Intraday Patterns in the Cross-Section of Stock Returns

STEVEN L. HESTON, ROBERT A. KORAJCZYK, and RONNIE SADKA*

November 5, 2008

Abstract

At short horizons equity returns exhibit negative autocorrelation, possibly due to bid/ask bounce, while at longer horizons returns exhibit momentum. We study the term structure of microstructure effects using half-hour observation intervals in the post-decimalization period. The microstructure induced reversal is pronounced within 24 hours. Notably, we find significant continuation of returns at intervals that are multiples of a day and this effect lasts for over twenty trading days. Percentage changes in volume, order imbalance, and volatility exhibit similar patterns, but do not explain the return patterns. Additionally, bid/ask spreads do not explain the return pattern. The return continuation at daily frequencies is more pronounced for, but not restricted to, the first and last half-hour periods of the day. These effects are not driven by firm size, systematic risk premia, or inclusion in the S&P500 index. The pattern is also not driven by particular months of the year, days of the week, or turn-of-the-month effects. This suggests that traders may wish to time portfolio rebalancing to account for these persistent intraday patterns.

*Heston: Robert H. Smith School of Business, University of Maryland, Van Munching Hall, College Park, MD 20742; sheston@rhsmith.umd.edu; 301-405-9686. Korajczyk: Kellogg School of Management, Northwestern University, 2001 Sheridan Road, Evanston, IL 60208-2001; r-korajczyk@kellogg.northwestern.edu; Phone 847-491-8336. Sadka: Carroll School of Management, Boston College, 140 Commonwealth Ave., Chestnut Hill, MA 02467; sadka@bc.edu. We would like to thank Joseph Cerniglia, Ian Domowitz, Lisa Goldberg, Campbell Harvey, Ravi Jagannathan, Bruce Lehmann, Maureen O'Hara, Michael Pagano, Mark Seasholes, Avanidhar Subrahmanyam, Julie Wu, and seminar participants at the NBER Microsturcture Meeting; Center for Research in Econometric Analysis of Time Series, Aarhus Universitet; Brandeis University; Cornell University; and the Citigroup Quant Conference for comments. Korajczyk wishes to acknowledge the financial support of the Zell Center for Risk Research and the Jerome Kenney Fund. The most recent version of this paper is available at http://ssrn.com/abstract=1107590.

1. Introduction

There is a long-standing literature on seasonal patterns, say at the monthly, quarterly, or annual frequency, in stock returns (see Keim (1983), Ariel (1987), Lakonishok and Smidt (1988)). Some of this periodicity is consistent with patterns of trading by investors. For example, Keim (1989) finds the turn-of-the-year trading patterns induce patterns in equity trades that occur at the ask price versus the bid price and that this trading pattern explains the size-related turn-of-the-year effect in stock prices. Intraday patterns in returns and volatility are found by Wood, McInish, and Ord (1985). Returns and volatility are higher, on average, at the beginning and end of the trading day. Harris (1986) and Andersen and Bollerslev (1997) find similar results.

While intraday patterns of volume and volatility found in Wood, McInish, and Ord (1985), Harris (1986), and Pagano, Peng, and Schwartz (2008) can be justified with models of discretionary liquidity trading (e.g., Admati and Pfleiderer (1998) and Hora (2006)), predictable patterns in returns are harder to explain. We study the nature of this intraday periodicity of returns. We divide the trading day into 13 half-hour trading intervals. A stock's return over a trading interval is negatively related to its returns over recent intervals, which is consistent with the negative autocorrelation induced by "microstructure effects" such as bid-ask bounce. However, there is a statistically significant positive relation between a stock's return over an interval and its past returns at daily frequencies (i.e., 13, 26, 39, ... interval lags). This relation is stronger over the first and last half-hour of the trading day, as one might expect, given the results of Wood, McInish, and Ord (1985) and Harris (1986), but remains statistically significant over the other periods of the day. Thus, the intraday return pattern is not merely due to uniformly high returns at the beginning and end of the trading day.

What can explain these patterns in intraday returns? There are several possible explanations, though some are quite difficult to test due to data limitations. One explanation is that traders consistently trade at the same time of the day and at the same direction. For example, if the output of an active trader's investment model is relatively stable from day to day, then executing similar trades for several accounts on different days could generate intraday periodicity in order flow. This is particularly true if the trader uses a trading algorithm that specifies a specific pattern of trades, such as Almgren and Chriss (2000), Grinold and Kahn (2000), Huberman and Stanzl (2005), Hora (2006), and Engle and Ferstenberg (2007). Another example is trading by index funds at the close to reduce tracking error. However, this index fund behavior would not explain the existence of periodicity during the rest of the trading day. Campbell, Ramadorai, and Schwartz (2007) present evidence that

there is strong persistence, at a daily frequency, in the direction of trades by institutional investors, in the aggregate. Our results might indicate that there is persistence in the intraday timing of institutional order flow as well. They are also consistent with the model of sequential information acquisition of Holden and Subrahmanyam (2002) if agents tend to become informed at intervals that correspond to our observed periodicity.

Explanations based on autocorrelation in trading activity would theoretically imply a similar periodicity in trading volume or order flow/imbalance. Indeed, an examination of trading volume shows that it has similar patterns to those of returns, i.e. firms that experience a relatively high change in their trading volume over a particular half-hour interval of a day typically experience a high change in their volume during the same half-hour interval during each of the next few days. Although related, the periodicity in trading volume does not completely explain the periodicity of returns. We also split volume into that due to large versus small trade size. Both measures of volume show daily periodicity, but neither explains the daily return periodicity. Oddly, the level of order imbalance (OI) does not exhibit obvious periodicity, even when partitioned into small versus large trades, e.g. Hvidkjaer (2008). However, percentage changes in order imbalance exhibit periodicity similar to returns, but that pattern in order imbalances does not explain the pattern in returns. Possibly the Lee and Ready (1991) algorithm used to classify buyer- versus seller-initiated trades, used to calculate OI, results in error-prone estimates for our experimental design (i.e., individual stocks over short, half-hour, intervals).

Several other tests indicate that the intraday periodicity at the daily frequency is not merely an artifact of previously shown patterns. For example, it is not concentrated in any particular weekday and, therefore, is not a manifestation of the day-of-the-week effect (see French (1980) and Smirlock and Starks (1986)). It is not concentrated in any particular month (for monthly seasonality see Heston and Sadka (2008a, b)). The effect is also not particularly related to the turn-of-the-month effect (Ariel (1987)) or the turn-of-the-quarter effect (Carhart, Kaniel, Musto, and Reed (2002)). The pattern of intraday returns is highly persistent as it seems to last for over a month (20 trading days). It is not due to a particular market capitalization group, inclusion in the S&P500 index, nor a manifestation of intraday movements in systematic risk. There is substantial evidence of intraday periodicity of return volatility (Andersen and Bollerslev (1997)), which we also find in our sample. However, patterns in volatility do not explain our return periodicity.

Finally, we compare the results for the post-decimalization period to prior periods which include 1993-1997, for which the minimum price increment was one eighth of a dollar, and 1997-2000, for

which the minimum price increment was one sixteenth of a dollar. We find that the strength of the intraday periodicity is greatest in the post-decimalization period.

The rest of the paper is organized as follows. In Section 2 we show the basic patterns of intraday periodicity. In section 3 we study whether the intraday periodicity is a manifestation of previously observed seasonal patterns. We discuss potential explanations of the observed patterns and the evidence either supporting of inconsistent with those explanations in section 4. Section 5 includes our conclusions.

2. Patterns of Resilience in Intraday Stock Returns

We begin this study by measuring intraday persistence in the cross-section of stock returns. It is well-known that short-term stock returns are negatively autocorrelated (Lehmann (1990) and Lo and MacKinlay (1990)). While this phenomenon does not occur in the model of Glosten and Milgrom (1985), in which the spreads are due solely to adverse selection caused by informed traders, it appears in other models with bid-ask spreads (Roll (1984) and Glosten and Harris (1988)), specialist inventory effects (Stoll (1978)), or other market microstructure frictions. We want to study the resilience of stock prices based the pattern of autocorrelation over various horizons.

Our sample of firms consists of all New York Stock Exchange (NYSE) listed firms from January 2001 through December 2005. The period of study is chosen to coincide with the period of decimalization, the transition to which was completed by February 2001. We use the NYSE Trade and Quotation (TAQ) database to calculate intraday stock returns. For each stock we calculate returns over half-hour intervals. This gives thirteen intraday intervals per trading day from 9:30 a.m. to 4:00 p.m. This excludes after-hours trading and overnight open-close price movements. Note that settlement on stock transactions occurs after the end of the trading day. This means trades at different times do not need to earn the risk-free rate intraday. In other words, intraday stock returns give compensation for liquidity and risk, not for time value of money. In addition to returns, we also measure changes in volume defined as the logarithm of ratio of the number of shares traded over a half-hour interval relative to the number of shares traded in the previous half-hour interval. This gives a measure of the price and quantity movements of individual stocks throughout the day.

We analyze intraday stock returns using the cross-sectional regression methodology of Jegadeesh (1990). For each half-hour period in our data set we run cross-sectional regressions of half-hour stock returns on lagged half-hour returns

$$r_{it} = \alpha_{tk} + \gamma_{tk} r_{i,t-k} + e_{it}, \quad (1)$$

where r_{it} is return on stock i in the half-hour interval, t. The slope coefficients γ_{tk} represent the response of returns at half-hour t to returns over a previous interval lagged by k half-hour periods. Therefore, we call them "return responses." Following Fama (1976), these responses have the interpretation of (excess) returns on costless portfolios that had (excess) returns of 100% in a previous half-hour interval. In addition to the simple regression (1), we also use a multiple regression to estimate all return responses jointly

$$r_{it} = \alpha_t + \gamma_{t1} r_{i,t-1} + \gamma_{t2} r_{i,t-2} + ... + \gamma_{t65} r_{i,t-65} + e_{it}. \quad (2)$$

In this case the slope coefficients retain the interpretation of (excess) returns on costless portfolios with (excess) returns of 100% over a previous interval. Both the simple regression and the multiple regression use all firms with returns available in interval t and interval $t-k$.

We calculate the pattern of return effects by averaging average return responses over time for half-hour lags, k. Figure 1 presents the average return responses across different lags, along with their t-statistics (as in Fama and MacBeth (1973)) for lags up to one week.[1] With thirteen half-hour intervals per day and five trading days per week, this produces 65 lagged intervals. Consistent with previous literature, the first several return responses are negative. This means that stock returns experience a reversal period lasting several hours. Following this reversal period the returns effects are positive, peaking at a horizon of exactly 13 half-hours, or one trading day.

Table 1 Panel A shows the simple regression return responses are highly statistically significant at almost all lags. Table 1 Panel B shows the results of the multiple regression responses are similar to the simple regression in both magnitude and statistical significance. Over the period of one calendar day these results indicate that returns are temporarily reversed but then rebound.

Looking beyond 13 lags, the return effects over half-hour intervals on subsequent days remain largely negative, with statistically significant positive effects at exact daily multiples of 13 lags, i.e.,

[1] We use Fama and MacBeth (1973) t-statistics, which assume no autocorrelation in the coefficients of the cross-sectional regressions, because we find no evidence of significant autocorrelation.

26, 39, 52, and 65. It appears that temporary price pressure is reversed at virtually all future times except at the same time interval on subsequent days.

Since the simple regression produces results almost identical to the multiple regression, we will focus on the results from eqn. (1). We also use a simpler methodology of sorting stocks into deciles based on their returns over a previous half-hour interval. This allows us to consider lags far beyond one week and to gauge the economic magnitude of the effect. Figure 2 and Table 2 present those results.

Based on a half-hour return on one day, the average difference between the top decile of winners and the bottom decile of losers is 3.11 basis points at the same time on the next day. This difference remains positive on subsequent days, albeit smaller. The difference remains positive and statistically significant for up to 40 days (520 half-hours). It appears there is a persistent and predictable pattern in intraday stock transaction prices. When a stock goes up on one day, buyers earn a premium by buying the stock prior to the same time in the future. Conversely sellers provide a discount by selling at this time when they could expect a higher average price 30 minutes earlier or later.

3. Robustness of Intraday Periodicity

The previous section uncovered a surprisingly robust daily pattern in intraday stock returns. This section examines the pattern in more detail to show it is widespread across stocks and across time. In particular, it does not seem confined to a particular subuniverse of stocks, nor restricted to periods of time.

A. Patterns Across Past-Return Deciles

Table 3 shows the performance of stock deciles ranked on their performance in previous half-hour intervals. The daily strategies sort stocks on just one half-hour interval from a previous day, matching the formation time of day to the holding period time of day. In contrast the nondaily strategies use average returns over twelve previous half-hour intervals that do not match the holding period time of day. By studying the returns on these decile spreads we can observe any nonlinearity and see whether the daily pattern is concentrated in the upper or lower performing stocks.

The table shows most of the statistical and economic significance comes from the highest and lowest decile. For example, the worst nondaily losers over the previous day earned an average of 3.16 basis points, while the best nondaily winners lost 1.51 basis points per half hour. The average

returns are nearly monotonic across intermediate deciles. The signs are reversed for the daily decile strategies. For example, the worst decile of losers over the same interval of the previous day continued to lose an average of 1.35 basis points, while the best decile of daily winners earned 1.66 basis points per half hour interval. The intermediate decile average returns are monotonic, but most of the significance comes from the lowest and highest decile.

For lags beyond one day, the magnitude of the nondaily decile spreads is less than one basis point. The daily decile spread remains above one basis point per half hour for lags of up to five days, i.e., one week. Average decile spreads for both strategies are statistically significant for lags of at least four days. We shall focus on these decile spreads and examine the effect across subuniverses of stocks.

B. Time of Day

We first investigate whether the intraday pattern is an artifact of biases in opening or closing prices. Overnight orders are executed at the open, and many traders (for example index funds concerned with minimizing daily tracking error) place market-at-close orders. Temporary price distortions caused by opening and closing procedures might produce predictability in stock returns that does not affect stock prices at other times of the day.

Table 4 shows the excess return of decile spread strategies during different half-hour intervals throughout the day. The daily decile spreads are sorted based on the return for lag 13, while the nondaily spreads are sorted based on the average return for lags one through twelve. The return effect is quite pronounced in the first and last half-hours of trading. The Day 1 daily decile spread earns over 11 basis points in the opening half-hour, while the Day 1 nondaily strategy loses over 8 basis points. This is a difference of 19 basis points between these strategies in the opening half-hour. Similarly the Day 1 daily decile spread earns over 8 basis points near the close of trading, while the corresponding nondaily strategy loses 11 basis points. A smaller daily effect remains during the middle of the day. The Day 1 daily strategy earn positive average excess returns in every half-hour interval from 10:00 a.m. to 3:30 p.m., averaging 1.75 basis points over this period. Meanwhile the Day 1 nondaily strategy loses over every half-hour period, losing 3.74 basis points over this period. This is a consistent pattern throughout the day. The pattern is smaller but still consistent based on previous days. When evaluated from 10:00 a.m. to 3:30 p.m. all the daily and nondaily decile spreads are significantly different from zero at conventional levels.

This evidence indicates that the intraday patterns in the cross-section of stock returns are stronger

at the beginning and end of the trading day, but are not merely a manifestation of uniformly higher returns in these periods for all assets. This is inconsistent with an argument that the patterns are completely driven by institutional trading at, or near, the opening or closing of the trading day.

C. Day of Week

Another potential concern is weekly effects. French (1980) found that the stock market earns different average returns on different days of the week. In particular, average returns on the day following a weekend are lower than average returns on other days. Therefore, we want to check whether our daily effect is really a weekend effect or part of some other weekly pattern.

Table 5 shows the performance of our daily and nondaily decile spread strategies on different days of the week. The effect is remarkably consistent throughout the week. The Day 1 nondaily strategy loses money at the open, midday, and close on every day. The amounts range from -3.51 basis points on Thursdays to -6.14 basis points on Mondays. Meanwhile the Day 1 daily strategy earns a small premium at the open, midday, and close on every day. This ranges from 2.62 basis points on Tuesdays to 3.44 basis points on Wednesdays. The results for longer lags are weaker, but they have the same sign and are usually statistically significant at the 95% level. We conclude that the daily results are not limited to a weekend effect or other weekday pattern.

D. Calendar Month and Turn-of-Month

There are well-known seasonal patterns in the stock market. This includes both market-wide January effects and year-long seasonality (Rozeff and Kinney (1976), Bouman and Jacobsen (2002), and Kamstra, Kramer, and Levi (2003)) and cross-sectional performance such as the size effect at turn-of-year (Keim (1983)). In addition to ruling out weekday effects, we want to ensure the daily pattern is not an artifact of some monthly seasonal effect.

Table 6 repeats the decile spread strategies in every calendar month. Again, the results are strikingly consistent. The Day 1 nondaily strategy loses money in every calendar month, ranging from -2.88 basis points in June to -5.90 basis pints in March. And the Day 1 daily strategy makes money in every month, ranging from 1.7 basis points in March to 7.80 basis points in November. The longer lag strategies have a similar pattern, albeit smaller and less consistent. Nevertheless the Day 5 daily strategy is still profitable in every calendar month. The results are not limited to a particular time of year, and certainly not limited to the turn-of-year.

While the results are not limited to a turn-of-year seasonality, they might be driven by intramonth

patterns. Ariel (1987) shows stocks earn a premium near the beginning and end of calendar months. Park and Reinganum (1986) find a similar pattern in Treasury bills. This suggests we test for a similar pattern in intraday stock returns.

Table 7 controls for turn-of-month by separately reporting the combined results for trading days that occur on the first or last day of the month. The results are remarkably consistent. The Day 1 and Day 2 nondaily strategies lose money at the open, midday, and close both at the turn of month and middle of month, while the daily strategies make money at all these times. With few exceptions the Days 3, 4, and 5 strategies maintain this pattern. The pattern is not related to turn-of-month.

4. Potential Explanations

The previous sections have shown a widespread daily pattern in stock returns. If high-frequency changes in risk or liquidity influence investors' demand for assets, then we might find periodicity in returns due to periodicity in risk or liquidity. For example, stocks might be riskier at certain times of the day when news is released, or they might be subject to institutional transactions that follow a business day cycle. This section explores these possibilities.

A. Beta

A priori, it seems unlikely for stocks to have large fluctuations in systematic risks during the day because companies do not change their financial exposures from hour to hour. On the other hand, some economic series are released at scheduled times, and firms may have exposure to systematic news released at those times. In this case traders may be reluctant to hold stocks at these risky times. To diagnose this possibility we control for risk by regressing stock returns on the equal-weighted market index. To correct for non-synchronous trading (Scholes and Williams (1977) and Dimson (1979)) we include the contemporaneous market return along with 13 leads and lags. Table 8 reports the average intercepts from these regressions. Since the intraday interest rate is effectively zero, these intercepts have the interpretation of risk-adjusted returns.

The results of Table 8 resemble the previous results using unadjusted average returns. The average risk-adjusted return on decile spreads of previous-day winners in excess of previous-day losers is 3.03 basis points when investing at the same time of day. Yet this decile spread underperforms by 4.65 basis points at non-daily intervals. These effects are particularly pronounced in the first half-hour and last half-hour of the day, but remain statistically significant in the middle of the day.

The average risk-adjusted returns for the daily decile spreads continue to be substantial in the opening and closing half hour even when sorting on half-hour returns up to five business days previous. The Day 5 average decile spread is 4.84 basis points in the first half-hour, and 3.42 basis points in the last half hour. This indicates a substantial tendency for some stocks to persistently trade up or down at the open and close. The effect is much smaller in the middle of the day, less than 1 basis point, but remains statistically significant. Controlling for market risk does not eliminate the daily pattern.

B. Index Membership

If stocks risk and fall at the same time of day then presumably there are buyers and sellers who persistently trade them at those times (with persistence in the direction of the trade). Index funds and benchmarked mutual funds are natural suspects for these actions. These funds may have large daily inflows or outflows and have an inelastic demand to invest those funds to replicate the index. To economize on trading activity they might perform "basket trades" at the open of trade, and to minimize tracking error they would have a particular motivation to trade near the close. This is consistent with previous results showing a strong effect at these times.

Table 9 separates the decile spread results for S&P500 firms and non-S&P500 firms. The results for both daily and non-daily strategies are much stronger among the non-S&P500 stocks. For example, the average decile spread based on the previous nondaily returns loses 5.58 basis points in the non-S&P500 stocks, but loses less than 1 basis point with the S&P500 index stocks. The Day 1 daily strategy earns 3.28 basis points with the non-S&P500 stocks, but earns only 2.19 basis points with the index stocks. Naturally we would expect the non-index stocks to be smaller and less liquid. So these results are consistent with some type of daily liquidity effect. But they are not consistent with a liquidity effect that driven by stocks indexed to the S&P 500.

C. Size and Transactions Costs

A concern about the nature of intraday patterns in stock returns is liquidity. If there is a return premium at certain times of the day then it may be compensation for illiquidity that makes stocks difficult to trade efficient prices at those times. For example, Admati and Pfleiderer (1988) develop models where traders pool trades in certain periods of the day. This implies a pattern primarily among smaller and less liquid stocks which face larger adverse selection problems.

Table 10 sorts stocks into three groups based on market capitalization. The table reports the

decile spread strategies separately for these subuniverses of small-, medium-, and large-capitalization firms. The Day 1 strategies are larger among small firms, consistent with those firms having larger proportional spreads. The Day 1 nondaily decile spread loses more than 10 basis points in the opening half-hour and more than 22 basis points in the closing half-hour, while averaging a loss of more than 8 basis points in the midday half-hour intervals. Conversely the daily decile spread strategies are profitable with small stocks. The Day 1 daily strategy averages over 5 basis points per half-hour. In contrast these numbers are in the range of 1-3 basis points for medium and large stocks. The average excess returns for strategies based on longer daily and nondaily lags are smaller and consequently do not differ much across size categories. However almost all strategies maintain statistical significance at the 95% level in all size categories at the open, midday, and close. This suggests that while a liquidity/microstructure effect explanation may have merit, it is not associated exclusively with small firms.

An important consideration is the magnitude of transaction costs associated with our trading strategies. We find predictable excess returns of several basis points within a half-hour interval based on transaction prices. However, a trader with no other motive for trade must pay the ask price or accept the offer price to get immediate execution. Larger orders also lead to larger price impacts. Table 11 reports the decile spread results for strategies that buy at the offer price and sell at the bid price. The average results are all negative for all size categories at all times of the day, indicating that the periodicity we find does not indicate a pure profit opportunity. It is important to remember that these results involve the round-trip transactions costs of two different long-short decile strategies. Therefore, they incur the average cost of a single transaction multiplied by four. For example, among small stocks the average decile spread on the Day 1 Nondaily strategy is -25.03 basis points, and the average decile spread on the Day 1 Daily strategy is -23.78 basis points. Recall Table 10 showed the Day 1 Nondaily strategy lost 9.92 basis points among small stocks while the Day 1 Daily strategy gained 5.16 basis points. Comparing the pre-transaction cost returns in Table 10 to the post-spread returns in Table 11 we see that the implied one-way spread cost is between 4 and 7 basis points. The difference between the performance of Daily and Nondaily strategies often compares favorably with the magnitude of one-way transaction costs. This suggests many investors have a demand for immediate execution of trades in small stocks and are not willing to shift their trades by 30 minutes to take advantage of the periodicity.

These trading strategies are not likely to be profitable for stocks with large bid/ask spreads. Therefore, the results in Table 11 exclude stocks that have a quoted relative spread of more than 10

basis points at the beginning of a given trading interval. We also condition on spreads of 5 and 25 basis points and obtain similar results. Note, very few small stocks have spreads less than 5 basis points, so there is no point conditioning on less than 5 basis points. Since our reported raw profits are not greater than 25 basis points, we do not condition on spreads greater than 25 basis points. The results suggest it is quite difficult to profit from these type of intraday strategies without some exogenous desire to trade.

The transaction costs for medium and large stocks are substantially smaller than those for small stocks. Table 11 shows that for medium stocks the average decile spread results are roughly -20 basis points and for large stocks they are roughly -14 basis points. This corresponds to one-way trading costs of less than 5 basis points. The losses of the Nondaily and Daily strategies in Table 11 are smaller for medium and large stocks than for small stocks. In particular they do not exceed the one-way cost of the bid-offer spread. But the magnitudes are similar, and this again raises the question of why investors do not time their trades to improve execution.

D. Volume and Trade Size

A possible explanation of daily price patterns is the existence of patterns in volume. If a single large trade or a collection of small trades moves prices then the excess demand may have been removed from one side of the market. This might explain the price reversal. But positive return effects on future days indicate that price pressure occurs at the same time of day. This suggests there are recurring transactions that produce price pressure at the same time of day. If the daily return effect is caused by these fluctuations in supply and demand for individual stocks, then a pattern should also manifest in the volume of stocks traded.

To address this we repeat the cross-sectional regression using volume data

$$v_{it} \quad = \quad a_{tk} + g_{tk} v_{i,t-k} + u_{it}, \tag{3}$$

where v_{it} is the percentage change in volume of stock i over half-hour interval t. Figure 3 shows the pattern of volume effects over different historical lags. It strongly resembles the return pattern in Figure 1. In particular the cross-sectional volume response effects are uniformly negative at all lags except multiples of 13, i.e., except at exact daily lags. Figure 3 shows the pattern for 65 lagged half-hour intervals corresponding to one week of calendar lags. Like the pattern of return responses,

the effect of volume responses lasts much longer. Figure 4 shows the strength of volume response at daily intervals decays with longer lags, but remains positive and statistically significant for up to 520 half-hour lags, corresponding to 40 days. Together Figures 2 and 4 show the intraday cross-sections of daily return and volume display similar persistence lasting one or two months. Note that to the extent that volume and volatility are correlated, the volume pattern is consistent with the patterns in intraday volatility documented in Andersen and Bollerslev (1997). Both returns and volume tend to be negatively autocorrelated intraday, but display positive autocorrelation at the same time of day.

To check for differential effects of volume generated by orders of different sizes, we determine, for each 30-minute interval, the volume generated by trades of less than 1,000 shares each (small trade volume) and the volume generated by trades of greater than, or equal to, 1,000 shares each (large trade volume). In Panels A and B of Figure 5 we show the t-statistics of the coefficients from cross-sectional regressions like (3) for small trades and large trades separately. Both percentage changes in small- and large-trade volume exhibit the type periodicity that we see in returns. We also regress returns on lagged returns, lagged small-trade volume, and lagged large-trade volume. The results are reported in Panel C and D. Panel C contains a plot of the t-statistics of the coefficients on lagged returns. The results show that the return periodicity is not subsumed by volume. Panel D shows the t-statistics of the coefficients on small-trade and large-trade volume. After controlling for lagged returns, the small-trade volume shows some explanatory power for returns at daily intervals. The t-statistics for large-trade volume do not exhibit any discernible pattern in Panel D.

E. Volatility

It is well documented that there is intraday periodicity in volatility, (e.g., Wood, McInish, and Ord (1985), Harris (1986), and Andersen and Bollerslev (1997)). In particular, volatility tends to be high at the beginning and end of the trading day. In addition, Andersen and Bollerslev (1997) find high returns for the Standard and Poor's 500 (S&P 500) composite stock index futures contract at the beginning and end of the day. It might be the case that movements in volatility are driving the return periodicity we observe here. For example, movements in volatility might be related to movements in bid-ask spreads. Bid-ask bounce induces negative autocorrelation in returns and an upward bias in arithmetic returns that is more severe for high-frequency returns (Blume and Stambaugh (1983)).

Figure 6A shows that percentage changes in volatility (measured by the absolute value of returns) exhibits intraday periodicity similar to that found for returns. In Panel B of the table we show the

t-statistics of the coefficients when we regress returns on lagged returns and lagged volatility. The periodicity in the lagged return coefficients (solid bars) is very pronounced while there is no apparent periodicity of the coefficients for lagged volatility. Panel C of the figure plots the t-statistics for the coefficients on lagged returns after including contemporaneous and lagged volatility and the interaction of lagged returns and lagged volatility. The strong periodicity in returns remains.

We find no evidence that the periodicity in returns is driven by changing volatility using our, admittedly crude, measure of volatility.

F. Spreads and Order Imbalance

Since the high-frequency return bias discussed in Blume and Stambaugh (1983) is related to bid-ask bounce, we wish to test whether the return patterns we find are related to systematic changes in bid-ask spreads. In Panel A of Figure 7 we show the average cross-sectional regression coefficients when the percentage changes in spreads are regressed on their lagged values. Spreads do not exhibit the type of periodicity that we observe in returns. Panel B shows the coefficient from a regression of returns on lagged returns and lagged spreads. The spreads explain some of the negative return coefficients at low lags but do not explain the strong positive return periodicity at lags corresponding to daily frequency. Thus, we conclude that the patterns we observe are not driven by periodicity in bid-ask spreads.

We also look at the behavior of percentage changes in signed volume, or order imbalance. Order imbalance is defined as the net signed volume over the interval where the sign is determined by a variant of the Lee and Ready (1991) trade classification algorithm.[2] For example, if a time interval had 100,000 shares transacted that were classified as buyer-initiated and 75,000 shares transacted that were classified as seller-initiated then the order imbalance for the period would be 25,000 shares (equal to 100,000 - 75,000). Panel C of Figure 7 shows that the percentage changes in order imbalance exhibit periodicity similar to, but less pronounced, than the periodicity in returns. In Panel D of Figure 7, we see that the strong periodicity of returns remains at lags corresponding to daily frequencies.

Unreported results indicate that the level of order imbalance does not exhibit any particular periodicity (even when partitioned into small versus large trades, e.g. Hvidkjaer (2008)). Perhaps applying trade classification algorithms for identify buyer- versus seller-initiated trades results in

[2] Given the increased transactions volume in our sample period ralative to that in Lee and Ready (1991), we do not require their 5 second minimum period between quotes and transactions.

noisy estimates for individual stocks over short horizons such as the half-hour intervals used here.

G. Transactions Prices Versus Bid and Ask Prices

As mentioned in the introduction, Keim (1989) finds the turn-of-the-year trading patterns induce systematic patterns in the fractions of equity trades that occur at the ask price versus the bid price and that this trading pattern explains the size-related turn-of-the-year effect in stock prices. It might be the case that the patterns we see are an artifact of periodicity in transactions prices relative to the bid/ask prices without any periodicity in the bid and ask prices. Certainly, the pervasive negative coefficients at lags less than 13 are likely to be due to bid-ask bounce and do not imply negative autocorrelation in the bid and ask prices. To check for this we re-ran our tests using three alternatives to returns calculated using transaction prices: (a) returns calculated using bid prices only, (b) returns calculated using ask prices only, and (c) returns calculated using the midpoint of the bid-ask spread only. These return series do not suffer from bid-ask bounce, so we expect that much, if not all, of the intraday negative autocorrelation to disappear. The results are shown in Figure 8. The figure shows that there is significant negative coefficient on last period's return (which might be indicative of temporary liquidity imbalances), generally positive coefficients at other lags, and pronounced positive coefficients at lags 13, 26, 39, 52, and 65. Thus, the pronounce periodicity in transaction price returns at the daily frequency is not solely an artifact of periodicity in where transactions occur relative to the bid and ask prices.

H. Pre-decimalization Results

We focus our analysis in this paper on the post-decimalization period. In Table 12 we compare the return spreads on daily-frequency strategies (lags 13, 26, 39, 52, and 65) over our sample period to two additional sample periods corresponding to tick sizes of one eighth and one sixteenth of a dollar. We find that the strength of the intraday periodicity is greatest in the post-decimalization period. This might be due to the increased use of trading algorithms (of the sort discussed in Almgren and Chriss (2000), Grinold and Kahn (2000), Huberman and Stanzl (2005), Hora (2006), and Engle and Ferstenberg (2007)) by institutional investors. Results during the period when the tick size is one sixteenth are quite volatile, and therefore we present additional results in Table 12, Panel B, where the returns are winsorized at the 1% level. The winsorized results do not represent implementable trading strategies, but reduce the influence of outliers. These Winsorized results with one sixteenth tick size resemble the post-decimalization results.

5. Conclusion

We study the periodicity of cross-sectional differences in returns using half-hour observation intervals in the period from January 2001 through December 2005. We document pronounced intraday return reversals due to bid/ask bound, and these reversals last for several trading days. However, we find significant continuation of returns at intervals that are multiples of a day and this effect lasts for over twenty trading days. Percentage changes in trading volume, order imbalances, and volatility exhibit similar patterns, but do not explain the return patterns. The return continuation at daily frequencies is more pronounced for the first and last half-hour periods. These effects are not driven by firm size, systematic risk premia, or inclusion in the S&P500 index (as a proxy for trading by index funds). The pattern is also not driven by particular months of the year, days of the week, or turn-of-the-month effects. The periodicity at the daily frequency is observed when we also use bid-to-bid, ask-to-ask, or midpoint-to-midpoint returns, so the periodicity is not merely due to patterns of where transactions prices occur relative to the bid and ask prices. The results are consistent with investors having a predictable demand for immediacy at certain times of the day. The pattern does not present a profit opportunity in the absence of other motives to trade, since strategies that attempt to take advantage of the daily periodicity lose money, after paying the bid/ask spread. However, traders who have other exogenous motives for trading might wish to exploit these persistent intraday patterns.

References

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

Almgren, Robert, and Neil Chriss, 2000, Optimal execution of portfolio transactions. *Journal of Risk* 3, 5-39.

Andersen, Torben G., and Tim Bollerslev, 1997, Intraday periodicity and volatility persistence in financial markets, *Journal of Empirical Finance* 4, 115-158.

Ariel, Robert A., 1987, A monthly effect in stock returns, *Journal of Financial Economics* 18, 161-174.

Avramov, Doron, Tarun Chordia, and Amit Goyal, 2006, Liquidity and autocorrelation in individual stock returns, *Journal of Finance* 61, 2365-2394.

Blume, Marshall E., and Robert F. Stambaugh, 1983, Biases in computed returns: An application to the size effect, *Journal of Financial Economics* 12, 387-404.

Bouman, Sven, and Ben Jacobsen, 2002, The Halloween indicator, 'Sell in May and go away': Another puzzle, *American Economic Review* 92, 1618-1635.

Campbell, John Y., Tarun Ramadorai, and Allie Schwartz, 2007, Caught on tape: Institutional trading, stock returns, and earnings announcements, Working paper, Harvard University (http://ssrn.com/abstract=998244), forthcoming, *Journal of Financial Economics.*

Carhart, Mark M., Ron Kaniel, David K. Musto, and Adam V. Reed, 2002, Leaning for the tape: Evidence of gaming behavior in equity mutual funds, *Journal of Finance* 58, 661-693.

Chordia, Tarun, Richard Roll, and Avanidhar Subrahmanyam, 2005, Evidence on the speed of convergence to market efficiency, *Journal of Financial Economics* 76, 271-292.

Chordia, Tarun, Richard Roll, and Avanidhar Subrahmanyam, 2007, Liquidity and market efficiency, *Journal of Financial Economics* 87, 249-268.

Dimson, Elroy, 1979, Risk measurement when shares are subject to infrequent trading, *Journal of Financial Economics* 7, 197-226.

Engle, Robert, and Robert Ferstenberg, 2007, Execution risk: It's the same as investment risk, *Journal of Trading* 2, 10-20.

Fama, Eugene F., 1976, *Foundations of Finance*, New York: Basic Books.

Fama Eugene F., and James D. MacBeth, 1973, Risk, return, and equilibrium: Empirical tests, *Journal of Political Economy* 81, 607-636

French, Kenneth R., 1980, Stock returns and the weekend effect, *Journal of Financial Economics* 8, 55-69.

Glosten, Lawrence R., and Lawrence E. Harris, 1988, Estimating the components of the bid/ask spread, *Journal of Financial Economics* 21, 123-142.

Glosten, Lawrence R., and Paul R. Milgrom, 1985, Bid, ask and transaction prices in a specialist market with heterogeneously informed traders, *Journal of Financial Economics* 14, 71-100.

Grinold, Richard C. and Ronald N. Kahn, 2000, Active *Portfolio Management: A Quantitative Approach for Producing Superior Returns and Selecting Superior Returns and Controlling Risk* (2nd edition), McGraw-Hill, New York, NY.

Harris, Lawrence, 1986, A transaction data study of weekly and intradaily patterns in stock returns, *Journal of Financial Economics* 16, 99-117.

Heston, Steven L., and Ronnie Sadka, 2008a, Seasonality in the cross-section of stock returns, *Journal of Financial Economics* 87, 418-445.

Heston, Steven L., and Ronnie Sadka, 2008b, Seasonality in the cross-section of stock returns: The international evidence, working paper (http://ssrn.com/abstract=971141).

Holden, Craig W., and Avanidhar Subrahmanyam, 2002, News events, information acquisition, and serial correlation, *Journal of Business* 75, 1-32.

Hora, Merrell, 2006, Tactical liquidity trading and intraday volume, Working Paper, Credit Suisse (http://ssrn.com/abstract=931667).

Huberman, Gur, and Werner Stanzl, 2005, Optimal Liquidity Trading, *Review of Finance* 9, 165–200.

Hvidkjaer, Soeren, 2008, Small trades and the cross-section of stock returns, *Review of Financial Studies* 21, 1123-1151.

Jegadeesh, Narasimhan, 1990, Evidence of predictable behavior of security returns, *Journal of Finance* 45, 881-898.

Kamstra, Mark J., Lisa A. Kramer, and Maurice D. Levi, 2003, Winter blues: Seasonal affective disorder (SAD) stock market returns, *American Economic Review* 93, 324-343.

Keim, Donald B., 1983, Size-related anomalies and stock return seasonality: Further evidence, *Journal of Financial Economics* 12, 13-32.

Keim, Donald B., 1989, Trading patterns, bid-ask spreads, and estimated security returns: The case of common stocks at calendar turning points, *Journal of Financial Economics* 25, 75-97.

Lakonishok, Josef, and Seymour Smidt, 1988, Are seasonal anomalies real? A ninety-year perspective, *Review of Financial Studies* 1, 403-425.

Lee, Charles M. C., and Mark J. Ready, 1991, Inferring trade direction from intraday data. *Journal of Finance* 46, 733-754.

Lehmann, Bruce, 1990, Fads, martingales and market efficiency, *Quarterly Journal of Economics* 105, 1-28.

Lo, Andrew W., 1991, Long-term memory in stock prices, *Econometrica* 59, 1279-1313.

Lo, Andrew W., and A. Craig MacKinlay, 1990, When are contrarian profits due to stock market overreaction? *Review of Financial Studies* 3, 175-208.

Pagano, Michael S., Lin Peng, and Robert A. Schwartz, 2008, The quality of price formation at market openings and closings: Evidence from the Nasdaq stock market, Working Paper, Villanova University.

Park, Sang Yong, and Marc R. Reinganum, 1986, The puzzling price behavior of treasury bills that mature at the turn of calendar months, *Journal of Financial Economics* 16, 267-283.

Roll, Richard, 1984, "A Simple Implicit Measure of the Effective Bid-Ask Spread in an Efficient Market," *Journal of Finance* 39, 1127-1139.

Rozeff, Michael S., and William R. Kinney, 1976, Capital market seasonality: The case of stock returns, *Journal of Financial Economics* 3, 379-402.

Scholes, Myron, and Joseph Williams, 1977, Estimating betas from nonsynchronous data, *Journal of Financial Economics* 5, 309-327.

Smirlock, Michael, and Laura Starks, 1986, Day-of-the-week and intraday effects in stock returns, *Journal of Financial Economics* 17, 197-210.

Stoll, Hans R., 1978, The supply of dealer services in securities markets, *Journal of Finance* 33, 1133-1151.

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

Table 1
Cross-Sectional Regressions

Intraday cross-sectional simple regressions of the form $r_{i,t} = \alpha_{k,t} + \gamma_{k,t} r_{i,t-k} + u_{i,t}$ are calculated for half-hour interval t and lag k, and where $r_{i,t}$ is return of stock i during interval t. The lagged variable $r_{i,t-k}$ is return of stock i in interval $t-k$. The regression is calculated for every half-hour interval t from January 2001 through December 2005 (16,261 intervals), and for lag k values 1 through 65 (past 5 trading days). Panel A reports the time-series averages of $\gamma_{k,t}$. Panel B calculates multiple cross-sectional regressions, including all past lags in the same regression. The analysis uses NYSE-listed stocks.

Panel A. Simple regressions

Lag	Estimate	*t*-statistic	Lag	Estimate	*t*-statistic	Lag	Estimate	*t*-statistic	Lag	Estimate	*t*-statistic	Lag	Estimate	*t*-statistic
1	-5.35	-59.22	14	0.04	0.60	27	0.05	0.74	40	0.05	0.87	53	0.19	3.13
2	-1.44	-17.96	15	-0.26	-3.97	28	-0.01	-0.11	41	-0.10	-1.65	54	0.08	1.29
3	-0.65	-8.26	16	-0.21	-3.24	29	-0.11	-1.66	42	-0.04	-0.60	55	0.00	0.01
4	-0.38	-5.02	17	-0.17	-2.49	30	-0.05	-0.81	43	-0.11	-1.65	56	-0.02	-0.31
5	-0.21	-2.73	18	-0.03	-0.42	31	-0.23	-3.51	44	-0.12	-1.83	57	-0.09	-1.36
6	-0.20	-2.58	19	-0.18	-2.68	32	-0.24	-3.63	45	-0.15	-2.30	58	-0.11	-1.65
7	-0.11	-1.44	20	-0.27	-3.92	33	-0.17	-2.57	46	-0.10	-1.58	59	-0.01	-0.08
8	0.05	0.68	21	-0.12	-1.75	34	-0.10	-1.55	47	0.01	0.10	60	-0.08	-1.31
9	0.00	-0.01	22	-0.03	-0.51	35	-0.15	-2.29	48	-0.10	-1.50	61	0.12	1.91
10	0.16	2.31	23	-0.13	-2.02	36	0.07	1.03	49	-0.05	-0.86	62	0.09	1.40
11	0.34	5.05	24	0.15	2.41	37	-0.07	-1.07	50	0.09	1.52	63	0.14	2.30
12	0.52	8.10	25	0.17	2.62	38	0.13	2.04	51	0.24	3.96	64	0.18	3.00
13	1.19	18.22	26	0.79	12.45	39	0.70	11.54	52	0.58	9.62	65	0.63	10.57

Panel B. Multiple regressions

Lag	Estimate	*t*-statistic	Lag	Estimate	*t*-statistic	Lag	Estimate	*t*-statistic	Lag	Estimate	*t*-statistic	Lag	Estimate	*t*-statistic
1	-5.01	-71.76	14	0.10	2.29	27	0.20	4.47	40	0.10	2.41	53	0.27	6.15
2	-1.32	-22.01	15	-0.16	-3.32	28	0.05	1.20	41	0.07	1.56	54	0.10	2.25
3	-0.50	-8.63	16	-0.29	-6.06	29	-0.10	-2.20	42	-0.01	-0.28	55	0.00	-0.03
4	-0.35	-6.11	17	-0.24	-4.96	30	-0.01	-0.31	43	-0.12	-2.48	56	0.04	0.89
5	-0.44	-7.95	18	-0.24	-4.86	31	-0.18	-3.71	44	-0.02	-0.33	57	-0.04	-0.94
6	-0.32	-5.72	19	-0.29	-5.89	32	-0.24	-4.91	45	-0.09	-1.75	58	-0.01	-0.24
7	-0.22	-4.04	20	-0.34	-6.89	33	-0.20	-4.23	46	-0.08	-1.70	59	0.03	0.58
8	-0.10	-1.79	21	-0.20	-4.09	34	-0.05	-1.14	47	-0.04	-0.75	60	0.00	-0.05
9	-0.02	-0.30	22	-0.12	-2.51	35	-0.18	-3.96	48	-0.04	-0.78	61	0.05	0.98
10	0.01	0.26	23	-0.07	-1.51	36	0.01	0.20	49	-0.06	-1.29	62	0.10	2.26
11	0.15	3.27	24	-0.07	-1.46	37	0.00	-0.09	50	0.08	1.88	63	0.10	2.35
12	0.34	7.46	25	0.15	3.38	38	0.13	3.03	51	0.22	5.20	64	0.18	4.24
13	1.05	22.68	26	0.71	16.21	39	0.52	12.22	52	0.49	11.69	65	0.38	8.93

Table 2
Long-Run Performance

Every half-hour interval stocks are grouped into ten portfolios (with equal number of stocks in each portfolio) according to various categories based on past performance. For example, Lag 65 trading strategy ranks stocks according to their return during the historical lag half-hour interval 65. The stocks in each portfolio are assigned equal weight, and the portfolios are rebalanced every half hour. The average returns (per half hour, in basis points) of the bottom and top decile portfolios, as well as their portfolio return spread, for trading strategies corresponding to each 13th lag from 13 through 520 for the period January 2001 through December 2005 (16,261 intervals) are reported below, as well as the corresponding t-statistics (in brackets). The analysis uses NYSE-listed stocks.

Strategy	1 (losers)		10 (winners)		10-1	
(lag)	Return	*t*-statistic	Return	*t*-statistic	Return	*t*-statistic
13	-1.35	-6.18	1.66	7.93	3.01	22.15
26	-0.90	-4.18	1.07	5.15	1.97	15.01
39	-0.63	-2.95	0.73	3.53	1.36	10.75
52	-0.58	-2.73	0.68	3.27	1.26	10.01
65	-0.43	-2.05	0.66	3.19	1.09	8.70
78	-0.53	-2.51	0.63	3.05	1.16	9.34
91	-0.52	-2.46	0.60	2.89	1.12	9.12
104	-0.32	-1.50	0.51	2.50	0.83	6.81
117	-0.33	-1.54	0.59	2.85	0.91	7.42
130	-0.45	-2.13	0.48	2.33	0.93	7.58
143	-0.35	-1.65	0.49	2.40	0.84	6.95
156	-0.30	-1.44	0.47	2.29	0.77	6.46
169	-0.35	-1.66	0.40	1.95	0.75	6.18
182	-0.31	-1.46	0.47	2.31	0.77	6.38
195	-0.14	-0.68	0.43	2.12	0.58	4.76
208	-0.24	-1.17	0.45	2.23	0.70	5.93
221	-0.26	-1.26	0.40	1.95	0.66	5.60
234	-0.08	-0.41	0.27	1.34	0.36	3.03
247	-0.06	-0.27	0.22	1.08	0.28	2.34
260	-0.30	-1.43	0.29	1.43	0.59	4.99
273	-0.27	-1.29	0.30	1.48	0.57	4.92
286	-0.18	-0.84	0.37	1.84	0.55	4.72
299	-0.16	-0.78	0.39	1.94	0.56	4.77
312	-0.19	-0.93	0.37	1.81	0.56	4.75
325	-0.17	-0.84	0.31	1.53	0.48	4.12
338	0.06	0.27	0.10	0.51	0.05	0.39
351	-0.21	-1.01	0.34	1.68	0.55	4.73
364	-0.04	-0.19	0.25	1.21	0.28	2.47
377	-0.05	-0.23	0.26	1.29	0.31	2.63
390	-0.18	-0.86	0.16	0.77	0.33	2.84
403	-0.02	-0.11	0.18	0.86	0.20	1.70
416	-0.09	-0.42	0.18	0.90	0.27	2.35
429	-0.16	-0.75	0.10	0.50	0.26	2.23
442	-0.13	-0.62	0.22	1.10	0.35	3.03
455	-0.13	-0.61	0.22	1.07	0.34	2.98
468	-0.07	-0.34	0.28	1.37	0.35	3.05
481	0.10	0.51	0.26	1.29	0.16	1.37
494	-0.11	-0.53	0.26	1.27	0.37	3.20
507	-0.21	-0.99	0.36	1.77	0.56	4.99
520	-0.19	-0.91	0.23	1.16	0.42	3.67

Table 3
Returns of strategies based on past performance

Every half-hour interval stocks are grouped into ten portfolios (with equal number of stocks in each portfolio) according to various categories based on past performance. For example, the Day 1 trading strategy that is formed based on a daily frequency ranks stocks according to their return during the historical lag half-hour interval 13, while the nondaily strategy ranks stocks according to their average returns over the lag half-hour intervals 1 through 12. The stocks in each portfolio are assigned equal weight, and the portfolios are rebalanced every half hour. The average returns (per half hour, in basis points) of the various trading strategies for the period January 2001 through December 2005 (16,261 intervals) are reported below, as well as the corresponding *t*-statistics (in brackets). The analysis uses NYSE-listed stocks.

Strategy	1 (losers)	2	3	4	5	6	7	8	9	10 (winners)	10-1
Day 1											
Nondaily	3.16	0.67	0.27	0.09	-0.02	-0.17	-0.15	-0.24	-0.59	-1.51	-4.67
	[13.64]	[3.68]	[1.62]	[0.57]	[-0.13]	[-1.09]	[-0.98]	[-1.48]	[-3.40]	[-7.16]	[-28.16]
Daily	-1.35	-0.64	-0.35	-0.07	0.06	0.16	0.44	0.63	0.92	1.66	3.01
	[-6.18]	[-3.51]	[-2.05]	[-0.42]	[0.39]	[1.03]	[2.76]	[3.83]	[5.22]	[7.93]	[22.15]
Day 2											
Nondaily	0.61	0.37	0.22	0.23	0.13	0.18	0.12	0.02	-0.10	-0.31	-0.92
	[2.78]	[2.06]	[1.30]	[1.42]	[0.81]	[1.13]	[0.77]	[0.11]	[-0.58]	[-1.55]	[-6.57]
Daily	-0.90	-0.42	-0.20	-0.06	0.13	0.22	0.37	0.50	0.75	1.07	1.97
	[-4.18]	[-2.34]	[-1.15]	[-0.37]	[0.80]	[1.41]	[2.32]	[2.99]	[4.25]	[5.15]	[15.01]
Day 3											
Nondaily	0.41	0.25	0.28	0.17	0.19	0.17	0.08	0.05	0.07	-0.21	-0.62
	[1.92]	[1.41]	[1.70]	[1.07]	[1.22]	[1.09]	[0.52]	[0.29]	[0.40]	[-1.04]	[-4.62]
Daily	-0.63	-0.27	-0.05	0.03	0.08	0.23	0.31	0.40	0.54	0.73	1.36
	[-2.95]	[-1.51]	[-0.28]	[0.18]	[0.52]	[1.42]	[1.90]	[2.44]	[3.09]	[3.53]	[10.75]
Day 4											
Nondaily	0.21	0.20	0.20	0.26	0.25	0.15	0.18	0.02	0.12	-0.13	-0.34
	[0.99]	[1.13]	[1.18]	[1.61]	[1.62]	[0.98]	[1.16]	[0.10]	[0.69]	[-0.64]	[-2.60]
Daily	-0.58	-0.25	-0.11	0.05	0.07	0.19	0.21	0.38	0.50	0.68	1.26
	[-2.73]	[-1.42]	[-0.66]	[0.32]	[0.44]	[1.22]	[1.28]	[2.26]	[2.83]	[3.27]	[10.01]
Day 5											
Nondaily	0.08	0.12	0.14	0.20	0.10	0.21	0.27	0.13	0.21	0.02	-0.06
	[0.39]	[0.66]	[0.86]	[1.24]	[0.62]	[1.32]	[1.66]	[0.80]	[1.20]	[0.09]	[-0.49]
Daily	-0.43	-0.17	0.01	-0.04	0.06	0.22	0.23	0.23	0.47	0.66	1.09
	[-2.05]	[-0.94]	[0.07]	[-0.26]	[0.38]	[1.39]	[1.44]	[1.39]	[2.66]	[3.19]	[8.70]

Table 4

Returns of strategies based on past performance in different half-hour intervals of the trading day

Every half-hour interval stocks are grouped into ten portfolios (with equal number of stocks in each portfolio) according to various categories based on past performance. For example, the Day 1 trading strategy that is formed based on a daily frequency ranks stocks according to their return during the historical lag half-hour interval 13, while the nondaily strategy ranks stocks according to their average returns over the lag half-hour intervals 1 through 12. The stocks in each portfolio are assigned equal weight, and the portfolios are rebalanced every half hour. The average returns of the top-minus-bottom-decile portfolios (per half hour, in basis points) for each half-hour interval of a trading day for the period January 2001 through December 2005 (there are 1,255 observations for each half-hour interval of a trading day) are reported below, as well as the corresponding *t*-statistics (in brackets). The analysis uses NYSE-listed stocks.

Strategy	1 (first) [9:30-10:00]	2 [10:00-10:30]	3 [10:30-11:00]	4 [11:00-11:30]	5 [11:30-12:00]	6 [12:00-12:30]	7 [12:30-13:00]	8 [13:00-13:30]	9 [13:30-14:00]	10 [14:00-14:30]	11 [14:30-15:00]	12 [15:00-15:30]	13 (last) [15:30-16:00]	2-12 [10:00-15:30]
Day 1														
Nondaily	-8.36	0.62	-1.00	-2.01	-1.96	-2.89	-4.88	-2.83	-3.38	-8.17	-5.96	-8.75	-11.24	-3.74
	[-8.80]	[0.77]	[-1.55]	[-3.61]	[-3.83]	[-5.99]	[-10.84]	[-6.38]	[-7.49]	[-16.08]	[-12.08]	[-17.27]	[-18.32]	[-22.60]
Daily	11.48	5.02	2.66	1.20	1.38	1.35	1.53	0.76	1.19	0.81	0.89	2.46	8.42	1.75
	[12.58]	[7.97]	[5.01]	[2.87]	[3.71]	[3.92]	[4.69]	[2.16]	[3.72]	[2.12]	[2.45]	[6.48]	[14.90]	[14.06]
Day 2														
Nondaily	-2.96	0.68	0.68	-0.06	-0.50	0.05	-0.42	-0.24	0.78	-1.94	-1.75	-2.58	-3.79	-0.48
	[-3.52]	[1.04]	[1.22]	[-0.13]	[-1.08]	[0.13]	[-1.10]	[-0.65]	[1.99]	[-4.88]	[-4.30]	[-6.03]	[-7.25]	[-3.44]
Daily	10.48	2.59	1.32	0.51	-0.06	0.35	0.84	0.06	0.27	0.22	1.35	1.10	6.52	0.78
	[12.32]	[4.22]	[2.67]	[1.21]	[-0.17]	[1.08]	[2.61]	[0.20]	[0.80]	[0.62]	[3.99]	[2.91]	[11.43]	[6.45]
Day 3														
Nondaily	-4.87	-0.24	0.88	-0.07	0.21	0.04	0.04	0.06	0.19	-1.31	-1.10	-0.63	-1.29	-0.17
	[-6.03]	[-0.39]	[1.59]	[-0.15]	[0.48]	[0.10]	[0.09]	[0.18]	[0.50]	[-3.33]	[-2.89]	[-1.58]	[-2.64]	[-1.31]
Daily	6.32	1.55	0.23	0.34	0.40	0.38	0.65	-0.18	0.57	0.06	1.19	0.56	5.57	0.52
	[7.59]	[2.70]	[0.46]	[0.80]	[1.06]	[1.14]	[2.07]	[-0.58]	[1.76]	[0.17]	[3.76]	[1.56]	[10.46]	[4.44]
Day 4														
Nondaily	-2.55	0.31	0.08	-0.89	0.08	-0.45	-0.58	0.34	0.28	0.00	0.27	-0.06	-1.26	-0.06
	[-3.31]	[0.51]	[0.15]	[-1.94]	[0.19]	[-1.13]	[-1.62]	[0.93]	[0.74]	[0.01]	[0.70]	[-0.14]	[-2.67]	[-0.43]
Daily	5.64	1.52	0.84	0.90	0.25	0.10	0.06	0.04	0.65	0.53	0.95	0.54	4.32	0.58
	[6.86]	[2.51]	[1.67]	[2.26]	[0.69]	[0.31]	[0.19]	[0.14]	[2.06]	[1.52]	[2.86]	[1.56]	[7.98]	[4.95]
Day 5														
Nondaily	-0.14	0.43	-0.43	-0.81	-0.28	-0.22	0.90	0.89	-0.31	-0.08	0.99	-0.49	-1.29	0.05
	[-0.18]	[0.72]	[-0.77]	[-1.76]	[-0.66]	[-0.57]	[2.44]	[2.50]	[-0.82]	[-0.21]	[2.66]	[-1.24]	[-2.83]	[0.42]
Daily	4.98	1.37	-0.68	0.89	0.18	0.45	0.34	0.88	0.64	0.62	0.25	0.78	3.50	0.52
	[6.13]	[2.34]	[-1.27]	[2.21]	[0.46]	[1.37]	[1.06]	[2.75]	[2.04]	[1.69]	[0.72]	[2.25]	[6.97]	[4.35]

Table 5
Controlling for Day of the Week

Every half-hour interval stocks are grouped into ten portfolios (with equal number of stocks in each portfolio) according to various categories based on past performance. For example, the Day 1 trading strategy that is formed based on a daily frequency ranks stocks according to their return during the historical lag half-hour interval 13, while the nondaily strategy ranks stocks according to their average returns over the lag half-hour intervals 1 through 12. The stocks in each portfolio are assigned equal weight, and the portfolios are rebalanced every half hour. The average returns of the top-minus-bottom-decile portfolios (per half hour, in basis points) for the period January 2001 through December 2005 are reported below, as well as the corresponding *t*-statistics (in brackets). The returns are reported separately using half-hour intervals of each day of the week. The returns are also partitioned using all half-hour intervals of a day, as well as using only the first, the last and the rest. The analysis uses NYSE-listed stocks.

Strategy	Mondays				Tuesdays				Wednesdays				Thursdays				Fridays			
	1-13 (all)	1 (first)	2-12	13 (last)	1-13 (all)	1 (first)	2-12	13 (last)	1-13 (all)	1 (first)	2-12	13 (last)	1-13 (all)	1 (first)	2-12	13 (last)	1-13 (all)	1 (first)	2-12	13 (last)
Day 1																				
Nondaily	-6.14	-10.78	-5.11	-12.89	-3.74	-5.75	-3.17	-8.10	-4.18	-5.92	-3.39	-11.15	-3.51	-7.35	-2.54	-10.29	-5.90	-12.22	-4.59	-13.98
	[-17.14]	[-4.88]	[-14.52]	[-10.42]	[-10.88]	[-3.09]	[-9.07]	[-6.25]	[-10.76]	[-2.81]	[-8.76]	[-6.71]	[-8.94]	[-3.24]	[-6.40]	[-8.34]	[-16.21]	[-5.67]	[-12.87]	[-10.49]
Daily	2.86	11.62	1.49	9.19	2.62	8.17	1.73	6.80	3.44	13.96	1.97	9.06	3.20	13.75	1.70	9.21	2.93	9.95	1.84	7.90
	[9.25]	[5.29]	[5.41]	[7.25]	[9.05]	[4.20]	[6.51]	[5.42]	[11.18]	[6.91]	[6.92]	[7.50]	[10.14]	[6.53]	[5.85]	[7.38]	[9.83]	[5.15]	[6.71]	[5.88]
Day 2																				
Nondaily	-0.68	-1.01	-0.53	-2.02	-0.95	-3.20	-0.50	-3.61	-0.88	-2.34	-0.48	-3.78	-0.94	-5.29	-0.25	-4.24	-1.15	-2.86	-0.63	-5.23
	[-2.25]	[-0.53]	[-1.78]	[-1.89]	[-3.18]	[-1.80]	[-1.69]	[-3.47]	[-2.72]	[-1.31]	[-1.48]	[-3.01]	[-2.95]	[-3.01]	[-0.77]	[-3.44]	[-3.55]	[-1.32]	[-2.04]	[-4.28]
Daily	1.95	10.13	0.84	5.88	1.40	7.58	0.45	5.77	2.28	12.94	0.95	6.28	2.28	12.59	0.96	6.47	1.92	9.17	0.70	8.20
	[6.38]	[4.69]	[3.05]	[4.97]	[5.07]	[4.16]	[1.77]	[4.39]	[7.69]	[7.01]	[3.41]	[5.15]	[7.51]	[6.32]	[3.48]	[4.84]	[6.81]	[5.46]	[2.63]	[6.27]
Day 3																				
Nondaily	-0.57	-6.48	0.03	-1.34	-0.59	-6.96	-0.06	0.05	-0.46	-5.11	0.05	-1.40	-0.53	-3.44	-0.12	-2.12	-0.97	-2.39	-0.77	-1.69
	[-1.85]	[-3.16]	[0.11]	[-1.32]	[-2.02]	[-4.11]	[-0.22]	[0.05]	[-1.49]	[-3.07]	[0.15]	[-1.21]	[-1.73]	[-1.92]	[-0.39]	[-1.81]	[-3.32]	[-1.31]	[-2.72]	[-1.53]
Daily	1.63	7.28	0.78	5.34	1.00	4.73	0.19	6.21	1.56	6.76	0.64	6.47	1.20	6.92	0.29	5.53	1.41	6.01	0.74	4.21
	[5.49]	[3.43]	[2.85]	[5.08]	[3.84]	[2.97]	[0.77]	[5.74]	[5.43]	[3.66]	[2.39]	[5.06]	[4.18]	[3.78]	[1.08]	[4.18]	[5.06]	[3.11]	[2.90]	[3.57]
Day 4																				
Nondaily	0.24	-3.20	0.66	-0.98	-0.48	-3.52	-0.30	0.59	0.02	-1.59	0.24	-0.74	-0.49	-3.68	-0.07	-2.00	-0.97	-0.81	-0.78	-3.24
	[0.80]	[-1.67]	[2.27]	[-0.89]	[-1.67]	[-2.14]	[-1.03]	[0.60]	[0.07]	[-0.95]	[0.77]	[-0.68]	[-1.69]	[-2.31]	[-0.23]	[-2.01]	[-3.39]	[-0.45]	[-2.81]	[-2.98]
Daily	1.53	7.44	0.55	6.34	1.16	5.05	0.59	3.53	1.11	6.47	0.43	3.19	1.23	4.52	0.78	2.85	1.28	4.84	0.54	5.88
	[5.39]	[3.75]	[2.16]	[5.18]	[4.25]	[2.93]	[2.26]	[3.14]	[3.84]	[3.62]	[1.57]	[2.58]	[4.40]	[2.55]	[2.97]	[2.25]	[4.60]	[2.49]	[2.15]	[4.97]
Day 5																				
Nondaily	-0.33	0.28	-0.28	-1.48	0.02	-0.58	0.15	-0.82	0.01	-1.22	0.32	-2.20	0.17	-0.60	0.26	-0.10	-0.20	1.46	-0.21	-1.86
	[-1.14]	[0.16]	[-0.97]	[-1.56]	[0.06]	[-0.36]	[0.53]	[-0.81]	[0.03]	[-0.69]	[1.01]	[-2.17]	[0.59]	[-0.36]	[0.92]	[-0.10]	[-0.69]	[0.78]	[-0.73]	[-1.78]
Daily	1.50	6.90	0.90	2.72	0.82	3.59	0.32	3.59	0.93	5.12	0.40	2.60	1.31	2.97	0.82	4.99	0.93	6.48	0.18	3.57
	[5.24]	[3.35]	[3.43]	[2.51]	[3.15]	[2.16]	[1.29]	[3.27]	[3.14]	[2.76]	[1.37]	[2.36]	[4.67]	[1.70]	[3.03]	[4.63]	[3.35]	[3.67]	[0.69]	[2.85]

Table 6
Controlling for Calendar Month

Every half-hour interval stocks are grouped into ten portfolios (with equal number of stocks in each portfolio) according to various categories based on past performance. For example, the Day 1 trading strategy that is formed based on a daily frequency ranks stocks according to their return during the historical lag half-hour interval 13, while the nondaily strategy ranks stocks according to their average returns over the lag half-hour intervals 1 through 12. The stocks in each portfolio are assigned equal weight, and the portfolios are rebalanced every half hour. The average returns of the top-minus-bottom-decile portfolios (per half hour, in basis points) for the period January 2001 through December 2005 are reported below, as well as the corresponding *t*-statistics (in brackets). The returns are reported separately for each calendar month (using all half-hour intervals in each calendar month). The analysis uses NYSE-listed stocks.

Strategy	January	February	March	April	May	June	July	August	September	October	November	December
Day 1												
Nondaily	-4.74	-5.37	-5.90	-5.07	-3.79	-2.88	-4.71	-4.88	-3.32	-6.14	-3.74	-5.27
	[-6.98]	[-9.36]	[-10.20]	[-9.17]	[-7.71]	[-5.87]	[-7.82]	[-9.57]	[-5.20]	[-9.21]	[-6.72]	[-10.48]
Daily	3.82	3.40	1.70	2.52	2.45	2.95	3.07	3.02	3.25	3.38	3.80	2.90
	[7.14]	[7.27]	[3.64]	[5.23]	[5.79]	[7.24]	[6.50]	[7.16]	[6.88]	[6.27]	[7.80]	[6.44]
Day 2												
Nondaily	0.18	-1.23	-1.12	0.24	-1.11	-0.91	-1.56	-0.47	-0.77	-1.72	-1.16	-1.43
	[0.34]	[-2.43]	[-2.26]	[0.48]	[-2.53]	[-2.04]	[-3.03]	[-1.08]	[-1.53]	[-3.10]	[-2.31]	[-3.55]
Daily	2.58	2.58	2.22	1.55	2.06	1.14	1.46	2.07	2.09	2.44	2.05	1.38
	[5.27]	[5.57]	[4.92]	[3.38]	[5.05]	[2.89]	[3.15]	[4.99]	[4.49]	[4.59]	[4.46]	[3.28]
Day 3												
Nondaily	-0.98	-0.56	-0.57	-0.14	-0.37	-0.92	0.04	-0.32	-0.38	-1.21	-1.25	-0.80
	[-1.86]	[-1.16]	[-1.17]	[-0.30]	[-0.89]	[-2.09]	[0.07]	[-0.81]	[-0.82]	[-2.35]	[-2.55]	[-1.99]
Daily	1.41	1.30	1.50	0.94	1.87	1.48	1.60	0.95	1.66	1.26	1.24	1.08
	[2.94]	[3.00]	[3.51]	[2.04]	[4.67]	[3.91]	[3.57]	[2.43]	[3.64]	[2.52]	[2.64]	[2.89]
Day 4												
Nondaily	-0.88	0.20	-0.08	-0.27	0.04	-0.30	-0.80	-0.69	-0.82	-1.34	0.40	0.56
	[-1.74]	[0.42]	[-0.17]	[-0.58]	[0.11]	[-0.76]	[-1.70]	[-1.70]	[-1.69]	[-2.61]	[0.86]	[1.45]
Daily	1.98	1.33	1.53	1.46	0.92	0.94	1.18	1.36	1.07	0.99	0.88	1.45
	[4.21]	[2.86]	[3.21]	[3.18]	[2.51]	[2.40]	[2.58]	[3.53]	[2.54]	[2.06]	[2.06]	[3.62]
Day 5												
Nondaily	0.45	-0.10	-0.99	-0.53	-0.78	0.08	-0.04	0.36	0.56	-0.08	0.27	0.10
	[0.92]	[-0.22]	[-1.98]	[-1.20]	[-1.92]	[0.20]	[-0.08]	[0.90]	[1.22]	[-0.15]	[0.59]	[0.25]
Daily	1.44	1.22	1.63	2.19	0.74	1.00	0.79	0.78	1.12	0.82	0.92	0.49
	[2.96]	[2.86]	[3.60]	[5.04]	[1.90]	[2.55]	[1.81]	[1.88]	[2.68]	[1.59]	[2.16]	[1.25]

Table 7
Controlling for Turn-of-Month

Every half-hour interval stocks are grouped into ten portfolios (with equal number of stocks in each portfolio) according to various categories based on past performance. For example, the Day 1 trading strategy that is formed based on a daily frequency ranks stocks according to their return during the historical lag half-hour interval 13, while the nondaily strategy ranks stocks according to their average returns over the lag half-hour intervals 1 through 12. The stocks in each portfolio are assigned equal weight, and the portfolios are rebalanced every half hour. The average returns of the top-minus-bottom-decile portfolios (per half hour, in basis points) for the period January 2001 through December 2005 are reported below, as well as the corresponding *t*-statistics (in brackets). The returns are reported separately using half-hour intervals during turn-of-month trading days (first and last trading day of the month) and non-turn-of-month days. The returns are also partitioned using all half-hour intervals of a day, as well as using only the first, the last and the rest. The analysis uses NYSE-listed stocks.

Strategy	Non-turn-of-month trading days				Turn-of-month trading days			
	1-13 (all)	1 (first)	2-12	13 (last)	1-13 (all)	1 (first)	2-12	13 (last)
Day 1								
Nondaily	-4.57	-8.38	-3.65	-10.84	-5.62	-8.10	-4.55	-14.97
	[-25.92]	[-8.25]	[-20.76]	[-16.86]	[-11.79]	[-3.19]	[-9.62]	[-7.45]
Daily	3.12	12.06	1.79	8.90	1.95	5.97	1.41	3.84
	[21.81]	[12.49]	[13.63]	[15.35]	[4.50]	[2.19]	[3.52]	[1.77]
Day 2								
Nondaily	-0.87	-2.74	-0.42	-3.99	-1.44	-5.11	-1.07	-1.83
	[-5.85]	[-3.05]	[-2.83]	[-7.36]	[-3.34]	[-2.15]	[-2.50]	[-0.97]
Daily	2.05	10.77	0.83	6.74	1.16	7.73	0.27	4.33
	[14.80]	[11.88]	[6.53]	[11.22]	[2.93]	[3.29]	[0.72]	[2.41]
Day 3								
Nondaily	-0.61	-5.11	-0.14	-1.28	-0.69	-2.53	-0.46	-1.40
	[-4.32]	[-5.96]	[-1.02]	[-2.52]	[-1.69]	[-1.11]	[-1.13]	[-0.80]
Daily	1.44	6.45	0.60	5.68	0.54	5.12	-0.24	4.50
	[10.84]	[7.29]	[4.87]	[10.20]	[1.36]	[2.12]	[-0.64]	[2.49]
Day 4								
Nondaily	-0.34	-2.78	-0.02	-1.42	-0.34	-0.40	-0.39	0.31
	[-2.47]	[-3.40]	[-0.15]	[-2.89]	[-0.84]	[-0.18]	[-0.97]	[0.20]
Daily	1.26	5.85	0.58	4.15	1.23	3.68	0.58	5.94
	[9.53]	[6.76]	[4.69]	[7.36]	[3.07]	[1.39]	[1.58]	[3.13]
Day 5								
Nondaily	-0.06	-0.65	0.12	-1.40	-0.10	4.68	-0.52	-0.25
	[-0.44]	[-0.79]	[0.83]	[-2.93]	[-0.24]	[2.14]	[-1.29]	[-0.16]
Daily	1.15	5.15	0.57	3.45	0.57	3.42	0.00	3.99
	[8.67]	[6.05]	[4.53]	[6.60]	[1.44]	[1.25]	[-0.00]	[2.23]

Table 8
Controlling for Market Risk

Every half-hour interval stocks are grouped into ten portfolios (with equal number of stocks in each portfolio) according to various categories based on past performance. For example, the Day 1 trading strategy that is formed based on a daily frequency ranks stocks according to their return during the historical lag half-hour interval 13, while the nondaily strategy ranks stocks according to their average returns over the lag half-hour intervals 1 through 12. The stocks in each portfolio are assigned equal weight, and the portfolios are rebalanced every half hour. The returns of the top-minus-bottom-decile portfolios (per half hour, in basis points) for the period January 2001 through December 2005 are regressed on the equal-weighted market average return (along with its 1 through 13 leads and 1 through 13 lags). The regression intercepts and their corresponding *t*-statistics (in brackets) are reported below. The risk-adjusted returns are also partitioned using all half-hour intervals of a day, as well as using only the first, the last and the rest. The analysis uses NYSE-listed stocks.

Strategy	Risk-adjusted returns			
	1-13 (all)	1 (first)	2-12	13 (last)
Day 1				
Nondaily	-4.65	-8.52	-3.71	-10.79
	[-28.26]	[-8.53]	[-22.62]	[-16.96]
Daily	3.03	11.64	1.76	8.40
	[22.33]	[12.24]	[14.17]	[14.17]
Day 2				
Nondaily	-0.90	-3.25	-0.45	-3.73
	[-6.44]	[-3.64]	[-3.27]	[-6.89]
Daily	1.98	10.30	0.79	6.92
	[15.14]	[11.52]	[6.56]	[11.53]
Day 3				
Nondaily	-0.61	-4.82	-0.17	-0.85
	[-4.57]	[-5.69]	[-1.26]	[-1.66]
Daily	1.38	6.82	0.55	5.96
	[10.94]	[7.80]	[4.67]	[10.61]
Day 4				
Nondaily	-0.34	-3.21	-0.06	-0.91
	[-2.58]	[-3.94]	[-0.43]	[-1.84]
Daily	1.25	5.96	0.57	4.26
	[9.96]	[6.92]	[4.86]	[7.46]
Day 5				
Nondaily	-0.04	-0.14	0.07	-0.53
	[-0.33]	[-0.17]	[0.56]	[-1.12]
Daily	1.10	4.84	0.53	3.42
	[8.76]	[5.63]	[4.42]	[6.40]

Table 9
Controlling for Inclusion in the S&P500 Index

Every half-hour interval stocks are grouped into ten portfolios (with equal number of stocks in each portfolio) according to various categories based on past performance. For example, the Day 1 trading strategy that is formed based on a daily frequency ranks stocks according to their return during the historical lag half-hour interval 13, while the nondaily strategy ranks stocks according to their average returns over the lag half-hour intervals 1 through 12. The stocks in each portfolio are assigned equal weight, and the portfolios are rebalanced every half hour. The average returns of the top-minus-bottom-decile portfolios (per half hour, in basis points) for the period January 2001 through December 2005 are reported below, as well as the corresponding t-statistics (in brackets). The returns of the long-short portfolios are partitioned into the parts attributed to firms that are included in the S&P500 Index and those that are not included in the index. The returns are also partitioned using all half-hour intervals of a day, as well as using only the first, the last and the rest. The analysis uses NYSE-listed stocks.

Strategy	Non-S&P500-Index stocks				S&P500-Index stocks			
	1-13 (all)	1 (first)	2-12	13 (last)	1-13 (all)	1 (first)	2-12	13 (last)
Day 1								
Nondaily	-5.58	-10.43	-4.48	-12.84	-0.72	1.32	-0.54	-4.81
	[-31.53]	[-10.58]	[-25.37]	[-18.62]	[-2.96]	[0.83]	[-2.26]	[-6.19]
Daily	3.28	12.95	1.93	8.56	2.19	8.23	0.98	9.42
	[22.18]	[13.25]	[14.07]	[14.13]	[10.93]	[6.74]	[5.17]	[10.43]
Day 2								
Nondaily	-0.86	-3.41	-0.37	-3.78	-1.10	-1.61	-0.77	-4.29
	[-5.71]	[-3.98]	[-2.43]	[-6.31]	[-5.00]	[-1.07]	[-3.60]	[-6.59]
Daily	2.09	10.93	0.90	6.37	1.81	9.58	0.52	8.27
	[14.66]	[12.09]	[6.69]	[10.70]	[9.25]	[8.11]	[2.81]	[8.66]
Day 3								
Nondaily	-0.65	-4.94	-0.15	-1.86	-0.52	-5.15	-0.24	1.00
	[-4.41]	[-5.84]	[-1.00]	[-3.32]	[-2.46]	[-3.56]	[-1.16]	[1.51]
Daily	1.47	6.67	0.63	5.56	1.19	5.44	0.26	7.09
	[10.62]	[7.42]	[4.80]	[9.80]	[6.18]	[4.62]	[1.44]	[8.08]
Day 4								
Nondaily	-0.37	-3.39	0.01	-1.44	-0.21	0.71	-0.25	-0.74
	[-2.56]	[-4.20]	[0.04]	[-2.73]	[-1.01]	[0.49]	[-1.24]	[-1.14]
Daily	1.29	5.93	0.62	4.04	1.07	5.00	0.49	3.58
	[9.42]	[6.78]	[4.76]	[7.03]	[5.59]	[4.28]	[2.67]	[4.05]
Day 5								
Nondaily	-0.16	-0.53	0.00	-1.55	0.20	0.90	0.16	-0.02
	[-1.09]	[-0.64]	[0.03]	[-2.97]	[0.95]	[0.61]	[0.78]	[-0.03]
Daily	1.17	5.14	0.61	3.39	0.60	3.35	0.13	2.97
	[8.56]	[6.01]	[4.58]	[6.33]	[3.08]	[2.83]	[0.70]	[3.40]

Table 10
Controlling for Size

Every half-hour interval stocks are grouped into ten portfolios (with equal number of stocks in each portfolio) according to various categories based on past performance. For example, the Day 1 trading strategy that is formed based on a daily frequency ranks stocks according to their return during the historical lag half-hour interval 13, while the nondaily strategy ranks stocks according to their average returns over the lag half-hour intervals 1 through 12. The stocks in each portfolio are assigned equal weight, and the portfolios are rebalanced every half hour. The average returns of the top-minus-bottom-decile portfolios (per half hour, in basis points) for the period January 2001 through December 2005 are reported below, as well as the corresponding *t*-statistics (in brackets). The strategies are performed separately for three equally sized groups sorted by firm market capitalization at the end of the previous calendar year. The returns are reported using all half-hour intervals of a day, as well as using only the first, the last and the rest. The analysis uses NYSE-listed stocks.

Strategy	Small				Medium				Large			
	1-13 (all)	1 (first)	2-12	13 (last)	1-13 (all)	1 (first)	2-12	13 (last)	1-13 (all)	1 (first)	2-12	13 (last)
Day 1												
Nondaily	-9.92	-10.89	-8.69	-22.55	-2.98	-12.11	-1.93	-5.45	-1.15	1.18	-0.94	-5.88
	[-30.94]	[-6.33]	[-26.73]	[-18.55]	[-16.16]	[-10.55]	[-10.62]	[-9.00]	[-6.24]	[1.03]	[-5.08]	[-10.77]
Daily	5.16	20.43	3.15	11.98	2.20	9.36	1.11	7.08	1.88	6.67	0.86	8.38
	[16.71]	[11.90]	[10.26]	[9.77]	[14.47]	[8.72]	[7.90]	[12.78]	[12.43]	[6.30]	[5.95]	[20.58]
Day 2												
Nondaily	-1.04	-4.55	-0.20	-6.82	-1.05	-2.22	-0.78	-2.77	-1.28	-3.70	-0.91	-2.91
	[-3.64]	[-2.95]	[-0.70]	[-6.12]	[-6.61]	[-2.19]	[-5.09]	[-4.76]	[-7.78]	[-3.37]	[-5.66]	[-6.19]
Daily	2.87	12.06	1.51	8.70	1.72	10.01	0.55	6.30	1.36	7.78	0.29	6.65
	[9.70]	[7.52]	[5.07]	[7.38]	[11.69]	[10.01]	[4.01]	[11.86]	[9.55]	[8.00]	[2.15]	[16.80]
Day 3												
Nondaily	-0.89	-7.69	0.08	-4.78	-0.66	-3.68	-0.39	-0.53	-0.53	-3.85	-0.34	0.80
	[-3.15]	[-5.03]	[0.29]	[-4.60]	[-4.41]	[-3.92]	[-2.69]	[-1.01]	[-3.41]	[-3.83]	[-2.24]	[1.85]
Daily	2.10	7.26	1.04	8.59	1.16	6.39	0.34	5.06	0.88	4.88	0.13	5.14
	[7.01]	[4.63]	[3.41]	[7.32]	[8.07]	[6.27]	[2.52]	[9.75]	[6.34]	[5.15]	[0.94]	[14.04]
Day 4												
Nondaily	-0.72	-4.33	-0.14	-3.50	-0.13	-1.01	-0.07	0.12	-0.30	-0.75	-0.30	0.18
	[-2.59]	[-3.02]	[-0.49]	[-3.35]	[-0.85]	[-1.07]	[-0.46]	[0.24]	[-1.99]	[-0.75]	[-2.04]	[0.42]
Daily	1.67	7.03	0.75	6.41	1.01	5.29	0.39	3.57	0.94	5.05	0.28	4.07
	[5.59]	[4.20]	[2.51]	[5.49]	[7.23]	[5.61]	[2.97]	[6.71]	[6.60]	[5.12]	[2.02]	[11.22]
Day 5												
Nondaily	-0.19	0.35	-0.08	-2.00	-0.06	-0.56	0.11	-1.50	0.20	1.52	0.12	-0.25
	[-0.70]	[0.24]	[-0.28]	[-1.93]	[-0.44]	[-0.60]	[0.78]	[-3.00]	[1.33]	[1.58]	[0.80]	[-0.58]
Daily	1.86	6.46	1.13	5.27	0.78	4.65	0.19	3.40	0.80	4.06	0.24	3.61
	[6.24]	[3.76]	[3.79]	[4.70]	[5.55]	[4.82]	[1.44]	[6.78]	[5.66]	[4.22]	[1.79]	[10.10]

Table 11
Controlling for Transaction Costs

Every half-hour interval stocks are grouped into ten portfolios (with equal number of stocks in each portfolio) according to various categories based on past performance. For example, the Day 1 trading strategy that is formed based on a daily frequency ranks stocks according to their return during the historical lag half-hour interval 13, while the nondaily strategy ranks stocks according to their average returns over the lag half-hour intervals 1 through 12. The stocks in each portfolio are assigned equal weight, and the portfolios are rebalanced every half hour. The table reports long-short portfolio strategies: the daily strategies are calculated as top-minus-bottom-decile portfolios, while the nondaily strategies are calculated as the bottom-minus-top-decile portfolios. The average returns of the different strategies (per half hour, in basis points), after accounting for transaction costs, for the period January 2001 through December 2005 are reported below, as well as the corresponding *t*-statistics (in brackets). The strategies are performed separately for three equally sized groups sorted by firm market capitalization at the end of the previous calendar year. The post-transaction-cost return of buying a stock is calculated as the return from the first quoted offer price of a half-hour interval to its last quoted bid price. The post-transaction-cost return of selling a stock is calculated as the negative of the return from the first quoted bid price of a half-hour interval to its last quoted offer price. The returns are reported using all half-hour intervals of a day, as well as using only the first, the last and the rest. In each given interval, only firms with the first quoted relative bid/ask spread (spread divided by the midpoint of quotes) no larger than 10 basis points in a given interval are used for the calculations. The analysis uses NYSE-listed stocks.

Strategy	Small				Medium				Large			
	1-13 (all)	1 (first)	2-12	13 (last)	1-13 (all)	1 (first)	2-12	13 (last)	1-13 (all)	1 (first)	2-12	13 (last)
Day 1												
Nondaily	-25.03	30.56	-24.91	-27.41	-19.67	-17.60	-19.89	-17.58	-14.77	-27.92	-14.24	-9.74
	[-27.51]	[0.90]	[-26.05]	[-9.54]	[-45.23]	[-1.81]	[-45.33]	[-13.18]	[-44.97]	[-7.92]	[-53.48]	[-13.03]
Daily	-23.78	-28.26	-23.68	-24.41	-18.58	-11.49	-19.03	-15.07	-13.25	-13.43	-13.91	-5.84
	[-28.37]	[-0.72]	[-27.43]	[-8.75]	[-49.79]	[-1.34]	[-52.11]	[-12.10]	[-46.50]	[-4.24]	[-61.05]	[-8.96]
Day 2												
Nondaily	-25.17	9.90	-24.84	-29.03	-20.52	-31.97	-20.30	-20.60	-12.98	-6.42	-13.62	-11.21
	[-30.97]	[0.22]	[-29.47]	[-10.83]	[-53.45]	[-4.16]	[-52.20]	[-18.59]	[-33.13]	[-1.22]	[-56.95]	[-16.66]
Daily	-24.49	-84.59	-24.31	-23.41	-19.38	-11.39	-19.83	-15.99	-13.46	-11.02	-14.07	-8.79
	[-29.41]	[-2.89]	[-28.20]	[-8.37]	[-53.34]	[-1.46]	[-54.83]	[-13.54]	[-49.00]	[-3.61]	[-63.68]	[-14.60]
Day 3												
Nondaily	-25.26	-59.52	-24.99	-26.72	-20.84	-35.56	-20.49	-22.03	-14.40	-13.72	-14.33	-15.72
	[-32.59]	[-2.51]	[-30.75]	[-10.54]	[-56.43]	[-4.26]	[-55.07]	[-19.55]	[-50.33]	[-4.44]	[-60.54]	[-24.69]
Daily	-24.29	-35.03	-24.61	-21.30	-20.31	-16.53	-20.64	-17.49	-13.77	-8.75	-14.48	-10.02
	[-30.68]	[-1.03]	[-30.07]	[-7.62]	[-54.89]	[-1.79]	[-57.42]	[-15.04]	[-52.27]	[-3.15]	[-65.83]	[-17.25]
Day 4												
Nondaily	-25.23	5.24	-25.06	-28.06	-20.67	-23.26	-20.53	-21.75	-14.65	-15.63	-14.53	-15.27
	[-31.85]	[0.22]	[-30.15]	[-11.15]	[-55.56]	[-2.78]	[-54.38]	[-19.32]	[-54.40]	[-5.33]	[-65.76]	[-23.97]
Daily	-23.77	-15.34	-23.44	-26.96	-20.38	-20.71	-20.43	-19.76	-14.13	-13.56	-14.50	-10.52
	[-28.87]	[-0.46]	[-27.75]	[-9.26]	[-56.52]	[-2.44]	[-57.60]	[-18.08]	[-53.48]	[-4.85]	[-65.71]	[-18.27]
Day 5												
Nondaily	-25.31	-28.62	-24.94	-28.27	-20.61	-23.79	-20.42	-22.11	-14.92	-18.84	-14.72	-14.09
	[-33.95]	[-1.40]	[-31.87]	[-12.15]	[-56.15]	[-3.15]	[-54.63]	[-20.42]	[-55.45]	[-6.65]	[-64.02]	[-21.71]
Daily	-25.92	-21.21	-25.63	-28.77	-20.27	-22.00	-20.37	-18.85	-13.66	-8.08	-14.28	-11.40
	[-32.58]	[-0.64]	[-30.95]	[-10.51]	[-56.64]	[-2.96]	[-56.85]	[-16.12]	[-35.73]	[-1.58]	[-61.98]	[-18.29]

Table 12
Returns of strategies based on past performance: Subperiod analysis

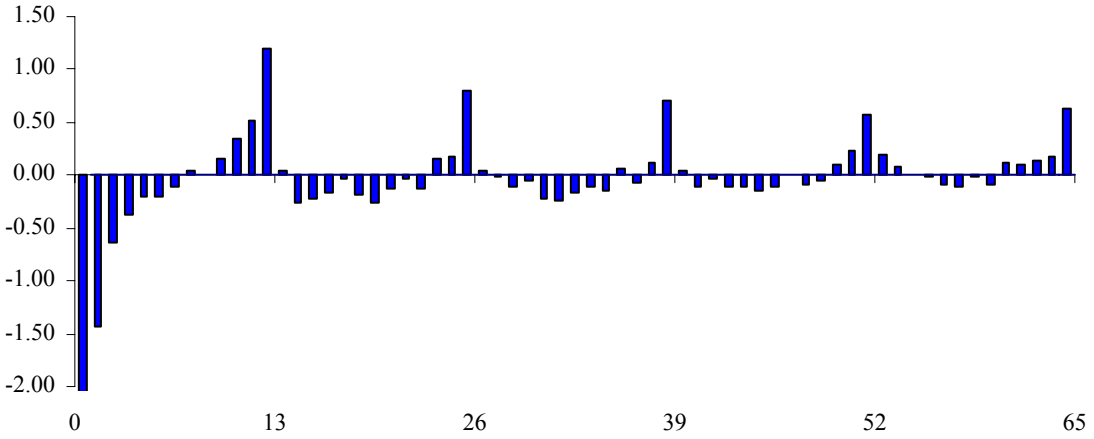
Every half-hour interval stocks are grouped into ten portfolios (with equal number of stocks in each portfolio) according to various categories based on past performance. For example, the Day 1 trading strategy that is formed based on a daily frequency ranks stocks according to their return during the historical lag half-hour interval 13. The stocks in each portfolio are assigned equal weight, and the portfolios are rebalanced every half hour. Three subperiods corresponding to different tick-size regimes are analyzed: January 1, 1993, through June 23,1997 (one eigth); June 24, 1997, through December 31, 2000 (one sixteenth); and January 1, 2001, through December 31, 2005 (decimal). The average returns of the top-minus-bottom-decile portfolios (per half hour, in basis points) of the various trading strategies for are reported below, as well as the corresponding t-statistics (in brackets). Panel A uses the raw portfolio returns while Panel B uses portoflio returns winsorized at the top and bottom 1% of the distribution each month (across all strategies). The analysis uses NYSE-listed stocks.

Panel A. Raw portfolio returns

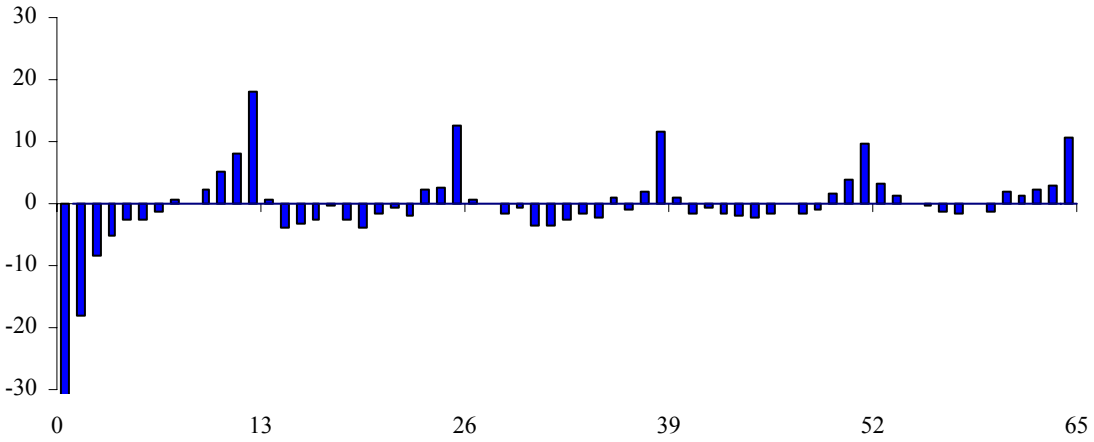
Strategy	January 1, 1993 - June 23, 1997 [14,190 observations)	June 24, 1997 - December 31, 2000 [11,506 observations]	January 1, 2001 - December 31, 2005 [16,261 observations]
Day 1	2.88	-10.30	3.01
[lag 13]	[4.90]	[-0.84]	[22.15]
Day 2	1.00	4.67	1.97
[lag 26]	[6.52]	[3.01]	[15.01]
Day 3	0.84	69.61	1.36
[lag 39]	[5.56]	[1.31]	[10.75]
Day 4	-0.21	-54.00	1.26
[lag 52]	[-0.21]	[-1.02]	[10.01]
Day 5	0.68	-15.15	1.09
[lag 65]	[4.44]	[-1.00]	[8.70]

Panel B. Winsorized portfolio returns (top and bottom 1%)

Strategy	January 1, 1993 - June 23, 1997 [14,190 observations)	June 24, 1997 - December 31, 2000 [11,506 observations]	January 1, 2001 - December 31, 2005 [16,261 observations]
Day 1	2.28	3.43	2.90
[lag 13]	[15.22]	[18.27]	[22.89]
Day 2	0.98	2.07	1.89
[lag 26]	[6.69]	[11.39]	[15.34]
Day 3	0.86	1.61	1.38
[lag 39]	[5.88]	[8.95]	[11.56]
Day 4	0.72	1.57	1.26
[lag 52]	[4.90]	[8.80]	[10.52]
Day 5	0.69	1.12	1.13
[lag 65]	[4.72]	[6.29]	[9.58]

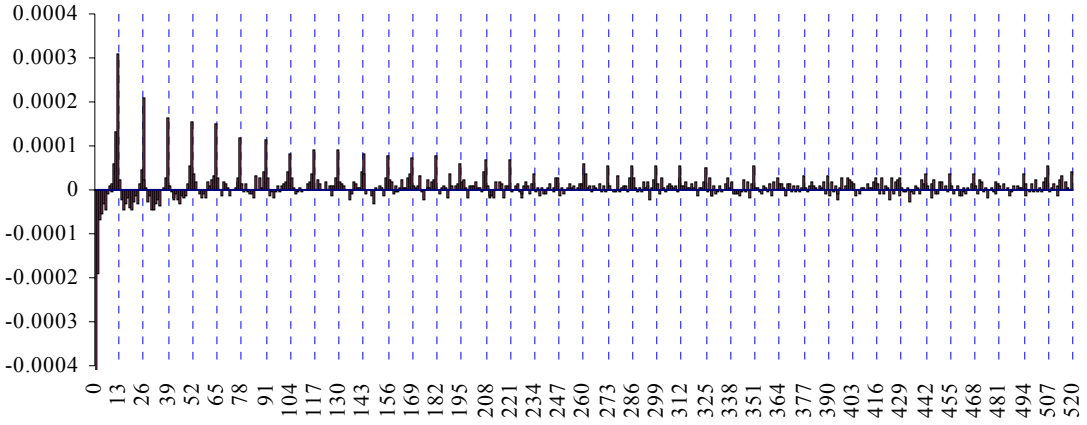


Panel A. Estimates of cross-sectional regressions

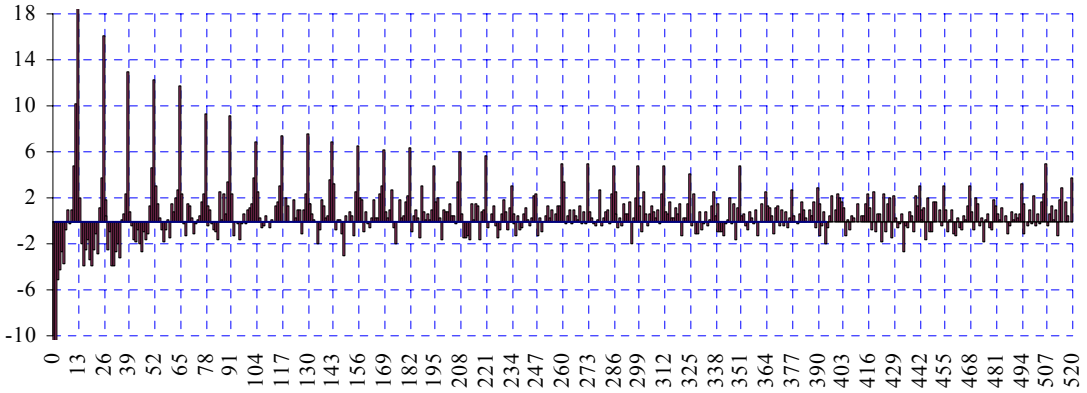


Panel B. *t*-statistics of cross-sectional regression estimates

Figure 1. Cross-sectional regressions of half-hour-interval returns. Intraday cross-sectional simple regressions of the form $r_{i,t} = \alpha_{k,t} + \gamma_{k,t} r_{i,t-k} + u_{i,t}$ are calculated for half-hour interval t and lag k, and where $r_{i,t}$ is return of stock i during interval t. The lagged variable $r_{i,t-k}$ is return of stock i in interval $t–k$. The regression is calculated for every half-hour interval t from January 2001 through December 2005 (16,261 intervals), and for lag k values 1 through 65 (past 5 trading days). Panel A plots the time-series averages of $\gamma_{k,t}$. Panel B plots the respective t–statistics. The analysis uses NYSE-listed stocks.

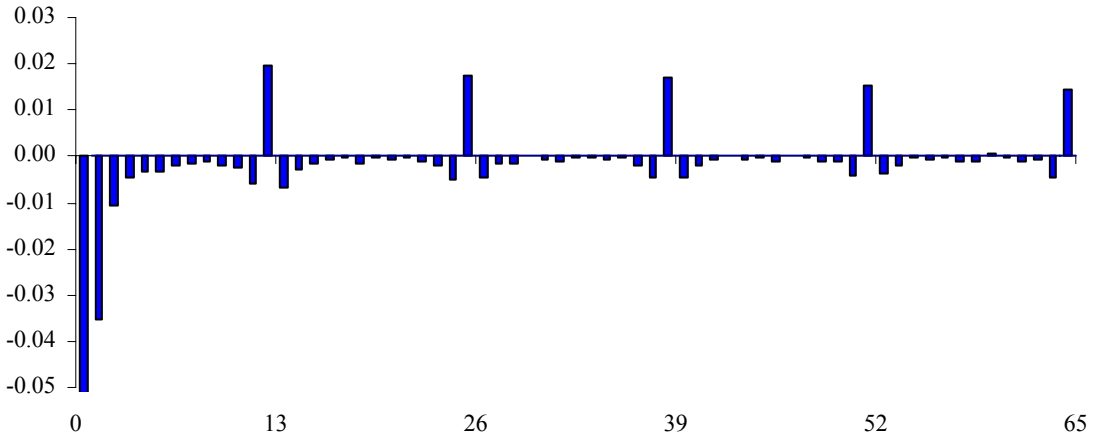


Panel A. Average decile portfolio spread returns

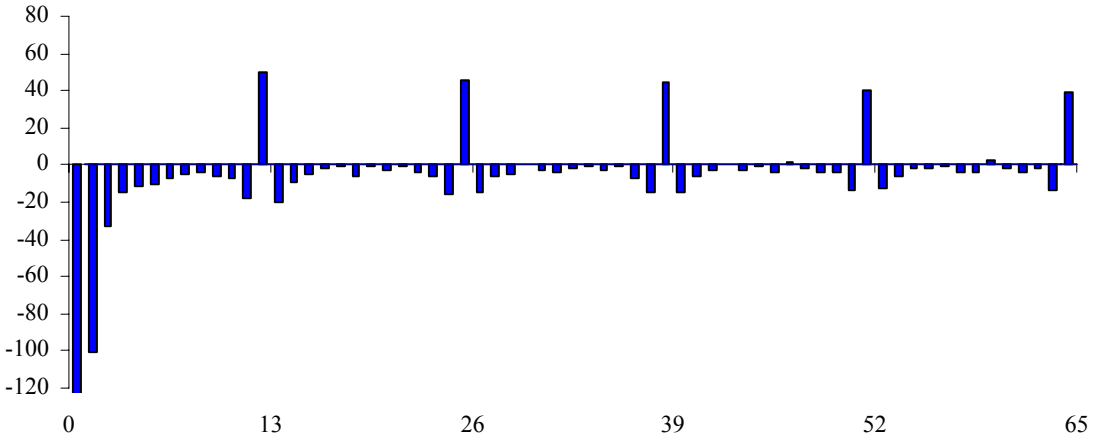


Panel B. *t*-statistics

Figure 2. Half-hour-interval returns for decile portfolio spreads. Every half-hour interval stocks are grouped into ten portfolios (with equal number of stocks in each portfolio) according to various categories based on past performance. For example, Lag 65 trading strategy ranks stocks according to their return during the historical lag half-hour interval 65. The stocks in each portfolio are assigned equal weight, and the portfolios are rebalanced every half hour. The average return (per half hour, in basis points) of the top-minus-bottom decile portfolios for trading strategies corresponding to lags 1 through 520 for the period January 2001 through December 2005 (16,261 intervals) are reported below, as well as the corresponding t-statistics (in brackets). The analysis uses NYSE-listed stocks.

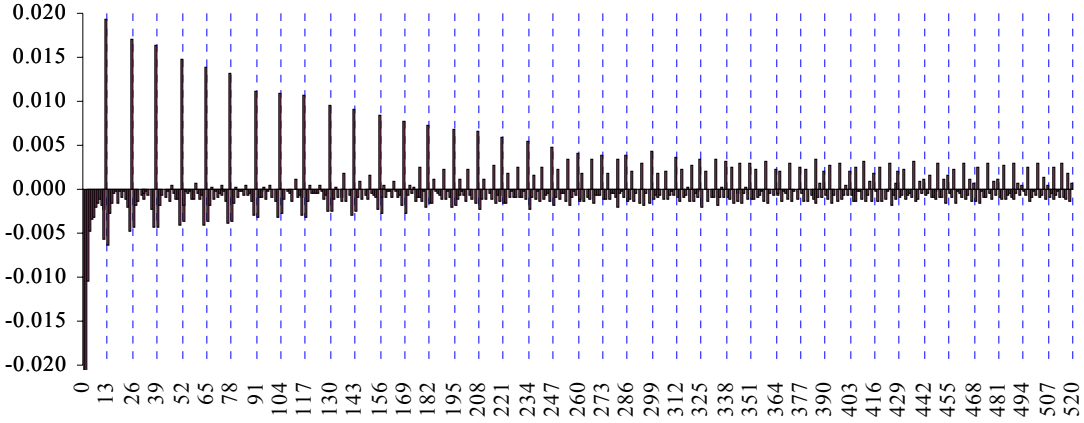


Panel A. Estimates of cross-sectional regressions

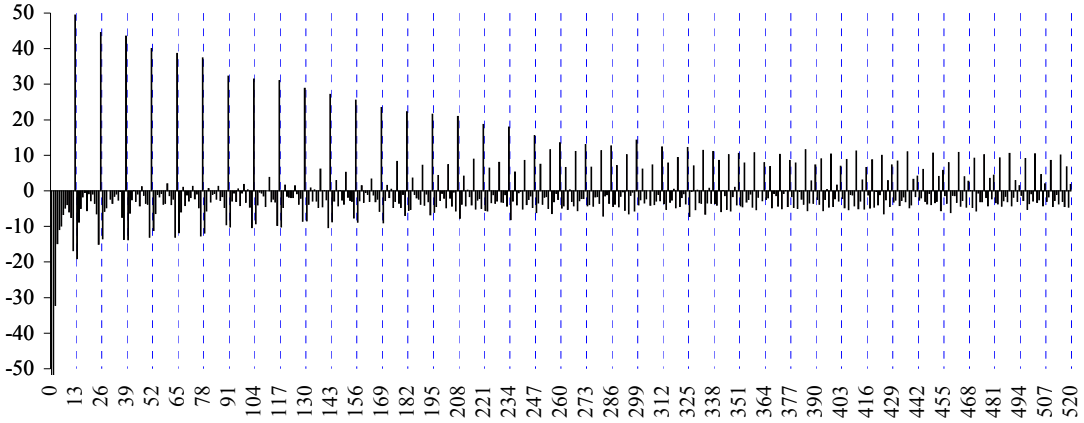


Panel B. *t*-statistics of cross-sectional regression estimates

Figure 3. Cross-sectional regressions of half-hour interval volume. Cross-sectional simple regressions of the form $v_{i,t} = \alpha_{k,t} + \gamma_{k,t}v_{i,t-k} + u_{i,t}$ are calculated for each interval t and lag k, and where $v_{i,t}$ is volume of stock i during interval t. Volume is defined as the number of shares traded. For the analysis, volume is the logarithm of the ratio of volume and its prior one lag value. The lagged variable $x_{i,t-k}$ is either volume or return of stock i in interval $t–k$. The regression is calculated for every half-hour interval t from January 2001 through December 2005 (16,261 intervals), and for lag k values 1 through 65 (past 5 trading days). Panel A plots the time-series averages of $\gamma_{k,t}$. Panel B plots the respective t–statistics. The analysis uses NYSE-listed stocks.

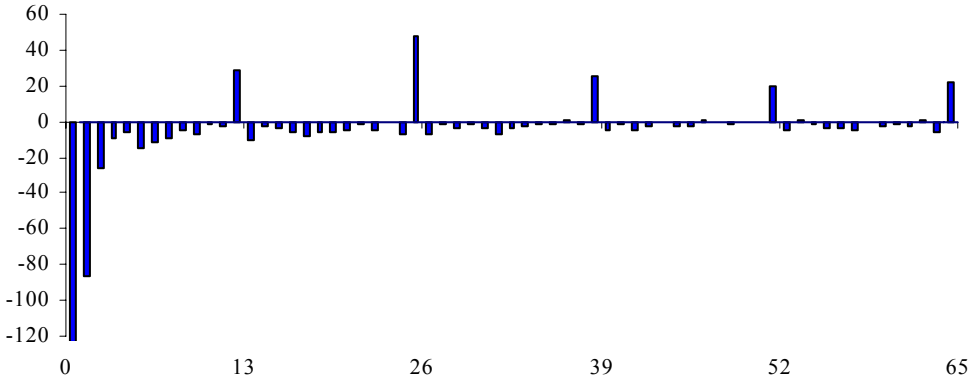


Panel A. Estimates of cross-sectional regressions

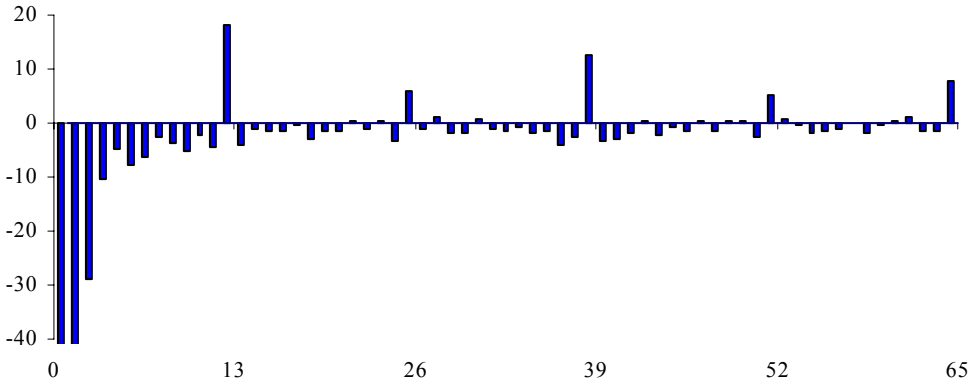


Panel B. *t*-statistics of cross-sectional regression estimates

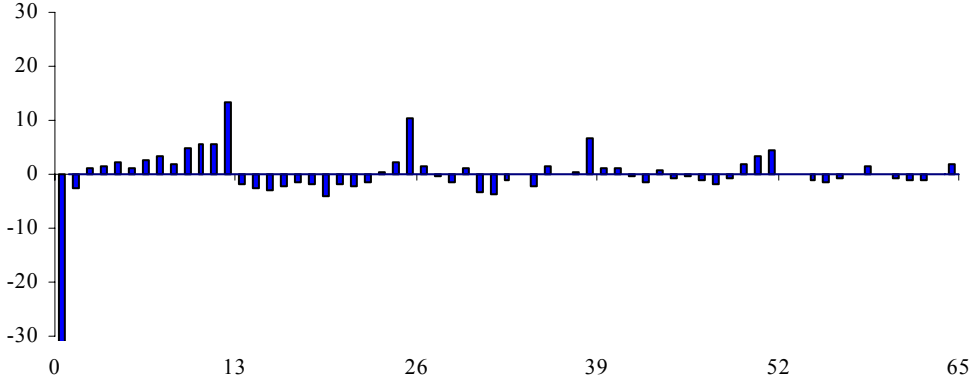
Figure 4. Cross-sectional regressions of half-hour interval volume. Cross-sectional simple regressions of the form $v_{i,t} = \alpha_{k,t} + \gamma_{k,t} v_{i,t-k} + u_{i,t}$ are calculated for each interval t and lag k, and where $v_{i,t}$ is volume of stock i during interval t. Volume is defined as the number of shares traded. For the analysis, volume is the logarithm of the ratio of volume and its prior one lag value. The lagged variable $x_{i,t-k}$ is either volume or return of stock i in interval $t–k$. The regression is calculated for every half-hour interval t from January 2001 through December 2005 (16,261 intervals), and for lag k values 1 through 520 (past 40 trading days). Panel A plots the time-series averages of $\gamma_{k,t}$. Panel B plots the respective t–statistics. The analysis uses NYSE-listed stocks.



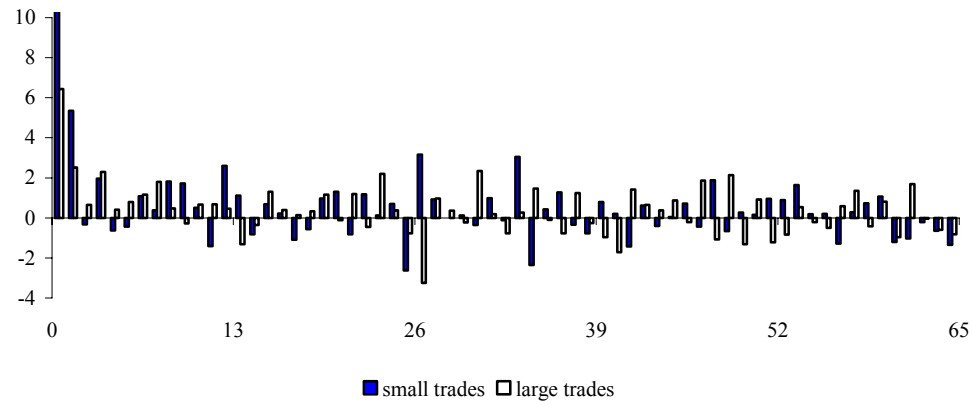
Panel A. Volume regressed on lagged volume (small trades)



Panel B. Volume regressed on lagged volume (large trades)

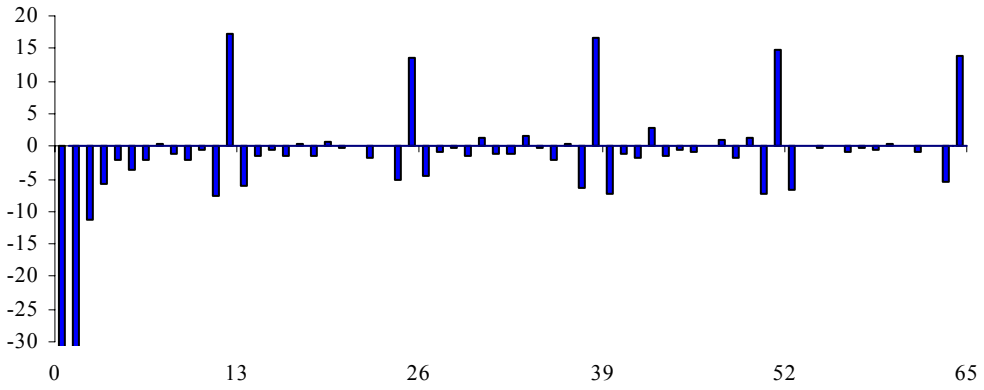


Panel C. Return regressed on lagged return and lagged small- and large-trade volume (lagged return coefficient)

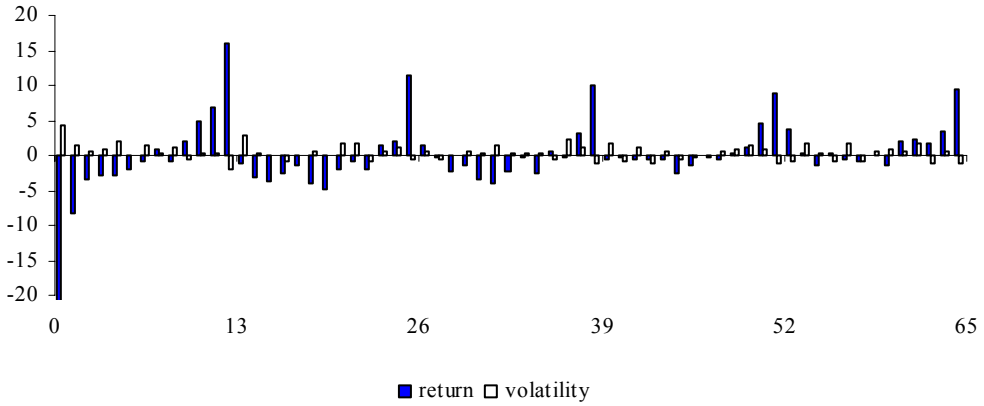


Panel D. Return regressed on lagged return and lagged small- and large-trade volume (volume coefficients)

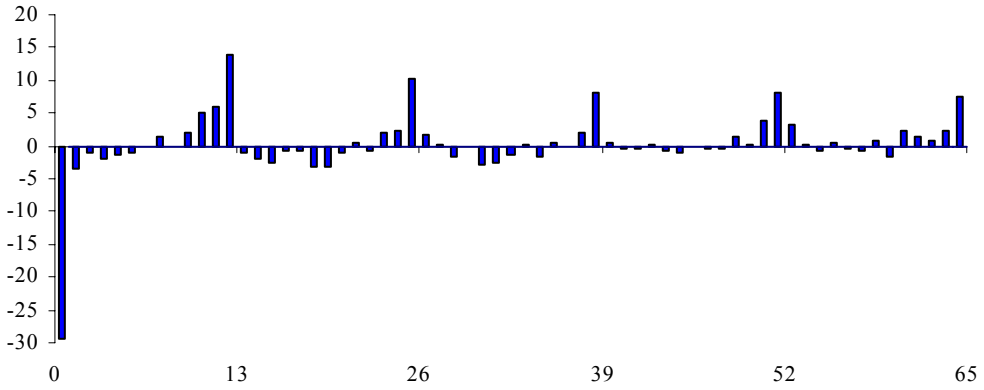
Figure 5. Cross-sectional regressions of half-hour interval returns and small- and large-trade volume (*t*-statistics). Cross-sectional regressions of the following forms are calculated for each interval t and lag k: $sv_{i,t} = \alpha_{k,t} + \gamma_{k,t} sv_{i,t-k} + u_{i,t}$ (Panel A), $lv_{i,t} = \alpha_{k,t} + \gamma_{k,t} lv_{i,t-k} + u_{i,t}$ (Panel B), and $r_{i,t} = \alpha_{k,t} + \gamma_{k,t} r_{i,t-k} + \delta_{k,t} sv_{i,t-k} + \eta_{k,t} lv_{i,t-k} + u_{i,t}$ (Panels C and D), where $sv_{i,t}$ and $lv_{i,t}$ are small- and large-trade volume and $r_{i,t}$ is the return of stock i during interval t. Small-trade volume is defined as the sum of shares traded during the time interval for trades below 1,000 shares. Large-trade volume is defined as the sum of shares traded during the time interval for trades above or equal to 1,000 shares. For the analysis, volume is the logarithm of the ratio of volume and its prior one lag value. The regressions are calculated for every half-hour interval t from January 2001 through December 2005 (16,261 intervals), and for lag k values 1 through 65 (past 5 trading days). All panels plot the *t*-statistics of the time-series averages of the regression coefficients. The analysis uses NYSE-listed stocks.



Panel A. Volatility regressed on lagged volatility

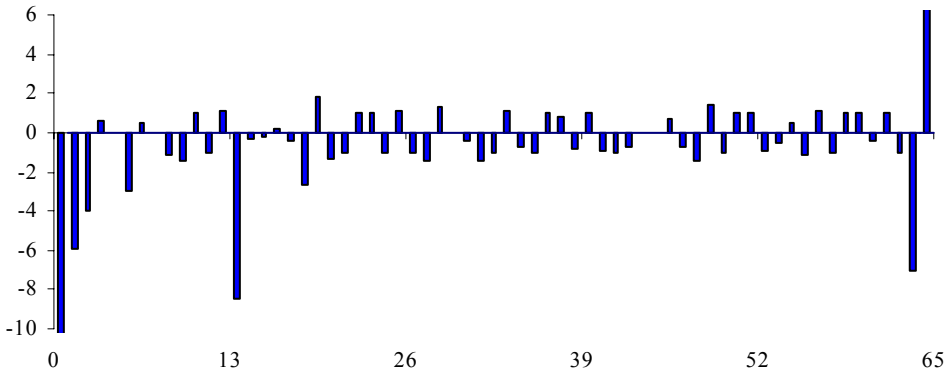


Panel B. Return regressed on lagged return and lagged volatility

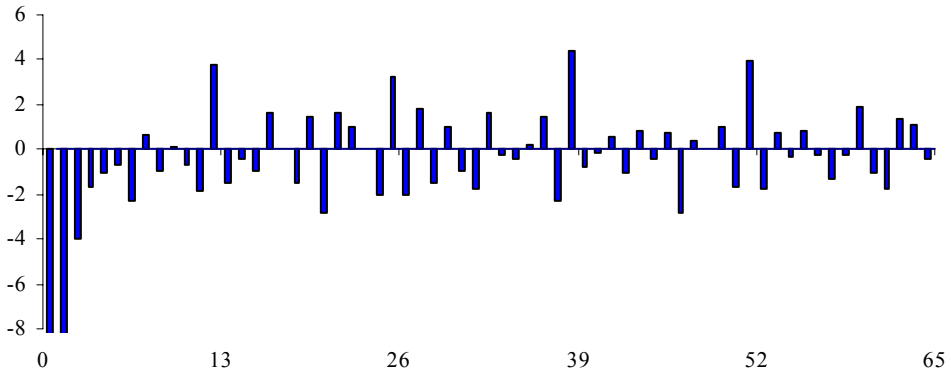


Panel C. Return regressed on lagged return, lagged volatility, their interaction, and contemporaneous volatility (lagged return coefficient)

Figure 6. Cross-sectional regressions of half-hour interval returns and volatilities (*t*-statistics). Cross-sectional regressions of the following forms are calculated for each interval t and lag k: $v_{i,t} = \alpha_{k,t} + \gamma_{k,t}v_{i,t-k} + u_{i,t}$ (Panel A), $r_{i,t} = \alpha_{k,t} + \gamma_{k,t}r_{i,t-k} + \delta_{k,t}v_{i,t-k} + u_{i,t}$ (Panel B), and $r_{i,t} = \alpha_{k,t} + \gamma_{k,t}r_{i,t-k} + \delta_{k,t}v_{i,t-k} + \rho_{k,t}r_{i,t-k}v_{i,t-k} + \phi_{k,t}v_{i,t} + u_{i,t}$, where $r_{i,t}$ is the return of stock i during interval t, and volatility is measured as the absolute value of return, i.e. $v_{i,t} \equiv |r_{i,t}|$. For the analysis, volatility is the logarithm of the ratio of volatility and its prior one lag value. The regressions are calculated for every half-hour interval t from January 2001 through December 2005 (16,261 intervals), and for lag k values 1 through 65 (past 5 trading days). All panels plot the t-statistics of the time-series averages of the regression coefficients. The analysis uses NYSE-listed stocks.

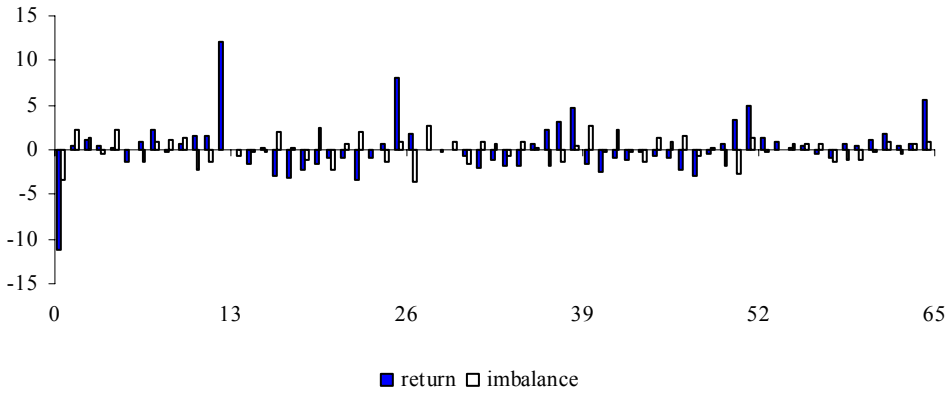


Panel A. Spread regressed on lagged spread



Panel C. Imbalance regressed on lagged imbalance

Panel B. Return regressed on lagged return and lagged spread



Panel D. Return regressed on lagged return and lagged imbalance

Figure 7. Cross-sectional regressions of half-hour interval returns, relative bid/ask spreads, and order imbalances (*t*-statistics). Cross-sectional regressions of the following forms are calculated for each interval t and lag k: $v_{i,t} = \alpha_{k,t} + \gamma_{k,t} v_{i,t-k} + u_{i,t}$ (Panels A and C) and $r_{i,t} = \alpha_{k,t} + \gamma_{k,t} r_{i,t-k} + \delta_{k,t} v_{i,t-k} + u_{i,t}$ (Panels C and D), where $v_{i,t}$ is either the quoted relative bid/ask spread (spread divided by the midpoint of the bid and ask; using the first quotes in each time interval) or the order imbalance over the time interval (buyer-initiated volume minus seller-initiated volume divided by their sum), and $r_{i,t}$ is the return of stock i during interval t. For the analysis, spread and order imbalance are the logarithm of the ratio of each and its prior one lag value. The regressions are calculated for every half-hour interval t from January 2001 through December 2005 (16,261 intervals), and for lag k values 1 through 65 (past 5 trading days), using all firms with relative bid/ask spread of no more than 25 basis points at the beginning of the interval. All panels plot the *t*-statistics of the time-series averages of the regression coefficients. The analysis uses NYSE-listed stocks.

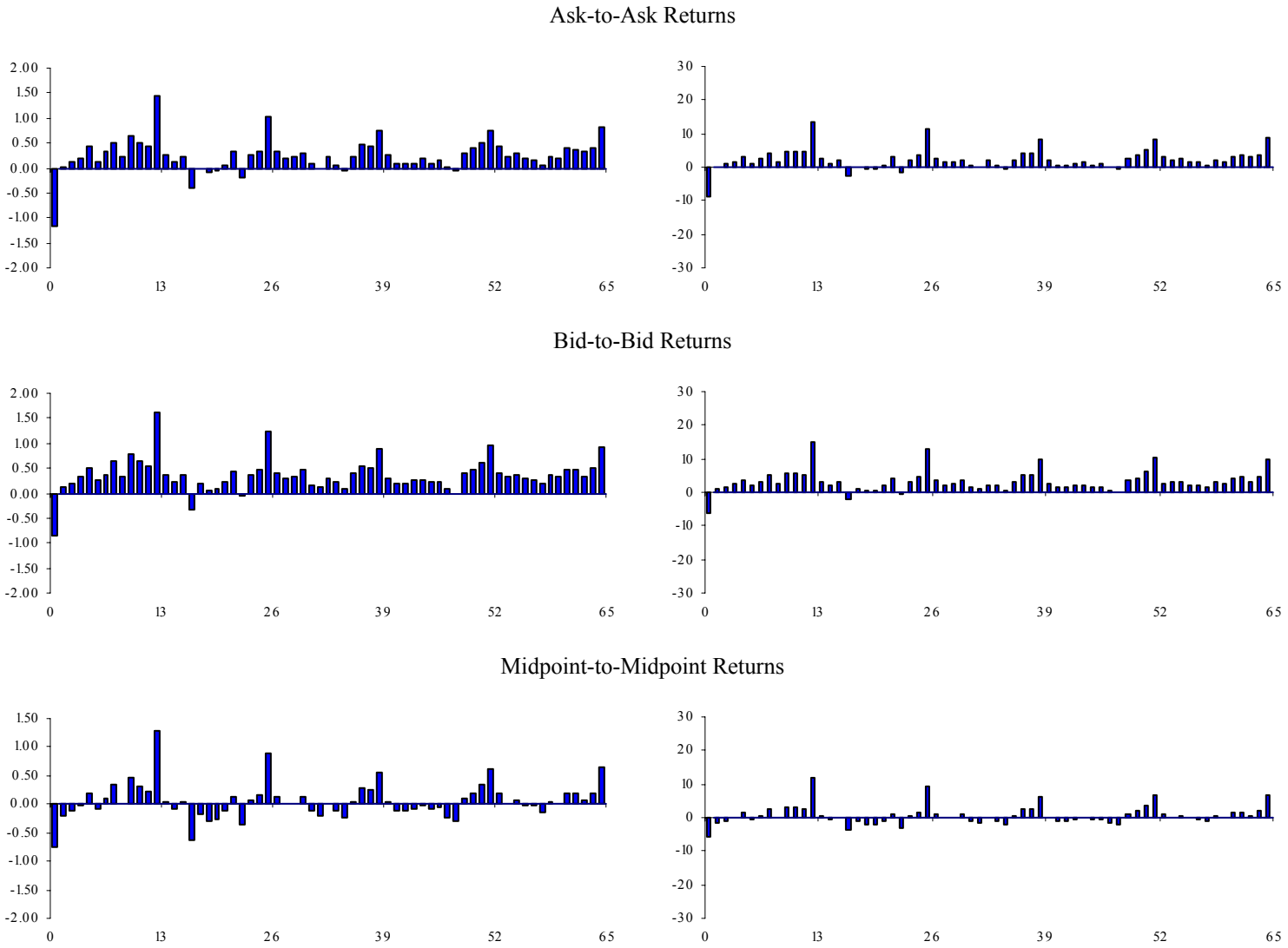


Figure 8. Cross-sectional regressions using different return measures over half-hour intervals. Intraday cross-sectional simple regressions of the form $r_{i,t} = \alpha_{k,t} + \gamma_{k,t} r_{i,t-k} + u_{i,t}$ are calculated for half-hour interval t and lag k, and where $r_{i,t}$ is return of stock i during interval t. The lagged variable $r_{i,t-k}$ is return of stock i in interval $t–k$. The regression is calculated for every half-hour interval t from January 2001 through December 2005 (16,261 intervals), and for lag k values 1 through 65 (past 5 trading days). Return is measured using either ask prices, bid prices, or the bid-ask midpoint prices. Panel A plots the time-series averages of $\gamma_{k,t}$. Panel B plots the respective t–statistics. The analysis uses NYSE-listed stocks.