating the S&P 500 index, Working paper, the Wharton School, University of Pennsylvania.

Cao, Charles, Eric Ghysels, and Frank Hatheway, 2000, Price discovery without trading: Evidence from the Nasdaq pre-opening, *Journal of Finance* 55, 1339–1365.

Chan, K.C., William Christie, and Paul Schultz, 1995, Market structure and the intraday pattern of bid–ask spreads for Nasdaq securities, *Journal of Business* 68, 35–60.

Ciccotello, Conrad, and Frank Hatheway, 2000, Indicating ahead: Best execution and the Nasdaq preopening, *Journal of Financial Intermediation* 8, 184–212.

Davies, Ryan, 2003, The Toronto Stock Exchange preopening session, *Journal of Financial Markets* 6, 491–516.

Easley, David, Nicholas Kiefer, Maureen O'Hara, and Joseph Paperman, 1996, Liquidity, information, and infrequently traded stocks, *Journal of Finance* 51, 1405–1436.

Foster, F. Douglas, and S. Viswanathan, 1990, A theory of intraday variations in volume, variance, and trading costs in securities markets, *Review of Financial Studies* 3, 593–624.

Foster, F. Douglas, and S. Viswanathan, 1993, Variations in trading volume, return volatility, and trading costs: Evidence on recent price formation models, *Journal of Finance* 48, 187–211.

Garbade, Kenneth, and William Silber, 1979, Structural organization of secondary markets: Clearing frequency, dealer activity and liquidity risk, *Journal of Finance* 34, 577–593.

Hasbrouck, Joel, 1988, Trades, quotes, inventories, and information, *Journal of Financial Economics* 22, 229–252.

Hasbrouck, Joel, 1991, Measuring the information content of stock trades, *Journal of Finance* 46, 179–207.

Hasbrouck, Joel, 1995, One security, many markets: Determining the contributions to price discovery, *Journal of Finance* 50, 1175–1199.

Hasbrouck, Joel, and George Sofianos, 1993, The trades of market makers: An empirical analysis of NYSE specialists, *Journal of Finance* 48, 1565–1593.

Huang, Roger, and Hans Stoll, 1994, Market microstructure and stock return predictions, *Review of Financial Studies* 7, 179–213.

Huang, Roger, and Hans Stoll, 1997, The components of the bid–ask spread: A general approach, *Review of Financial Studies* 10, 995–1034.

Lee, Charles, 1993, Market integration and price execution for NYSE-listed securities, *Journal of Finance* 48, 1009–1038.

Lee, Charles, and Mark Ready, 1991, Inferring trade direction from intraday data, *Journal of Finance* 46, 733–747.

Lin, Ji-Chai, Gary Sanger, and G. Geoffrey Booth, 1995, Trade size and components of the bid–ask spread, *Review of Financial Studies* 8, 1153–1183.

Lyons, Richard, 1995, Tests of microstructural hypotheses in the foreign exchange market, *Journal of Financial Economics* 39, 321–351.

Macey, Jonathan, and Maureen O'Hara, 1999, Regulating exchanges and alternative trading systems: A law and economics perspective, *Journal of Legal Studies* 28, 17–54.

Madhavan, Ananth, 2000, Market microstructure: A survey, *Journal of Financial Markets* 3, 205–258.

Madhavan, Ananth, Matthew Richardson, and Mark Roomas, 1997, Why do security prices change? A transaction-level analysis of NYSE stocks, *Review of Financial Studies* 10, 1035–1064.

Madhavan, Ananth, and Seymour Smidt, 1991, A Bayesian model of intraday special pricing, *Journal of Finance* 30, 99–134.

Madhavan, Ananth, and George Sofianos, 1997, An empirical analysis of NYSE specialist trading, *Journal of Financial Economics* 48, 189–210.

Mendelson, Haim, 1982, Market behavior in a clearing house, *Econometrica* 50, 1505–1524.

Mendelson, Haim, 1987, Consolidation, fragmentation, and market performance, *Journal of Financial and Quantitative Analysis* 22, 189–207.

Pagano, Marco, 1989a, Trading volume and asset liquidity, *Quarterly Journal of Economics* 104, 255–274.

Pagano, Marco, 1989b, Endogenous market thinness and stock price volatility, *Review of Economic Studies* 56, 269–287.

Wood, Robert, Thomas McInish, and J. Keith Ord, 1985, An investigation of transactions data for NYSE stocks, *Journal of Finance* 40, 723–739.