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PRICE FORMATION AND LIQUIDITY IN THE  
U.S. TREASURY MARKET: EVIDENCE FROM  
INTRADAY PATTERNS AROUND ANNOUNCEMENTS

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**Price Formation and Liquidity  
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Around Announcements**

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# **Price Formation and Liquidity in the U.S. Treasury Market: Evidence from Intraday Patterns Around Announcements**

## **Abstract**

We identify striking adjustment patterns for price volatility, trading volume, and bid-ask spreads in the U.S. Treasury market when public information arrives. Using newly available high-frequency data, we find a notable lack of trading volume upon a major announcement when prices are most volatile. The bid-ask spread widens dramatically with price volatility and narrows just as dramatically with trading volume. Trading volume surges only after an appreciable lag following the announcement. High levels of price volatility and trading volume then persist, with volume persisting somewhat longer.

## Price Formation and Liquidity in the U.S. Treasury Market: Evidence from Intraday Patterns Around Announcements

Much of what we know about price formation and liquidity in financial markets is based on circumstantial evidence from equity markets. Here we often see significant price changes without directly observing the arrival of information. In a landmark paper, French and Roll (1986) infer that these price movements are due to private information conveyed through trading.<sup>1</sup> Indeed such information would explain the well-established correlation between price volatility and trading volume.<sup>2</sup> The importance of private information has the further implication that it complicates the behavior of bid-ask spreads. To explain these spreads, empirical studies have relied on models of asymmetric information implying that relatively uninformed market makers hesitate to provide liquidity unless they can also trade with other uninformed investors.<sup>3</sup> Krinsky and Lee (1996) suggest that even at earnings announcements, private information plays an important role in bid-ask spreads.

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<sup>1</sup> By comparing trading and nontrading periods, Jones, Kaul, and Lipson (1994) infer an important role for public information as well. However, Berry and Howe (1994) and Mitchell and Mulherin (1994) encounter difficulty linking price movements to more direct measures of public information flows.

<sup>2</sup> Karpoff (1987) reviews the literature on the price-volume relationship. One explanation of the relationship is formally known as the "mixture-of-distributions hypothesis," first proposed by Clark (1973), in which volatility and volume jointly depend on information arrival. In a recent contribution, Andersen (1996) specifies Poisson processes for informed and uninformed trading volume.

<sup>3</sup> Stoll (1989), for example, finds that 43% of the bid-ask spread is due to such information asymmetry. Affleck-Graves, Hegde, and Miller (1994) attribute a similar magnitude, while George, Kaul, and Nimalendran (1991) attribute a smaller portion to this source.

The U.S. Treasury market offers a useful alternative testing ground for theories of price formation and liquidity provision, because it differs from equity markets in important ways. In particular, much of the price variability in the market is apparently driven by public rather than private information. With the benefit of high-frequency data, Ederington and Lee (1993), Becker, Finnerty, and Kopecky (1996), and Balduzzi, Elton, and Green (1996) document the importance of monthly macroeconomic announcements as a major source of price volatility.<sup>4</sup> In addition, the arrival of such information in the market is observable with a high degree of accuracy, because the announcements are released at known precise times. These features of the Treasury market allow an examination of prices, trading volume, and bid-ask spreads when information is public instead of private and when market making is therefore less subject to informational asymmetry.<sup>5</sup> Until now, the lack of data on trading volume and bid-ask spreads has inhibited such an analysis.

In this study, we rely on newly available high-frequency data from the U.S. Treasury market to examine the behavior of price volatility, trading volume, and bid-ask spreads around the time of major macroeconomic announcements. After identifying the major announcements, we compare patterns on major announcement days with those on nonannouncement days at one-minute and five-minute intervals. The patterns we find are striking. First, the most volatile prices occur upon an announcement, at which time there is a notable lack of trading volume. Second, the bid-ask spread widens unambiguously with the volatility spike and narrows unambiguously with a surge in trading volume. Third, the volume surge comes only after an

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<sup>4</sup> In addition, Fleming and Remolona (1997) attribute to public announcements the 25 largest five-minute price movements during August 1993 to August 1994. They also review stock market studies of the impact of macroeconomic announcements, in which the effects appear to be weaker than the effects in the bond market.

<sup>5</sup> Other distinctive features of the market, including its organization and operation, are discussed in the next section.

appreciable lag following the announcement. Fourth, high price volatility and high trading volume persist for an extended period. Finally, high volume persists longer than high volatility.

These patterns shed new light on price formation and liquidity provision in financial markets. The lack of volume during the volatility spike lends empirical significance to French and Roll's (1986) theoretical identification of public information as what moves prices without requiring trading activity. The bid-ask spread's behavior seems to represent an uncomplicated reaction by market makers to the traditional inventory risks of high volatility and low volume. The delayed surge in volume suggests a lack of consensus about prices, in which dealers speculate on the price adjustments that follow the sharp initial adjustment. The formation of a consensus price appears to be a protracted process involving a persistence of both high volatility and high volume. This persistence is consistent with predictions of He and Wang's (1995) model, in which noise serves to obscure traders' views from one another. Finally, liquidity traders seem to react to price changes and thus extend the period of high volume beyond that of high volatility.

The paper is organized as follows: In Section I, we characterize the market described by our data. In Section II, we describe the data used in the analysis and distinguish the intraday patterns that can be attributed to the macroeconomic announcements. In Section III, we identify the announcements that have the most impact on the market. In Section IV, we document five stylized facts about the timing and persistence of the announcements' effects and discuss their implications for price formation and liquidity provision.

## I. The Interdealer Treasury Securities Market <sup>6</sup>

Trading in U.S. Treasury securities takes place primarily in a multiple-dealer over-the-counter market rather than in an organized exchange. While there are 1,700 brokers and dealers in the secondary market, the majority of trading volume is accounted for by the primary dealers (Department of the Treasury, et al., 1992), of which there are currently 39. Primary dealers are those eligible to trade directly with the Federal Reserve Bank of New York. Their ranks include specialized securities firms as well as subsidiaries of diversified securities firms, U.S. banks, and foreign banks (Appendix A). Primary dealers are expected to bid competitively at Treasury auctions, participate in the Fed's open market operations, and provide market intelligence to the Fed. Until recently, primary dealers were also required to maintain a liquid secondary market for Treasury securities by transacting significant volume with customers.<sup>7</sup> While trading with customers is no longer required, primary dealers remain the predominant market makers in U.S. Treasury securities.

As market makers, the primary dealers take positions and stand ready to buy and sell securities for their own account at their quoted bid and ask prices. The positions taken tend to be highly leveraged, as they are typically financed with borrowings in the overnight repo market. The dealers trade 22 to 23 hours per day during the five day trading week, although 95% of trading activity

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<sup>6</sup> Additional sources on the U.S. Treasury market are Bollenbacher (1988), Department of the Treasury et al. (1992), Fleming (1997), Madigan and Stehm (1994), Stigum (1990), and U.S. General Accounting Office (1986).

<sup>7</sup> Customers include non-primary dealers, other financial institutions (e.g., banks, insurance companies, pension funds, and mutual funds), non-financial institutions, and individuals.

occurs during New York trading hours.<sup>8</sup> These trades amount to an average of \$125 billion a day in the U.S. Treasury cash market. Just over half of this volume is with customers and just under half is transacted with other primary dealers. Roughly 90% of the interdealer volume, or \$53 billion a day, passes through interdealer brokers. Thus volume in the interdealer cash market is comparable to turnover in the interest rate futures markets, where an average of \$57 billion worth of contracts trade daily.<sup>9</sup>

The interdealer brokers form the core of the secondary market for U.S. Treasury securities.<sup>10</sup> The brokers provide primary dealers with electronic screens that post the best bids and offers phoned in by the dealers. Dealers execute trades by phone through the brokers, who then post the resulting trade price and size electronically. For the most part, the brokers act only as agent and serve only primary dealers.<sup>11</sup> The interdealer broker market is extremely liquid with *minimum* trade sizes of \$1 million (\$5 million for bills), average bid-ask spreads of about 1/64 of a point for the most active 5-year note, and modest brokerage fees.<sup>12</sup>

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<sup>8</sup> Madigan and Stehm (1994) and Fleming (1997) describe the round-the-clock market. The cash market volume statistics in this paragraph are from Fleming (1997) who examines the April-August 1994 period.

<sup>9</sup> This turnover figure includes \$4 billion in bill futures on the Chicago Mercantile Exchange and \$53 billion in note and bond futures on the Chicago Board of Trade between August 23, 1993 and August 19, 1994.

<sup>10</sup> The six major interdealer brokers are: Cantor Fitzgerald Inc., Garban Ltd., Hilliard Farber & Co. Inc., Liberty Brokerage Inc., RMJ Securities Corp., and Tullett & Tokyo Securities Inc.

<sup>11</sup> Cantor Fitzgerald Inc. is the most notable exception on both points.

<sup>12</sup> Typical brokerage fees (paid by the transaction initiator) are as follows: \$12.50 per \$1 million on 3-month bills ( $\frac{1}{2}$  of a hundredth of a point), \$25 per \$1 million on 6-month and 1-year bills ( $\frac{1}{2}$  and  $\frac{1}{4}$  of a hundredth of a point respectively), and \$39.06 per \$1 million on notes and bonds ( $\frac{1}{8}$  of a 32nd of a point). These are the fees reported by Stigum (1990), and recent communication with market participants suggests that fees today are similar. The fees are negotiable, however, and can vary with volume.



An important feature of the interdealer broker market is the anonymity of trading. The brokers are “blind” in the sense that they do not reveal to a transaction’s counterparties the other’s name. Clearing trades through a clearing bank allows anonymity to be maintained even after the trade. Such anonymous trading indicates the importance of individual primary dealers’ views. Different dealers are known to have different analytical strengths, investment strategies, and customers, and the same trade by one dealer, if identified, might not convey the same information if undertaken by another dealer. While diverse views may be interpreted as differential private information, there is no evidence that some dealers have superior views and thus no implication of informational asymmetry.

## II. Data and intraday patterns

### *A. Data on the Treasury securities market*

Our data cover one year of tick-by-tick trading activity among the primary dealers in the interdealer broker market. The source of the data is GovPX, Inc., a joint venture set up by the primary dealers and interdealer brokers in 1991 to improve the public’s access to U.S. Treasury security prices. GovPX consolidates and posts real-time quote and transactions data from 5 of the 6 major interdealer brokers, accounting for two-thirds of the interdealer broker market.<sup>13</sup> Posted data include the best bids and offers, trade prices and sizes, and the aggregate volume of trading for all Treasury bills, notes, and bonds. GovPX data are distributed electronically to the public through several on-line vendors.

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<sup>13</sup> Cantor Fitzgerald Inc. is not included. Cantor specializes in longer-term securities and in particular the 30-year bond.

The sample period is August 23, 1993 to August 19, 1994, a bear-market year for bonds in which the Federal Reserve raised its target fed funds rate five times. After excluding 10 days when the market was closed, we have a sample of 250 trading days. We focus our analysis on the *on-the-run* 5-year Treasury note. On-the-run securities (also called *active* or *current*) are the most recently issued securities of a given maturity and account for the majority of interdealer trading volume.<sup>14</sup> Among the on-the-run issues, the 5-year note is the most actively traded security among the brokers reporting to GovPX (Fleming, 1997).<sup>15</sup> During our sample period, GovPX posted a daily average of 2,189 bid-ask quotations and 659 trades for the on-the-run 5-year note. Appendix B describes the cleaning and processing of the data in detail.

#### B. Data on announcements

We also collected data on the date and time of 19 different regularly scheduled macroeconomic announcements. These include the 18 monthly announcements that regularly appear in “The Week Ahead” section of *Business Week* as well as one weekly announcement.<sup>16</sup> The federal government’s “Schedule of Release Dates,” the *Wall Street Journal*, and Bloomberg were used in

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<sup>14</sup> Fleming (1997) finds that 64% of interdealer trading is in on-the-run issues, 25% is in *off-the-run* issues, and 12% is in *when-issued* securities. Off-the-run securities are issued securities that are no longer active, while when-issued securities are securities that have been announced for auction but not yet issued.

<sup>15</sup> In conversations with the authors, traders characterized the interdealer cash market as generally more liquid than the futures market in the case of the 5-year note (with the futures market as more liquid in the case of the 30-year bond). In our sample, the five brokers covered by GovPX report an average daily volume of \$5.4 billion for the on-the-run 5-year note, while data from the Chicago Board of Trade for the same period show average daily turnover of \$4.4 billion for all 5-year note futures contracts.

<sup>16</sup> One of these “monthly” announcements is gross domestic product (GDP). While GDP is a quarterly statistic, advance, preliminary, and final estimates are released in successive months. Our list of announcements is the same as Ederington and Lee’s (1993) except for the addition of initial jobless claims and consumer confidence, and the omission of installment credit. We exclude installment credit since it does not occur at a fixed time.

addition to *Business Week* to determine announcement dates and times. We took pains to verify the announcement dates and times, because the precise time for the arrival of information is critical to our analysis. As seen in Table I, 11 of our announcements are released at 8:30 AM eastern time (ET), one at 9:15 AM, six at 10:00 AM and one at 2:00 PM.<sup>17</sup> The government statistical agencies impose “lock-up conditions” to ensure that information is released to the public at only these times.<sup>18</sup> Seventeen of the announcements come from government agencies and two from the private sector. Our period of analysis encompasses 268 releases of our 19 announcements on 173 separate days.

### *C. Measuring volatility, volume, and spread*

In this study, we analyze price volatility, trading volume, and bid-ask spreads for the on-the-run 5-year Treasury note at both one-minute and five-minute intervals. Our measure of price volatility is based on the change in log prices,  $\log P_t - \log P_{t-1}$ , where the price  $P_t$  is defined as the midpoint between the last bid and ask quotes posted during interval  $t$ .<sup>19</sup> Trading volume is measured as the total face value of securities traded during each interval. For the bid-ask spread, we divide the difference between each set of bid and ask quotes by the midpoint between the bid and ask quotes and then take the mean for all quotes posted during each interval. In the figures and in our discussion we refer to the

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<sup>17</sup> Included in the 8:30 AM count is personal income, which was released at 10:00 AM for the first three announcements in our sample.

<sup>18</sup> At the Bureau of Labor Statistics, for example, financial reporters enter the lock-up room at least half an hour before an 8:30 AM announcement. At 8:00 AM, they receive the report and begin typing their stories into computers. Their computers have modems but the phone lines remain dead. At 8:29 AM, they press their “reconnect” buttons and wait for a ten-second countdown. At precisely 8:30 AM, the phone lines are turned on, and only then are the reporters able to transmit their stories.

<sup>19</sup> We also have data on transactions prices but using the bid-ask midpoints allows us to avoid complications associated with the “bid-ask bounce” and provides us with more observations.

different time intervals by the interval starting times, e.g., 8:30 AM for the 8:30-8:35 AM interval.

#### *D. Intraday patterns*

In the rest of this section, we summarize the data by describing the intraday patterns of price volatility, trading volume, and bid-ask spreads. We calculate the standard deviation of log price changes, the mean trading volume, and the mean bid-ask spread across our sample of announcement and nonannouncement trading days for successive five-minute intervals from 7:30 AM to 5:00 PM (ET). As mentioned earlier, these trading hours account for nearly 95 percent of interdealer trading, and all of the announcements we examine occur during these hours. To isolate the role of the scheduled macroeconomic announcements, we compare the intraday patterns on days in which one or more of our 19 scheduled announcements was released with those on days in which none of them was released.

The most distinctive feature of the intraday pattern of price volatility is a spike in the 8:30 AM interval. As shown in Figure 1A, volatility rises sharply at that time and remains relatively flat the rest of the day, except for minor spikes at 10:00 AM and 1:45 PM. Ederington and Lee (1993) find similar spikes in the Treasury bond, Eurodollar, and deutsche mark futures markets, which they attribute to the effects of scheduled macroeconomic announcements released at those times of day.<sup>20</sup> Indeed, as shown in Figure 1B, volatility on announcement days exhibits a pronounced spike at 8:30 AM and a less pronounced one at 10:00 AM. In our sample, 11 different scheduled announcements are released at 8:30 AM and six at 10:00 AM. By comparison, volatility stays relatively flat through nonannouncement trading days.

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<sup>20</sup> Crain and Lee (1995), Andersen and Bollerslev (1996), and Locke (1996) find similar announcement effects in precious metals and other interest rate and currency markets.

Our data provide new evidence on the intraday patterns of trading volume in the U.S. Treasury market. In this market, trading volume also surges around 8:30 AM but its subsequent decline is more gradual than the decline in volatility. As shown in Figure 2A, volume begins to rise from the start of New York trading at 7:30 AM. It then peaks at 8:35 AM or five minutes after the volatility peak. Except for a minor surge after 10:00 AM, volume declines only gradually until 3:00 PM, when it then falls sharply. The great volume surge around 8:30 AM and the minor surge around 10:00 AM can be attributed to the announcements. As shown in Figure 2B, the surge at 8:35 AM is much more pronounced for announcement days, and the smaller surge around 10:00 AM is clearly evident only for announcement days. For much of the rest of day, volume on announcement days remains higher than volume on nonannouncement days. Announcement and nonannouncement day patterns are similar, however, in that both show a rise in volume before 8:30 AM and a sharp drop after 3:00 PM.<sup>21</sup>

Our data also provide new evidence on the intraday patterns of liquidity in the U.S. Treasury market as measured by the bid-ask spread. In this market, the bid-ask spread displays a rough reverse J-shaped pattern interrupted by a sharp rise around 8:30 AM and a smaller rise around 10:00 AM. As shown in Figure 3A, the spread is widest at the start of New York trading indicating an initial reluctance by dealers to provide liquidity. The spread narrows rapidly from 7:30 AM, but then widens sharply for a brief period around 8:30 AM. It then narrows again, and widens briefly around 10:00 AM. The spread then rises gradually until the early afternoon, tapers off slightly and then rises sharply just before trading ends. The momentary loss of liquidity around 8:30 AM and 10:00 AM, as indicated by the wide spreads, can be attributed to the announcements.

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<sup>21</sup> The early morning volume surge and the sharp drop in the afternoon may be related to the start of trading in U.S. Treasury futures at 8:20 AM (ET) on the Chicago Board of Trade and the closing of that market at 3:00 PM (ET).

As shown in Figure 3B, the reverse J-shaped pattern is evident on both announcement and nonannouncement days, while the interruptions of wide spreads are evident only for announcement days.

### III. The Major Announcements

#### A. Previous studies

Recent papers relying on high-frequency data have established the importance of certain macroeconomic announcements for price volatility in interest rate markets. Ederington and Lee (1993) exploit data on Treasury bond and Eurodollar futures and find strong announcement effects from employment, PPI, CPI, and durable goods orders releases. Crain and Lee (1995) find significant effects on Eurodollar spot and futures price volatility from employment and durable goods orders announcements. Becker, Finnerty, and Kopecky (1996) find nonfarm payrolls and CPI surprises to significantly affect Treasury bond and Eurodollar futures prices. In this section, we examine the impact of announcements on the U.S. Treasury cash market, and we investigate the effects on trading volume and bid-ask spreads in addition to price volatility.<sup>22</sup>

#### B. Measuring the impact of announcements

We examine the effects of the various announcements on price volatility, trading volume, and the bid-ask spread by following Ederington and Lee's (1993) use of announcement dummy variables as explanatory variables in regressions for given intervals. We define dummy variables  $D_{kt}$  where  $D_{kt} = 1$  if

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<sup>22</sup> Balduzzi, Elton, and Green (1996) also examine the effects on trading volume and bid-ask spreads using GovPX data in an analysis that focuses on the implications for yield curve models.

announcement  $k$  is made on day  $n$  and  $D_{kn} = 0$  otherwise.<sup>23</sup> For the dependent variables, we measure price volatility by taking the absolute value of the change in log prices,  $|\log P_t - \log P_{t-1}|$ , where  $P_t$  is the midpoint of the bid and ask quotes at the end of interval  $t$ . As before, trading volume is the total face value of securities traded during an interval and the bid-ask spread is the mean of the difference between bid and ask quotes divided by the midpoint of the bid and ask quotes for all quotes posted during an interval. The regression equation is then  $Y_{nt}^j = a_{0t}^j + \sum_{k=1}^K a_{kt}^j D_{kn} + e_{nt}^j$  where the superscript  $j$  indicates whether the dependent variable is volatility, volume, or spread, the subscript  $t$  indicates a specific five-minute time interval, and  $K$  equals the number of announcements included in the regression. The intercept  $a_{0t}^j$  measures the average value of the variable in time interval  $t$  in the absence of announcements and the coefficient  $a_{kt}^j$  measures the average impact of announcement  $k$ .

For each dependent variable we run a regression for four different time intervals corresponding to the four times of day that the 19 reports are released.<sup>24</sup> In the case of price volatility and the bid-ask spread the regressions are run for the five-minute intervals immediately following the announcements (e.g., 8:30-8:35 AM for the 8:30 AM announcements). In the case of trading volume these regressions are run for the succeeding five-minute interval (e.g., 8:35-8:40 AM for the 8:30 AM announcements). The patterns displayed in Figures 1B, 2B, and 3B suggest that these are the intervals in which the announcements have their most pronounced effects on the corresponding variables.

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<sup>23</sup> In our sample, two announcements -- construction spending and the NAPM survey -- were released at the same time on the same day in 10 of 12 instances. In those 10 cases, we set the dummy variable equal to one; and for the days with only one of these announcements, we set it equal to one-half.

<sup>24</sup> Following Ederington and Lee (1993), our  $K$  included announcements control for the effects of announcements released earlier in the day.

### *C. The major announcements*

Our regression results measure the immediate impact of the various announcements on price volatility, trading volume, and the bid-ask spread for the on-the-run 5-year Treasury note. As shown in Table II, five of the 19 announcements show significant effects on price volatility at the 1% level and two at the 5% level. In the order of their importance, the announcements with significant volatility effects at the 1% level are: (1) employment, (2) PPI, (3) CPI, (4) construction spending and the NAPM survey, and (5) industrial production and capacity utilization. In the absence of an announcement, the typical price move over the five-minute 8:30 AM interval is between  $1/64$  and  $1/32$  of a point or half a basis point in yields. On days of the employment report, the corresponding price move is close to  $9/32$  of a point or just under 7 basis points in yields.

Six of the announcements show significant effects on trading volume at the 1% level and five at the 5% level. As shown in Table II, the announcements with significant volume effects at the 1% level are: (1) employment, (2) construction spending and the NAPM survey, (3) PPI, (4) personal income (at 10:00 AM), (5) industrial production and capacity utilization, and (6) initial jobless claims, in that order. In the absence of an announcement, volume averages \$77 million during the five-minute 8:35 AM interval. On employment report days, volume averages \$259 million in the corresponding interval.

Four show significant effects on the bid-ask spread at the 1% level and seven at the 5% level. As shown in the table, the significant announcements at the 1% level are: (1) employment, (2) CPI, (3) PPI, and (4) industrial production and capacity utilization, in that order. In the absence of an announcement, the average bid-ask spread during the 8:30 AM interval is about  $1/64$  of a point. On an employment report day, the typical bid-ask spread during the corresponding interval is about  $3/64$  of a point.



Our findings show that largely the same announcements matter for price volatility, trading volume, and bid-ask spreads.<sup>25</sup> For all three variables, the 8:30 AM employment report is far and away the most important announcement.<sup>26</sup> In the first five minutes upon the report's release, volatility rises 13-fold on average and the spread widens to three times its usual value. Then in the next five-minute interval, volume surges to three-and-a-half times its normal amount. While the rank ordering of announcements varies somewhat after employment, there is nonetheless a strong relationship across variables in which announcements matter. The PPI, for example, is ranked second for impact on price volatility, third for trading volume, and third for the bid-ask spread.

#### IV. Five Stylized Facts

Studies relying on futures market data have identified interesting intraday patterns for prices and trading activity. Ederington and Lee (1993) find substantially higher volatility in interest rate futures for 15 minutes after a major announcement and slightly higher volatility for several hours. They suggest that the release of further details of a report and traders' reassessment of the news and its implications may explain the persistence. In addition to volatility persistence, Locke (1996) finds a significant increase in market maker activity in the first 15-minute interval after major announcements for a variety of futures markets. Data from the futures markets, however, do not permit observations at higher frequencies, because transactions are time-stamped in 15-minute batches.

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<sup>25</sup> The correlation between the 19 price volatility and trading volume coefficients in Table II is 0.85, significant at the .01 level. Corresponding figures for the price volatility and bid-ask spread coefficients and the trading volume and bid-ask spread coefficients are 0.91 and 0.68, respectively (both significant at the .01 level).

<sup>26</sup> As noted by Ederington and Lee (1993), the employment report is the first government report released concerning economic activity in a given month.

We similarly use announcements as conditioning variables to document the behavior of prices, trading volume, and bid-ask spreads when public information arrives. As with Ederington and Lee (1993) and Locke (1996), we mark the times of information arrival at the precise announcement release times. To sharpen the analysis, we focus on the major 8:30 AM announcements, defined as those that show significant effects on at least two of the variables at the 1% level in Table II. By this criterion, our major 8:30 AM announcements are employment, PPI, and CPI.<sup>27</sup> Our conclusions are unchanged when we consider a larger set of announcements.<sup>28</sup>

We detail the market's behavior around the major announcements with a series of tables and charts. Table III compares days with any of our major 8:30 AM announcements to days with none of our eighteen morning announcements for every *one-minute* interval from 8:25 to 8:37 AM. Price volatility is presented in panel A, with the standard deviation for announcement days and nonannouncement days included, as well as the ratio between the two. Trading volume and bid-ask spread means for announcement and nonannouncement days are presented in panels B and C, respectively, along with the differences between the two groups. Table IV uses the same format to compare major announcement and nonannouncement days by *five-minute* interval from 8:15 to 8:45 AM, and for every third five-minute interval from 9:00 to 10:20 AM. Figures 4A to 4C compare major announcement and nonannouncement days by five-minute interval for the trading day, indicating the instances where the differences are significant.<sup>29</sup> The ratio of the price volatility standard deviations

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<sup>27</sup> These represent three of the four announcements considered "major" by Ederington and Lee (1993) and exactly match Locke's (1996) set of conditioning announcements.

<sup>28</sup> Our results were very similar in an earlier version of the paper which considered GDP and retail sales among the major announcements.

<sup>29</sup> Fleming and Remolona (1997) document a significant market impact from Federal Reserve target rate announcements and Treasury auction results. Figures 4A to 4C exclude the observations for the days of these announcements starting half an hour before their release.

is presented in Figure 4A, the difference in the trading volume means is presented in Figure 4B, and the difference in the bid-ask spread means is presented in Figure 4C. These tables and figures serve to document five stylized facts.

*A. Stylized fact 1: Volatility spikes without volume*

The most volatile prices occur with a notable lack of trading volume in the first few minutes after a major 8:30 AM announcement. As shown in Panel A of Table III, price volatility starts to rise a minute before an announcement. Volatility then spikes up in the next two minutes, reflecting the market's reaction to the announcement. At its peak, volatility is over 13 times the volatility for the same interval on nonannouncement days. As shown in Panel B, during the same two minutes, trading volume tends to be less than the normal volume on nonannouncement days, with a statistically significant difference in the 8:31 AM interval.<sup>30</sup> This lack of volume during the time of the most volatile prices shows a market that dramatically reprices without the help of trading activity.<sup>31</sup> It is a phenomenon that to our knowledge has not been documented in the literature.

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<sup>30</sup> As noted in Appendix B, the volume of a trade is reported when the “work-up” stage of a transaction is complete, while bid and ask quotes are posted instantaneously. Such asynchrony between our observations of price volatility (based on the quotes) and trading volume do not explain our first stylized fact. We conducted the same minute-by-minute analysis using actual transactions prices (which are recorded at exactly the same time as the volume data), and we find that price volatility still spikes in the 8:30 AM one-minute interval before trading volume starts to surge at 8:32 AM.

<sup>31</sup> It is conceivable that active trading takes place in the futures pits during the trading pause in the cash market. As explained above, however, there is no way to verify this with futures market transactions data, which are time-stamped at only 15-minute intervals. Moreover, traders point out that in the first minute after a major announcement, there is limited opportunity to trade in the futures market because the quotes are one-sided depending on whether the number was bullish or bearish. Note also that for the 5-year note the cash market is generally more liquid than the futures market (see footnote 15 above).

The fact that the most volatile prices occur with relatively little trading imparts empirical meaning to the theoretical dichotomy between public and private information. In French and Roll's (1986, p. 9) statement of the theory, public information "affects prices before anyone can trade on it," while private information "only affects prices through trading." Our stylized fact shows precisely such a price adjustment to public information. We have long known, of course, that it is possible for prices to move in the absence of trading. French and Roll, after all, find that there is stock price volatility when the exchanges are closed, albeit less than when the exchanges are open. Our first stylized fact demonstrates that in the Treasury bond market the sharpest price movements take place without a rise in trading activity at the very time that we observe the arrival of public information.

The positive correlation between price volatility and trading volume is one of the best documented facts about financial markets.<sup>32</sup> The correlation may be attributed to private information conveyed through trading or to differences of opinion among traders regarding prices. We find a notable absence of this relationship in the two-minute period after a major announcement. As shown in Table V, the 8:30 and 8:31 AM intervals are exceptional in not showing positive volatility-volume correlations. This absence of correlation not only confirms the public nature of the information but suggests that a large component of the resulting changes in expectations is commonly shared.

*B. Stylized fact 2: The market suffers a momentary liquidity loss at the time of announcements*

Using the bid-ask spread as an inverse measure of liquidity, we find that the market suffers a dramatic liquidity loss during a brief period around a major

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<sup>32</sup> Karpoff (1987) provides a review of the literature.

announcement. As shown in Panel C of Table III, the spread starts to widen during the 8:28 AM interval to anticipate an announcement. The most illiquid time then coincides with the volatility spike in the first minute after the announcement, when the bid-ask spread is over seven times wider than its average on nonannouncement days. Two minutes after the announcement, the spread narrows sharply, indicating a dramatic return of liquidity. Three minutes after the announcement, the spread is no longer significantly different from the nonannouncement day average.<sup>33</sup> Price volatility remains high at this time, but trading volume has started to surge.

The short period of illiquidity around a major announcement is consistent with the behavior of competing dealers trying to control the risks in their inventories. The inventory-control models of Demsetz (1968), Tinic and West (1972), Amihud and Mendelson (1980), and Ho and Stoll (1983) emphasize the increased risk to market makers of high price volatility and low trading volume. In the Treasury market, the effort to control inventory risk in the face of extreme price volatility evidently causes dealers to sharply widen their spreads. A few minutes after the announcement, the dealers begin to narrow their spreads in spite of continued high price volatility as the ensuing surge in trading volume greatly reduces the transaction flow uncertainty.

Our characterization of the bid-ask spread's behavior in terms of the arrival of public information is more straightforward than characterizations drawn from equity markets. For these other markets, the asymmetric-information models of Glosten and Milgrom (1985), Kyle (1985), Admati and Pfleiderer (1988), and Easley and O'Hara (1992) emphasize the risk to market makers of dealing with investors with private information. The bid-ask spread

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<sup>33</sup> Panel C of Table IV and Figure 4C show that except for occasional intervals, the spread remains close to normal for the rest of the day.

then depends on when uninformed investors choose to trade.<sup>34</sup> If volatility in the Treasury bond market is driven by the arrival of public information, however, dealers would face little risk from trading with investors with superior information. Indeed the spread's unambiguous behavior in this market is consistent with inventory risks brought about by public information and does not require a private information explanation.<sup>35</sup> While it is hard to rule out the possibility that some investors in the stock market obtain advance information about earnings announcements, advance information about macroeconomic announcements seems less likely given the "lock-up conditions" imposed by the government agencies (see footnote 18).

*C. Stylized fact 3: Volume surges with a lag*

Trading volume does rise after a major announcement, but only with an appreciable lag. As shown in Panel B of Table III, it takes two minutes for volume to start to pick up after an announcement, by which time price volatility has already come down to a third of its level at the peak. Volume then surges to its highest levels between four and seven minutes after the announcement, when it averages about four times its average for nonannouncement days. During this volume surge, volatility remains high but at a level that is only a fifth of its peak level.

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<sup>34</sup> Empirical studies of bid-ask spreads in the stock market thus find mixed results in examining the effects of earnings announcements. Morse and Ushman (1983) find no effect, while Venkatesh and Chiang (1986) find an effect only for announcements that follow an initial announcement within 10 days. Krinsky and Lee (1996) attribute these mixed results to the offsetting effects of asymmetric information and inventory control.

<sup>35</sup> An asymmetric information explanation of the spread's behavior requires not only that some investors receive the information ahead of time but that they act on it *just before* the public announcement. It is even harder to explain the spread's widening in terms of the risk of trading with investors who are quick to react to the announcement, because traders routinely withdraw their quotes just before major announcements so that the brokers' screens "go blank." The traders, in fact, point only to inventory risk as the reason for this behavior.

The surge in trading volume suggests wide disagreement among dealers regarding the initial price adjustment. Beaver (1968, p. 69) attributed price changes in the stock market in weeks of earnings announcements to “changes in the expectations of the market as a whole” and the rise in trading volume to “a lack of consensus regarding the price.” In the Treasury market, most participants seem to draw rather similar price implications from the headline number of a major announcement, suggesting that the largest part of the price adjustment reflects a shared change in expectations. The precise magnitude of the appropriate price change, however, is a matter of analysis or interpretation, which differs among dealers. Some of them see the initial price adjustment as an overreaction, others an underreaction. The dealers then take positions on the strength of their views and thus produce the volume surge.

In the price formation literature, a number of models show that differences of views among investors generate speculative trading activity. Kim and Verrecchia (1991), Foster and Viswanathan (1993), Harris and Raviv (1993), Shalen (1993), and Kandel and Pearson (1995) specify various forms of investor heterogeneity to explain volume surges after announcements. Morse (1981) suggests that in the stock market the volume surge following earnings announcements represents the unwinding of prior speculative positions. He and Wang (1995) show that in theory investors would take speculative positions just before and unwind just after an announcement. In the Treasury market, however, we observe no significant volume surge before announcements. The dealers seem to speculate not on the announcement itself but on the price adjustments after the sharp initial price reaction.

*D. Stylized fact 4: Both volatility and volume persist at high levels*

Price volatility and trading volume both remain high for over an hour after a major 8:30 AM announcement. Panel A of Table IV indicates that

volatility proceeds to decline after the spike but remains significantly higher than average for about 80 minutes after a major announcement. Figure 4A suggests that such volatility may last even longer. Panel B of Table IV shows that trading volume starts to decline 15 minutes after the announcement but remains significantly elevated for about an hour-and-a-half. Figure 4B suggests that high volume may persist even longer. Table V shows that the volatility-volume persistence gives rise to a significant positive correlation for several intervals beyond the first two minutes after the announcement.

The persistence of high price volatility along with high trading volume suggests a sluggish process of price formation in the market's attempt to reconcile heterogeneous views of investors. The persistence of volatility alone might suggest a sequential arrival of further public information, perhaps in the form of more detailed data in the announcements beyond the headline number (Ederington and Lee, 1993).<sup>36</sup> However, the fact that high volume accompanies high volatility suggests that there is more going on than such an information flow. He and Wang's (1995) model of differentially informed investors is one that gives rise to persistence in both volatility and volume in a slow process of convergence to a consensus price. Although the model assumes differential private information, the results are consistent with what we observe in the Treasury market. In the model, investors trade for several rounds after they receive information. Hence, volume and volatility persist even when the arrival of information does not.<sup>37</sup> Persistence is possible because prices are noisy and not

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<sup>36</sup> In the employment report for example, nonfarm payrolls employment is usually the headline number, but the report also contains data on the unemployment rate, average weekly hours, and average hourly earnings. Our inspection of a recent Bloomberg feed, however, shows that all these statistics along with some analysis become available within a minute after the release time. This is possible because financial reporters have access to the report half an hour earlier and can thus transmit their full stories at the release time (see footnote 18).

<sup>37</sup> Note that this is different from the mixture-of-distributions hypothesis of Clark (1973), Epps and Epps (1976), Tauchen and Pitts (1983), and Lamoureux and Lastrapes (1990), which requires a sequential arrival of new information to explain the price-volume relationship.



fully revealing of all the traders' information. In the Treasury market, differential information may take the form of differential views of the announcement. The noise that allows persistence may come from strategic trading by dealers or from their use of customers' liquidity trades to disguise their speculative trades.<sup>38</sup>

*E. Stylized fact 5: High volume persists longer than high volatility*

The announcement effects on trading volume appear to last longer than the effects on price volatility. Figure 4A shows that numerous intervals of significantly high volatility occur until noon, but afterwards there is little evidence of unusual volatility. In contrast, Figure 4B shows that intervals of significantly high volume remain fairly common until 1:00 PM.<sup>39</sup> Moreover, there is further evidence that price volatility leads to trading volume. Table VI reports Granger causality tests of volume and volatility based on six lags of five-minute intervals for our full sample of trading days.<sup>40</sup> The tests confirm a persistence in volatility controlling for past volume and a persistence of volume controlling for past volatility. The tests also show that volatility causes subsequent volume and to a lesser extent that volume causes subsequent volatility. Jain and Joh (1988) and Gallant, Rossi, and Tauchen (1992) similarly find that volatility causes volume in the stock market.

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<sup>38</sup> Foster and Viswanathan (1996) analyze strategic trading when agents forecast one another's forecast. The analysis focuses on the correlation structures of information signals rather than on price-volume relationships.

<sup>39</sup> Charts presented by Beaver (1968) and Morse (1981) also suggest a persistence of volume beyond that of volatility for common stocks after earnings announcements.

<sup>40</sup> Volatility is measured as the absolute change in log prices times a thousand and volume is measured in tens of millions of U.S. dollars.

The existence of liquidity traders who react to price changes is a possible explanation for the persistence of high volume beyond the period of high volatility. In existing microstructure models, liquidity traders do not need to react to price changes; they trade for purely exogenous reasons. In the Treasury market, however, there are good reasons for a reaction. Investment strategies that involve duration targets and dynamic hedging strategies for swaps, options, and mortgage-backed securities require a reaction to price changes. In theory the reaction should be continuous, but in practice transactions costs lead to an optimal reaction lag. Investors following these strategies are liquidity traders in the sense that they do not speculate on prices and their trades would not cause price volatility. Having an optimal reaction lag limits their discretion over when they may trade during the day. Some liquidity traders may react with lags of half an hour or longer, generating high volumes even after volatility has returned to normal levels.<sup>41</sup>

*F. The stylized facts in one episode*

The stylized facts we describe above are discernible even when we look at a single episode. The largest volatility shock in our sample took place just after 8:30 AM on August 5, 1994 when the July employment report was released. The headline number was a nonfarm payrolls figure that exceeded the consensus forecast by 54,000 jobs.<sup>42</sup> Figure 5 shows the spread between the mean bid and ask quotes, the mean transactions price, and trading volume by one-minute interval from 8:00 AM to 10:00 AM that day. As shown in the figure, the price of the 5-year note was relatively stable in the half hour before the announcement,

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<sup>41</sup> Another possibility is that the longer persistence of volume reflects the unwinding of speculative positions later in the day. In theory dealers should be able to execute such unwinding without causing price volatility and in practice such execution would be made easier by the presence of liquidity traders.

<sup>42</sup> Fleming and Remolona (1997) note that this was a relatively small surprise in a sample year in which the average absolute deviation from forecast was 92,000 jobs.

the bid-ask spread narrow, and trading volume low. The bid-ask spread then started to widen a minute before the announcement. Upon the report's release, the price of the 5-year note fell about half of a point within three minutes of the announcement, with trading still relatively thin. In fact, there were no recorded trades in the first minute after the announcement, when both bid and ask quotes were falling. The spread was at its widest in the first two minutes after the announcement, but it narrowed quickly in the third minute as trading volume started to pick up. Volume then surged as the price continued to fluctuate. For the next hour-and-a-half, both price volatility and trading volume remained substantially higher than on nonannouncement days.

## V. Conclusion

The recent availability of data from the U.S. Treasury market allows us to examine in a new light how secondary markets form prices and provide liquidity. The market we study is of interest, because it is one where public information is a major source of price volatility and therefore also one where market makers are less concerned about informational asymmetry. We focus the examination on intraday patterns around the release times of macroeconomic announcements, because these releases mark exact times for the arrival of information in the market. In the body of the paper, we describe our most striking results in the form of five stylized facts, linking them to various explanations in the literature. In this section, we recapitulate by pulling the facts and explanations together.

Our analysis suggests that major announcements set off an extended price formation process. The sharpest price adjustments take place in the first few moments of the process, when prices adjust without a rise in trading volume.

This initial price adjustment suggests that a large part of the change in expectations caused by public information is widely shared. After the initial price adjustment, there remains a residual disagreement among investors about what precisely the information means for prices. The disagreement is wide enough to give rise to a surge in trading activity, in which dealers speculate on subsequent price adjustments. Hence, the price formation process continues, but this time further price adjustments are accompanied by significant trading volume.

The persistence of high volatility and high volume suggests that the formation of a consensus price is a rather sluggish process. Even so liquid a market seems to have great difficulty resolving disagreement among investors. He and Wang's (1995) model shows that such a sluggish process is at least a theoretical possibility. The source of the difficulty is not that views are held stubbornly, since the consensus price that ultimately prevails should reflect all the views. The difficulty arises from noise in prices and trades that serves to obscure investors' views from one another. The noise may come from strategic trading by dealers or from the use of customers' liquidity trades to disguise speculative trades.

The moments in which prices adjust sharply to public information are also among the few times the market is disrupted by illiquidity. These are the moments of the widest bid-ask spreads away from the start and end of the trading day. The dealers apparently hesitate to provide liquidity because of the uncertainty about the price changes immediately following the announcement. Indeed, the dealers soon become willing to provide liquidity at the very time when high volatility and a surge in volume might otherwise suggest trading by better informed investors. Instead of widening, the bid-ask spread narrows dramatically. We believe the spread narrows because the volume surge emanates from speculative trading by investors who disagree on the price

adjustment as well as from liquidity trading by investors who react with a lag to the price changes.

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**Appendix A: Primary Government Securities Dealers**

BA Securities, Inc.  
Bear, Stearns & Co., Inc  
BT Securities Corporation  
BZW Securities Inc.  
Chase Securities Inc.  
CIBC Wood Gundy Securities Corp.  
Citicorp Securities, Inc.  
Credit Suisse First Boston Corporation  
Daiwa Securities America Inc.  
Dean Witter Reynolds Inc.  
Deutsche Morgan Grenfell/C.J. Lawrence Inc.  
Dillon, Read & Co. Inc.  
Donaldson, Lufkin & Jenrette Securities Corporation  
Dresdner Kleinwort Benson North America LLC  
Eastbridge Capital Inc.  
First Chicago Capital Markets, Inc.  
Fuji Securities Inc.  
Goldman, Sachs & Co.  
Greenwich Capital Markets, Inc.  
HSBC Securities, Inc.  
Aubrey G. Lanston & Co., Inc.  
Lehman Brothers Inc.  
Merrill Lynch Government Securities Inc.  
J.P. Morgan Securities, Inc.  
Morgan Stanley & Co. Incorporated  
NationsBanc Capital Markets, Inc.  
Nesbitt Burns Securities Inc.  
The Nikko Securities Co. International, Inc.  
Nomura Securities International, Inc.  
Paine Webber Incorporated  
Paribas Corporation  
Prudential Securities Incorporated  
Salomon Brothers Inc.  
Sanwa Securities (USA) Co., L.P.  
SBC Warburg Inc.  
Smith Barney Inc.  
UBS Securities LLC  
Yamaichi International (America), Inc.  
Zions First National Bank

Source: Federal Reserve Bank of New York (1997).

## Appendix B: Data Cleaning and Processing

GovPX distributes its information through on-line vendors by sending out a digital ticker feed. Daily backup copies of the feed are used in this study. The data provide a precise history of the tick-by-tick trading information sent to GovPX subscribers. Any posting errors made by the interdealer brokers that are not filtered out by GovPX are of course included in the backup files. Additionally, since the purpose of the digital feed is to refresh vendors' screens, the data must be processed before it can be effectively analyzed.

### *Trades*

When a trade occurs two pieces of information are typically transmitted by GovPX. First, during the "work-up" stage when traders are jumping into a transaction, the news is posted that a bid is being "hit" or that an offer is being lifted (a "take"), as are price and volume information.<sup>43</sup> Seconds later the total volume of the trade or trades is posted. Transactions through the same interdealer broker at the same price and virtually the same time are thus counted as a single trade. Occasionally GovPX posts several lines of data per trade, and sometimes there is only a single line.

The volume data is processed to ensure that each trade is counted once and only once. This is done by retaining the price and volume data from the first line reporting an increase in total daily volume for that security. This is typically the second line of data reported for any given trade since the first line usually reports only that a trade is occurring (with no trade size or increase in daily volume reported). In our year of intraday data there are a few instances where total daily volume shows a trade-to-trade *decline* for the on-the-run 5-year note. These errors are corrected based on that day's history of trades and the total daily volume reported for that security.<sup>44</sup> In our year of data we find 164,822 trades for the on-the-run 5-year note, or an average of 659 per day.

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<sup>43</sup> These work-ups have been reported by GovPX since November 16, 1993.

<sup>44</sup> For example, at 3:32 PM eastern time (ET) on September 28, 1993 GovPX reports an unprecedented trade of \$810 million. Seventy minutes later GovPX reports a decline in accumulated volume of \$807 million for that same security. The size of the trade, its subsequent reversion (as measured by accumulated volume), and the daily total volume statistic (reported in a separate file) all suggest that the original trade size reported was an error. We therefore scale down the original trade size by the size of the reversion (\$807 million).

Trade prices are then screened for errors. Trade-to-trade price changes of  $7/16$  of a point or more (roughly 10 basis points in yields) that are followed by a similarly sized movement in the opposite direction (of at least 75% of the preceding change) are dropped.<sup>45</sup> This eliminates an average of 0.3 prices per day (volumes for these trades are not dropped, however). Prices for 164,749 trades are retained for our year of data for the on-the-run 5-year note, or an average of 659 per day.

#### *Quotations*

We put bid-ask quotes through a multi-step screening procedure:

- Bid-ask spreads that are greater than  $1/2$  point are dropped.<sup>46</sup> This eliminates an average of 2 quotes per day.
- Quote-to-quote price changes of  $7/16$  of a point or more (in the bid or the offer) that are followed by a similarly sized movement in the opposite direction (of at least 75% of the preceding change) are dropped (see footnote 45 for a brief discussion). This eliminates an average of 0.4 quotes per day.
- One-sided quotes (a bid *or* an offer but not both) are occasionally posted by dealers. This study makes no use of these bids (an average of 22 per day) or offers (an average of 18 per day).

As spreads posted by the interdealer brokers do not include the brokerage fee charged to the transaction initiator, zero spreads (referred to as "locked" markets) are common and can persist for lengthy periods. Quotes calculated to be zero are therefore kept in the dataset. In addition, since GovPX posts the highest bid and the lowest offer from five brokers representing all the primary dealers, even negative spreads can be posted momentarily. An average of 21 spreads per day that are less than zero but

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<sup>45</sup> The 10 basis-point threshold, which is somewhat arbitrary, is roughly the size of the largest valid trade-to-trade price changes seen during the sample year. The requirement that the price change revert virtually eliminates the possibility that any valid prices are omitted while screening out the largest price errors from the dataset. One example of such an error occurred May 10, 1994 when the posted transaction price went from 98  $5+/32$  to 99  $5+/32$  and back to 98  $5+/32$  in successive trades (the "+" indicates a half). Our cleaning procedure drops the 99  $5+/32$  price from the dataset.

<sup>46</sup> These high spreads seem implausible in a market where the typical bid-ask spread for the on-the-run 5-year note is  $1/64$  of a point. One incidence of large spread errors occurred October 25, 1993 between 2:02 PM and 3:53 PM. The bid became stuck at a price of 99  $23/32$  for a series of 127 quotes, during which time the offer price was declining, leading to a long series of spreads that appeared to be negative.

greater than  $-5/100$  are therefore retained.<sup>47</sup> Our cleaned dataset contains 547,185 quotes from the sample period for the on-the-run 5-year note, or an average of 2,189 per day.

#### *Times*

GovPX's digital ticker feed contains a minute-by-minute time stamp. The stamps typically appear 60 seconds apart within a day, but the exact timing of the stamp varies across the days. One day may have time stamps of 8:28:40, 8:29:40, 8:30:40, etc. while another day has time stamps of 8:28:53, 8:29:53, 8:30:53, etc. In our analysis each interval is assumed to start at the beginning of the new minute that starts in that interval. Our 8:30-35 interval therefore refers to the five minute period starting between 8:29 and 8:30 and ending five minutes later between 8:34 and 8:35, while our 8:30-31 interval refers to the one-minute period starting between 8:29 and 8:30 and ending between 8:30 and 8:31.

Missing time stamps on a few of our sample days indicate times when we are missing data. The most serious case of missing data in our sample is December 10, 1993 when our daily file ends at 12:10 PM (ET) instead of 6:00 PM. Most of our periods of missing data occur outside of New York trading hours (7:30 AM - 5:00 PM), however, and none appear within even a few hours of one of our announcements.

#### *Time Intervals*

For tractability purposes our data is consolidated and analyzed at the five-minute or one-minute interval. While the on-the-run 5-year note is the most actively traded Treasury security, we are nevertheless missing some bid-ask spread and price volatility observations.<sup>48</sup> Specifically, the bid-ask spread is defined for 98.2% of the five-minute trading intervals in our sample.<sup>49</sup> As our definition of price volatility is based on the change in price between successive intervals, this variable is defined for a slightly lower 96.9% of five-minute trading intervals. Not surprisingly, most of our missing

<sup>47</sup> Offers in the dataset are quoted off of the bids (for example, a quote of 99.17 / 18 represents a bid of 99 17/32 and implies an offer of 99 18/32). One consequence of this quoting system is that small negative spreads (for example,  $-1/64$  of a point) are indistinguishable from large positive spreads ( $63/64$  of a point). Since small negative spreads are far more plausible in this market, however, the data is processed in a manner that assumes that the spreads can be slightly negative.

<sup>48</sup> There are no missing observations for trading volume as it is defined to be zero when there are no transactions in an interval.

<sup>49</sup> We count trading intervals as the number of five-minute intervals between 7:30 AM (ET) and the market close for our 250 day sample. The market close is defined as the time of the last bid-ask quotation (for the on-the-run 5-year note) for days when the market closed early and 5:00 PM otherwise.

observations are either early in the morning (7:30 - 8:00 AM) or late in the afternoon (4:00 PM - 5:00 PM) when trading activity is light.<sup>50</sup> Looking at the one-minute interval, we have bid-ask spread (price volatility) observations for 94.2% (89.4%) of the trading intervals on which we focus our one-minute analysis (8:25 - 8:37 AM).

#### *Holidays*

We exclude 10 days from our sample when the Treasury market was closed. The market was closed on nine of these days in recognition of a holiday and on one day (April 27, 1994) for the funeral of President Nixon.<sup>51</sup> We retain one day in our sample, April 1, 1994 (Good Friday), when the Public Securities Association (an industry trade group) recommended that the bond market stay closed. The release of the March employment report that day resulted in significant morning trading volume. We also retain several days in our sample when the market closed early (e.g., 2:00 PM), typically before a holiday.

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<sup>50</sup> In the one hour period (8:20 AM - 9:20 AM) around the important 8:30 AM announcements, we have bid-ask spread (price volatility) observations for 99.97% (99.77%) of the trading intervals.

<sup>51</sup> GovPX recorded at least some overseas trading on five of these days and on two of the days some light trading occurred during morning trading hours in New York.

Table I

## Macroeconomic Announcements

Announcement time, title, and reporting entities for eighteen monthly macroeconomic announcements and one weekly (initial jobless claims) macroeconomic announcement. All times are eastern time (ET).

Time	Short Title	Full Title	Reporting Entity
8:30 A.M.	Consumer Price Index (CPI)	Consumer Price Index	Bureau of Labor Statistics
8:30 A.M.	Durable Goods Orders	Advance Report on Durable Goods Manufacturers' Shipments and Orders	Bureau of the Census
8:30 A.M.	Employment	The Employment Situation	Bureau of Labor Statistics
8:30 A.M.	Gross Domestic Product (GDP)	Gross Domestic Product	Bureau of Economic Analysis
8:30 A.M.	Housing Starts	Housing Starts and Building Permits	Bureau of the Census
8:30 A.M.	Initial Jobless Claims	Initial Jobless Claims	Bureau of Labor Statistics
8:30 A.M.	Leading Indicators	Composite Indexes of Leading, Coincident, and Lagging Indicators	Bureau of Economic Analysis
8:30 A.M. <sup>a</sup>	Personal Income	Personal Income and Outlays	Bureau of Economic Analysis
8:30 A.M.	Producer Price Index (PPI)	Producer Price Indexes	Bureau of Labor Statistics
8:30 A.M.	Retail Sales	Advance Retail Sales	Bureau of the Census
8:30 A.M.	Trade Balance <sup>b</sup>	U.S. International Trade in Goods and Services	Bureau of the Census, Bureau of Economic Analysis
9:15 A.M.	Industrial Production and Capacity Utilization	Industrial Production and Capacity Utilization	Federal Reserve Board
10:00 A.M.	Business Inventories	Manufacturing and Trade: Inventories and Sales	Bureau of the Census
10:00 A.M.	Consumer Confidence	Consumer Confidence Index	Conference Board
10:00 A.M.	Construction Spending	Value of New Construction Put in Place	Bureau of the Census
10:00 A.M.	Factory Inventories	Manufacturers' Shipments, Inventories, and Orders	Bureau of the Census
10:00 A.M.	NAPM Survey	National Association of Purchasing Management Index	National Association of Purchasing Management
10:00 A.M.	New Single-Family Home Sales	New One-Family Houses Sold and For Sale	Bureau of the Census
2:00 P.M.	Federal Budget	Treasury Statement (The Monthly "Budget")	Department of the Treasury

<sup>a</sup> Personal income was reported at 10:00 A.M. for the first three announcements in the period of analysis and at 8:30 A.M. thereafter.

<sup>b</sup> This report replaced the Census Bureau's Report of U.S. Merchandise Trade in March 1994.

Table II

**The Impact of Announcements on Price Volatility, Trading Volume, and Bid-Ask Spreads for the Five-Year Treasury Note**

Regressions of price volatility, trading volume, and bid-ask spread on announcement day dummy variables for the five-year treasury note.\* Results are presented for four five-minute intervals (Panels A, B, C, and D) corresponding to the four sets of announcement times from Table I. For price volatility and the bid-ask spread the five-minute period immediately following the announcements is presented (e.g., 8:30-8:35 for the 8:30 A.M. announcements), while for trading volume the succeeding five-minute period is presented (e.g., 8:35-8:40 for the 8:30 A.M. announcements). The Panel B, C, and D regressions were run including dummy variables for announcements that are reported earlier in the day, although these coefficients are excluded from the table. One and two asterisks indicate significance at the .05 and .01 levels, respectively, determined using heteroskedasticity consistent (White) standard errors. The period of analysis is August 23, 1993 - August 19, 1994.

	Price Volatility			Trading Volume			Bid-Ask Spread		
	Regression Coefficient	P-Value		Regression Coefficient	P-Value		Regression Coefficient	P-Value	
Intercept	0.227**	0.001		7.677**	0.001		1.602**	0.001	
Consumer Price Index	0.682**	0.003		4.433*	0.034		1.372**	0.001	
Durable Goods Order	0.139	0.284		0.013	0.996		0.762*	0.044	
Employment	2.624**	0.001		18.249**	0.001		3.417**	0.001	
Gross Domestic Product	0.717	0.063		4.110	0.062		0.756*	0.014	
Housing Starts	0.137	0.281		3.438	0.074		0.594*	0.029	
Initial Jobless Claims	0.113	0.187		3.048**	0.010		0.269	0.061	
Leading Indicators	-0.322	0.268		-0.176	0.937		0.329	0.179	
Personal Income	0.188	0.357		-1.777	0.616		0.701*	0.023	
Producer Price Index	1.365**	0.001		7.783**	0.003		1.215**	0.005	
Retail Sales	0.680*	0.034		6.548	0.060		0.580	0.206	
Trade Balance <sup>b</sup>	0.143	0.130		1.756	0.326		0.709*	0.046	
Adjusted R <sup>2</sup>		0.476			0.305			0.484	

Panel A: 8:30 A.M. Announcements



Table II - Continued

	Panel B: 9:15 A.M. Announcements					
Intercept	0.152**	0.001	6.024**	0.001	1.389**	0.001
Industrial Production and Capacity Utilization	0.357**	0.003	4.835**	0.006	0.649**	0.001
Adjusted R <sup>2</sup>	0.215		0.169			0.103
	Panel C: 10:00 A.M. Announcements					
Intercept	0.166**	0.001	6.006**	0.001	1.279**	0.001
Business Inventories	0.073	0.467	3.567*	0.049	0.343	0.088
Construction Spending-NAPM Survey <sup>c</sup>	0.638**	0.001	8.214**	0.001	0.353*	0.050
Consumer Confidence	0.331*	0.014	4.015*	0.018	0.273	0.194
Factory Inventories	0.044	0.686	4.184*	0.044	0.204	0.348
New Single-Family Home Sales	0.308	0.138	6.063*	0.016	0.690*	0.033
Personal Income	-0.167	0.338	6.359**	0.001	-0.269	0.305
Adjusted R <sup>2</sup>	0.180		0.191			0.137
	Panel D: 2:00 P.M. Announcements					
Intercept	0.188**	0.001	4.586**	0.001	1.478**	0.001
Federal Budget	-0.016	0.763	-0.844	0.422	0.282	0.149
Adjusted R <sup>2</sup>	-0.022		0.020			0.012

\* Price volatility is defined as the absolute value of the log price change times 10<sup>3</sup>. Trading volume is reported in tens of millions of U.S. dollars. The bid-ask spread equals the actual bid-ask spread times 10<sup>4</sup>.

<sup>b</sup> The U.S. International Trade in Goods and Services report and the report it replaced in March 1994 (Report of U.S. Merchandise Trade) are combined into a single dummy variable.

<sup>c</sup> Construction spending and NAPM Survey are combined into a single dummy variable since they were released at the same time ten of twelve times in the sample. The dummy variable is set equal to one for days when both reports were released, 1/2 for days when only one report was released, and zero otherwise.

Table III

**Dynamics of Price Volatility, Trading Volume, and Bid-Ask Spread by One-Minute Intervals**

One-minute log price change standard deviation, trading volume mean, and bid-ask spread mean are reported and compared for announcement (major 8:30 A.M.) and nonannouncement days for the five-year treasury note.<sup>a</sup> All one-minute intervals between 8:25 and 8:37 A.M. are reported. One and two asterisks denote significance at the .05 and .01 levels, respectively. The period of analysis is August 23, 1993 - August 19, 1994.

	8:25-8:26	8:26-8:27	8:27-8:28	8:28-8:29	8:29-8:30	8:30-8:31	8:31-8:32	8:32-8:33	8:33-8:34	8:34-8:35	8:35-8:36	8:36-8:37
Panel A: Price Volatility												
Announcement day <sup>b</sup>	0.116	0.141	0.111	0.139	0.390	1.615	1.587	0.562	0.363	0.265	0.274	0.312
Nonannouncement day <sup>c</sup>	0.108	0.118	0.088	0.110	0.102	0.119	0.126	0.087	0.103	0.119	0.101	0.098
Standard Deviation Ratio	1.070	1.197	1.257	1.261	3.836**	13.592**	12.621**	6.449**	3.531**	2.238**	2.707**	3.185**
F-ratio p-value <sup>d</sup>	0.636	0.656	0.656	0.236	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Panel B: Trading Volume												
Announcement day	1.387	1.053	1.233	1.323	0.767	1.197	0.943	3.370	4.030	5.553	3.950	5.303
Nonannouncement day	1.324	1.191	1.623	1.354	1.090	1.348	1.566	1.305	1.464	1.147	1.232	1.368
Difference in Means	0.063	-0.137	-0.390	-0.031	-0.323	-0.152	-0.622*	2.065**	2.566**	4.406**	2.718**	3.936**
t-statistic p-value <sup>e</sup>	0.887	0.636	0.232	0.923	0.078	0.757	0.031	0.002	0.001	0.001	0.001	0.001
Panel C: Bid-Ask Spread												
Announcement day	1.995	1.760	1.853	2.108	2.608	8.982	6.323	2.838	1.836	1.754	1.552	1.643
Nonannouncement day	1.614	1.579	1.612	1.476	1.449	1.505	1.455	1.321	1.488	1.558	1.532	1.559
Difference in Means	0.381	0.181	0.241	0.632**	1.159**	7.476**	4.868**	1.517**	0.347	0.196	0.020	0.083
t-statistic p-value	0.175	0.437	0.170	0.002	0.007	0.001	0.001	0.002	0.243	0.556	0.926	0.721

<sup>a</sup> The reported log price change standard deviation is the actual standard deviation times  $10^3$ . Trading volume is reported in tens of millions of U.S. dollars. The reported bid-ask spread is the actual spread times  $10^4$ .

<sup>b</sup> Announcement days are defined as days with at least one of the following announcements: Consumer Price Index, Employment, Producer Price Index. These are the 8:30 A.M. announcements significant at the .01 level in at least two models of Table II. Excluded are days in which there are any of our 9:15 A.M. or 10:00 A.M. announcements.

<sup>c</sup> Nonannouncement days are defined as days in which none of our eighteen morning announcements occur.

<sup>d</sup> P-value from Brown-Forsythe-modified Levene F-statistic comparing variances for announcement and nonannouncement days.

<sup>e</sup> P-value from t-statistic comparing means for announcement and nonannouncement days assuming unequal variances.

Table IV

**Dynamics of Price Volatility, Trading Volume, and Bid-Ask Spread by Five-Minute Intervals**

Five-minute log price change standard deviation, trading volume mean, and bid-ask spread mean are reported and compared for announcement (major 8:30 A.M.) and nonannouncement days for the five-year treasury note.<sup>a</sup> All five-minute intervals between 8:15 and 8:45 A.M. are reported as well as intervals from every fifteen minutes between 9:00 and 10:30 A.M.. One and two asterisks denote significance at the .05 and .01 levels, respectively. The period of analysis is August 23, 1993 - August 19, 1994.

	8:15-8:20	8:20-8:25	8:25-8:30	8:30-8:35	8:35-8:40	8:40-8:45	9:00-9:05	9:15-9:20	9:30-9:35	9:45-9:50	10:00-10:05	10:15-10:20
Panel A: Price Volatility												
Announcement day <sup>b</sup>	0.183	0.214	0.458	2.606	0.865	0.695	0.401	0.359	0.253	0.259	0.305	0.231
Nonannouncement day <sup>c</sup>	0.210	0.267	0.218	0.210	0.239	0.241	0.180	0.196	0.181	0.178	0.198	0.248
Std. Deviation Ratio	0.873	0.803	2.101*	12.390**	3.619**	2.882**	2.232**	1.831**	1.396*	1.453**	1.538	0.932
F-ratio p-value <sup>d</sup>	0.204	0.202	0.014	0.001	0.001	0.001	0.001	0.001	0.018	0.007	0.065	0.445
Panel B: Trading Volume												
Announcement day	4.850	5.920	5.763	15.093	20.410	20.177	14.553	11.480	10.127	10.133	9.500	7.470
Nonannouncement day	3.199	5.738	6.582	6.830	7.033	6.471	5.024	5.180	5.769	5.555	5.874	5.951
Difference in Means	1.651	0.182	-0.818	8.263**	13.377**	13.705**	9.529**	6.299**	4.358**	4.578**	3.626**	1.519
t-statistic p-value <sup>e</sup>	0.067	0.805	0.257	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.099
Panel C: Bid-Ask Spread												
Announcement day	1.718	1.735	2.130	3.749	1.591	1.520	1.565	1.457	1.386	1.315	1.485	1.450
Nonannouncement day	1.745	1.630	1.536	1.475	1.453	1.470	1.455	1.409	1.367	1.287	1.215	1.313
Difference in Means	-0.027	0.105	0.595**	2.274**	0.138	0.050	0.110	0.048	0.019	0.028	0.270*	0.138
t-statistic p-value	0.889	0.501	0.002	0.001	0.318	0.679	0.362	0.567	0.840	0.764	0.014	0.182

<sup>a</sup> The reported log price change standard deviation is the actual standard deviation times 10<sup>3</sup>. Trading volume is reported in tens of millions of U.S. dollars. The reported bid-ask spread is the actual spread times 10<sup>4</sup>.

<sup>b</sup> Announcement days are defined as days with at least one of the following announcements: Consumer Price Index, Employment, Producer Price Index. These are the 8:30 A.M. announcements significant at the .01 level in at least two models of Table II. Excluded are days in which there are any of our 9:15 A.M. or 10:00 A.M. announcements.

<sup>c</sup> Nonannouncement days are defined as days in which none of our eighteen morning announcements occur.

<sup>d</sup> P-value from Brown-Forsythe-modified Levene F-statistic comparing variances for announcement and nonannouncement days.

<sup>e</sup> P-value from t-statistic comparing means for announcement and nonannouncement days assuming unequal variances.

Table V  
**Correlations of Price Volatility and Trading Volume**

Correlations of price volatility (absolute value of log price change) and trading volume for the five-year treasury note. All one-minute intervals between 8:25 and 8:49 A.M. are reported. One and two asterisks denote significance at the .05 and .01 levels, respectively. The period of analysis is August 23, 1993 - August 19, 1994.

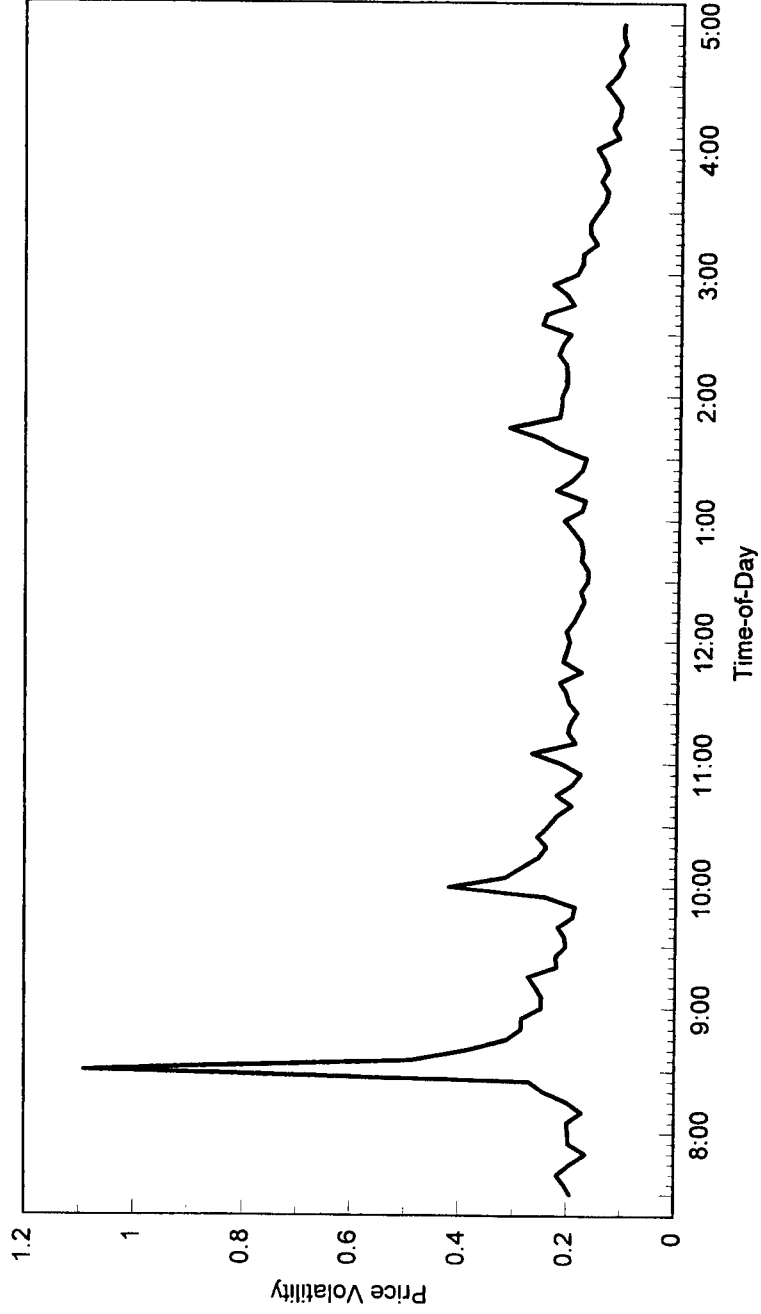
	8:25-8:26	8:26-8:27	8:27-8:28	8:28-8:29	8:29-8:30	8:30-8:31	8:31-8:32	8:32-8:33	8:33-8:34	8:34-8:35	8:35-8:36	8:36-8:37
Correlation	0.231**	0.196**	0.154*	0.274**	0.185**	0.056	-0.070	0.327**	0.141*	0.173**	0.294**	0.188**
p-value	0.001	0.004	0.023	0.001	0.007	0.411	0.291	0.001	0.031	0.009	0.001	0.005
	8:37-8:38	8:38-8:39	8:39-8:40	8:40-8:41	8:41-8:42	8:42-8:43	8:43-8:44	8:44-8:45	8:45-8:46	8:46-8:47	8:47-8:48	8:48-8:49
Correlation	0.259**	0.236**	0.281**	0.140*	0.173*	0.268**	0.255**	0.265**	0.297**	0.100	0.189**	0.136*
p-value	0.001	0.001	0.001	0.034	0.009	0.001	0.001	0.001	0.001	0.134	0.005	0.041

Table VI

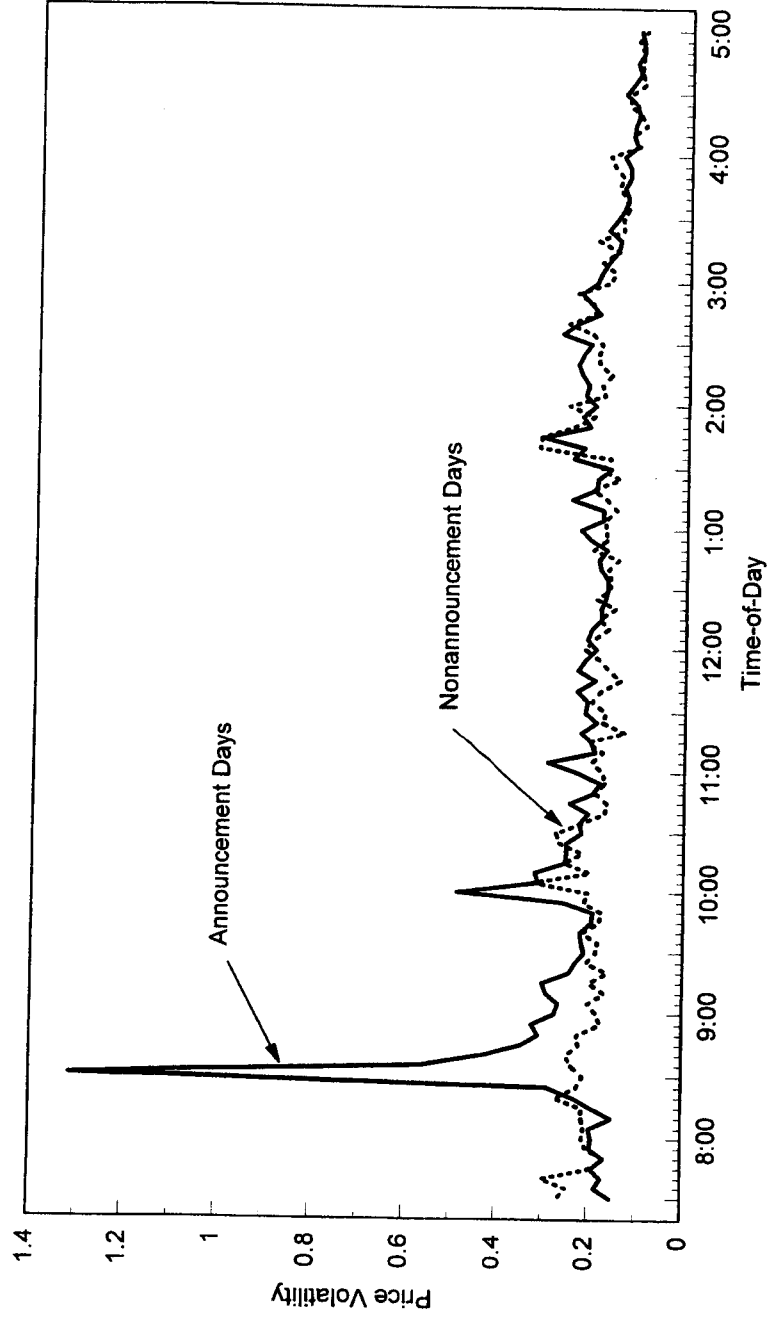
**Granger Causality Tests of Trading Volume and Price Volatility**

Results from Granger causality tests of trading volume and price volatility for the five-year treasury note. Tests are conducted for New York trading hours (7:30 A.M. - 5:00 P.M.) using six lags of both price volatility and trading volume. Variables are measured in five-minute intervals with price volatility defined as the absolute value of the log price change times  $10^3$  and trading volume measured in tens of millions of U.S. dollars. One and two asterisks denote significance at the .05 and .01 levels, respectively. The period of analysis is August 23, 1993 - August 19, 1994.

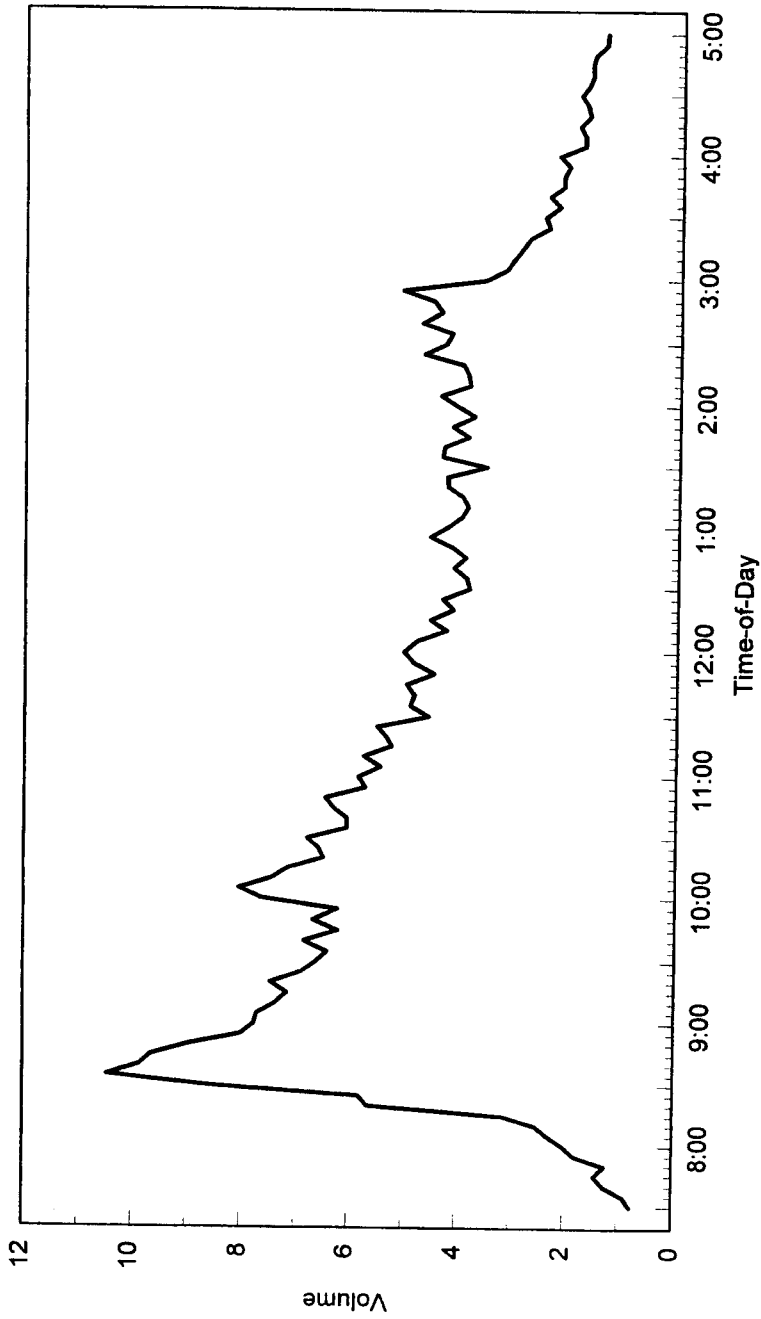
Question	Dependent variable	Lagged variables	Sum of coefficients	F-statistic	p-value
Is price volatility persistent?	price volatility	price volatility	0.473	307.956**	0.001
Is trading volume persistent?	trading volume	trading volume	0.619	852.283**	0.001
Does price volatility cause trading volume?	trading volume	price volatility	6.524	185.994**	0.001
Does trading volume cause price volatility?	price volatility	trading volume	0.003	18.347**	0.001



**Figure 1A. Intraday Price Volatility for the Five-Year Treasury Note.** Standard deviation of log price changes by five-minute interval from August 23, 1993 - August 19, 1994. The standard deviation equals the actual standard deviation times 1000 and times shown are interval start times eastern time (ET).

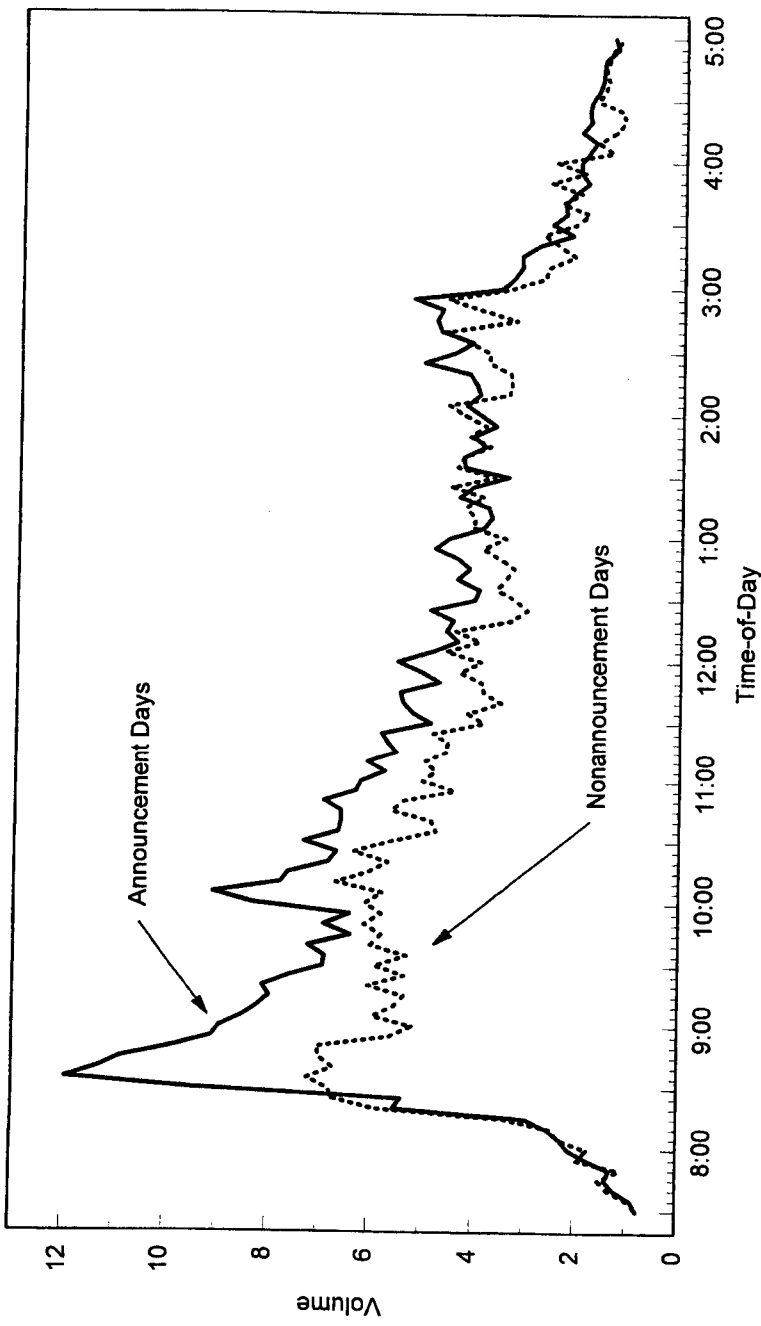


**Figure 1B. Intraday Price Volatility on Announcement and Nonannouncement Days.** Standard deviation of log price changes for the five-year treasury note for days with at least one of the nineteen announcements listed in Table I and days with none of these announcements. The standard deviation equals the actual standard deviation times 1000, the period of analysis is August 23, 1993 - August 19, 1994, and times shown are interval start times (ET).

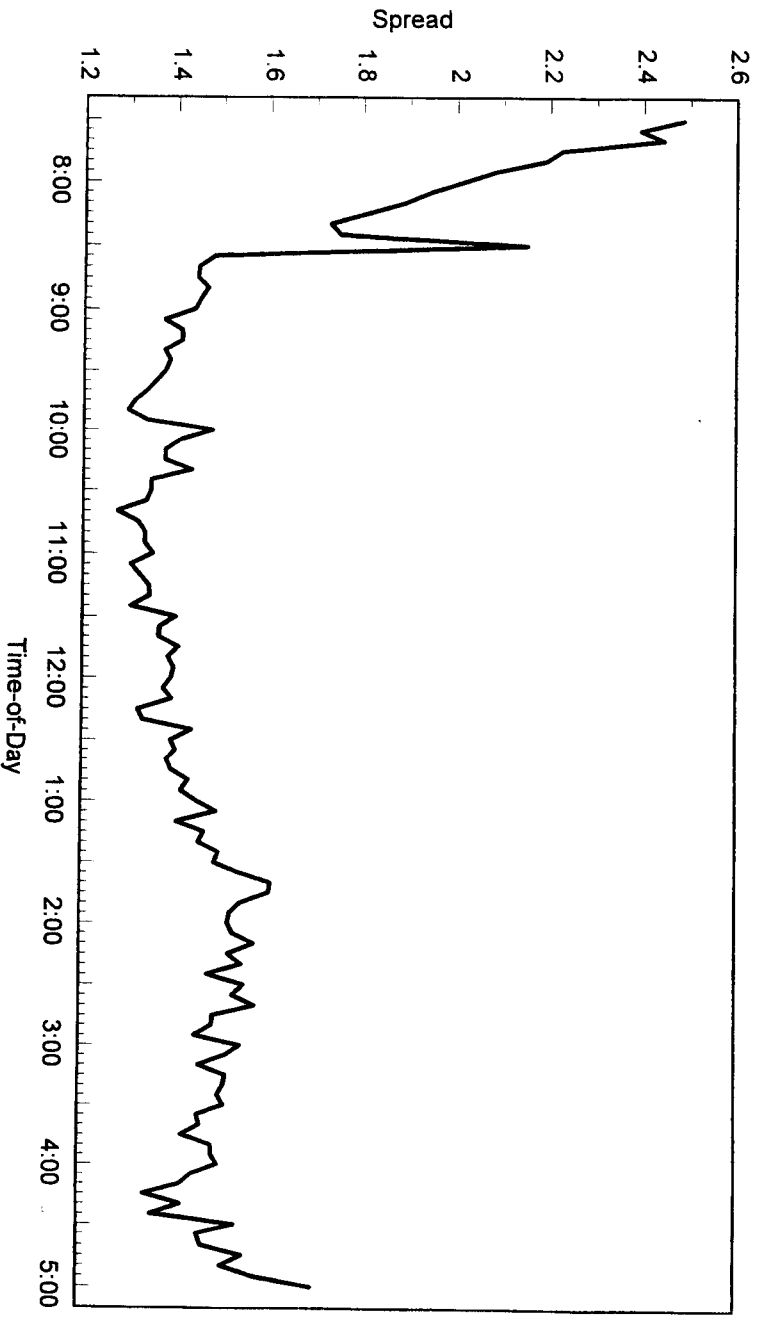


**Figure 2A. Intraday Trading Volume for the Five-Year Treasury Note.** Mean interdealer trading volume by five-minute interval from August 23, 1993 - August 19, 1994. Trading volume is reported in tens of millions of U.S. dollars and times shown are interval start times (ET).

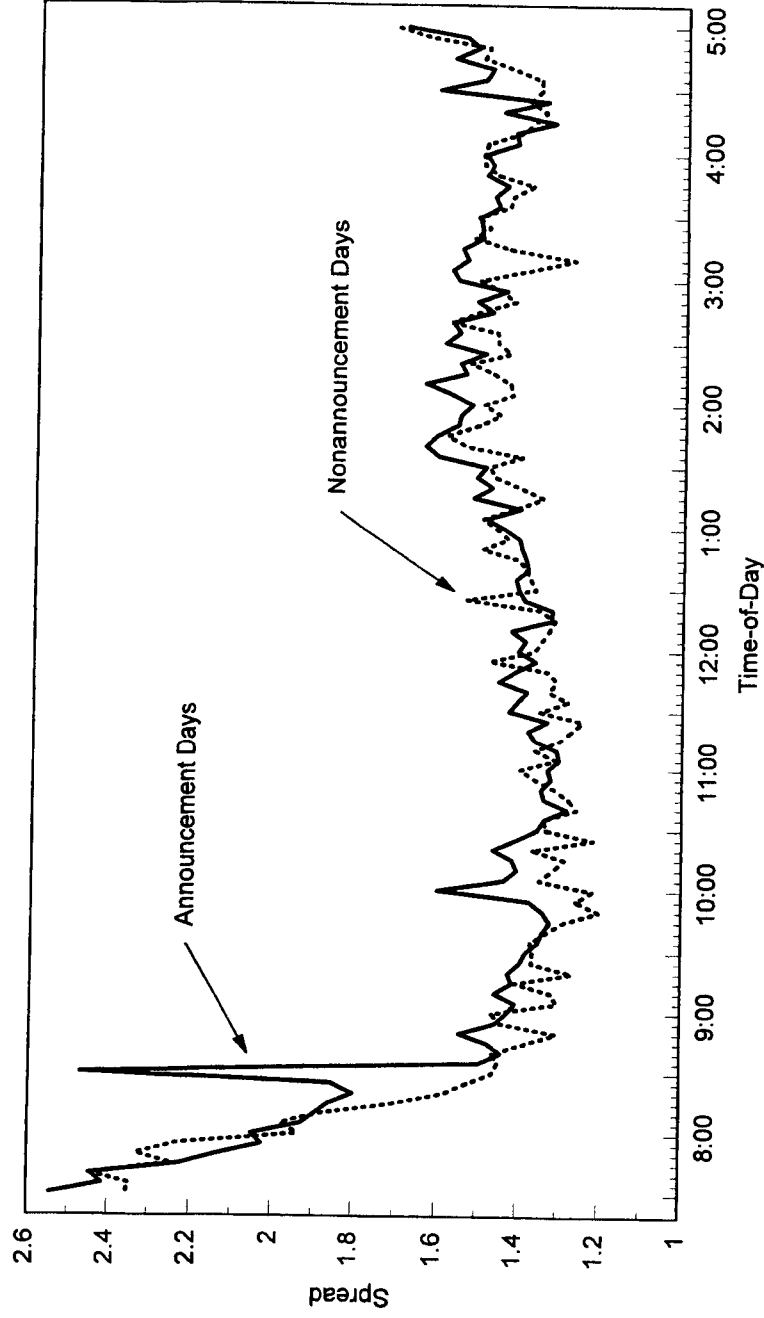




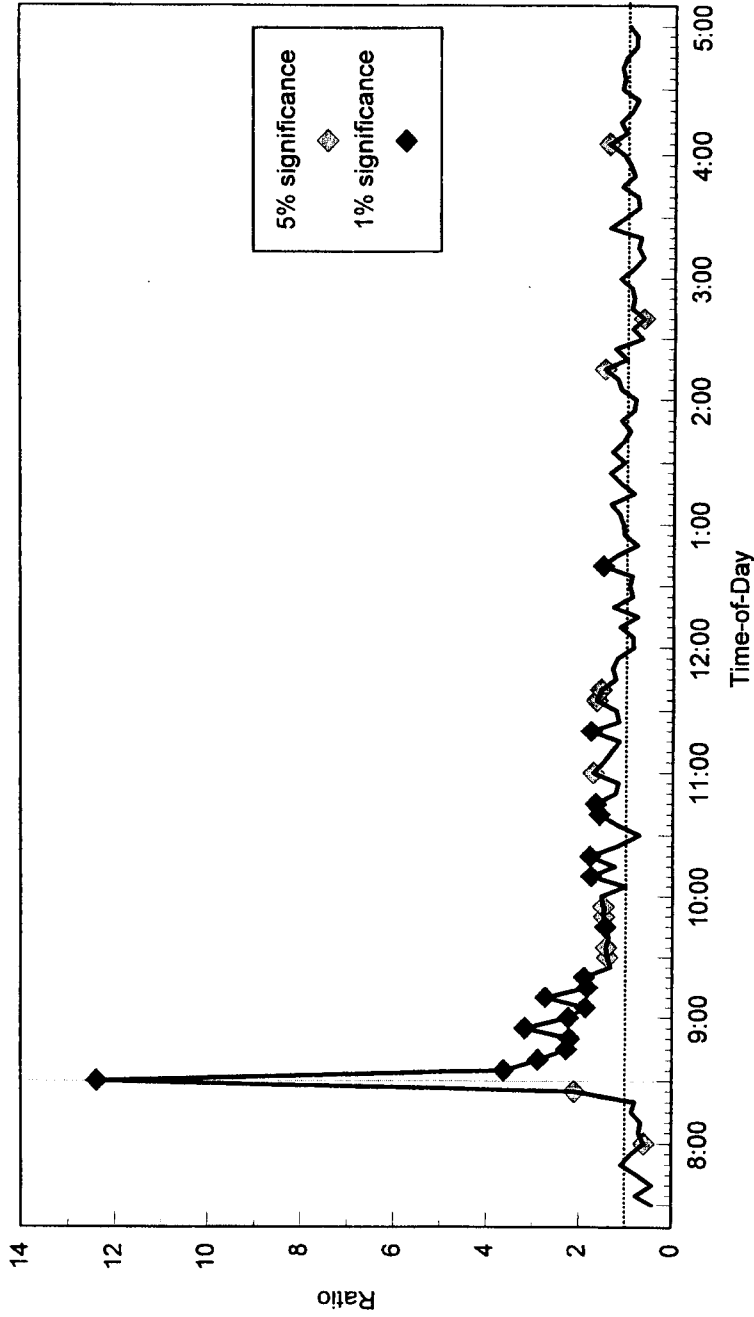
**Figure 2B. Intraday Trading Volume on Announcement and Nonannouncement Days.** Mean interdealer trading volume for the five-year treasury note for days with at least one of the nineteen announcements listed in Table I and days with none of these announcements. Trading volume is reported in tens of millions of U.S. dollars, the period of analysis is August 23, 1993 - August 19, 1994, and times shown are interval start times (ET).



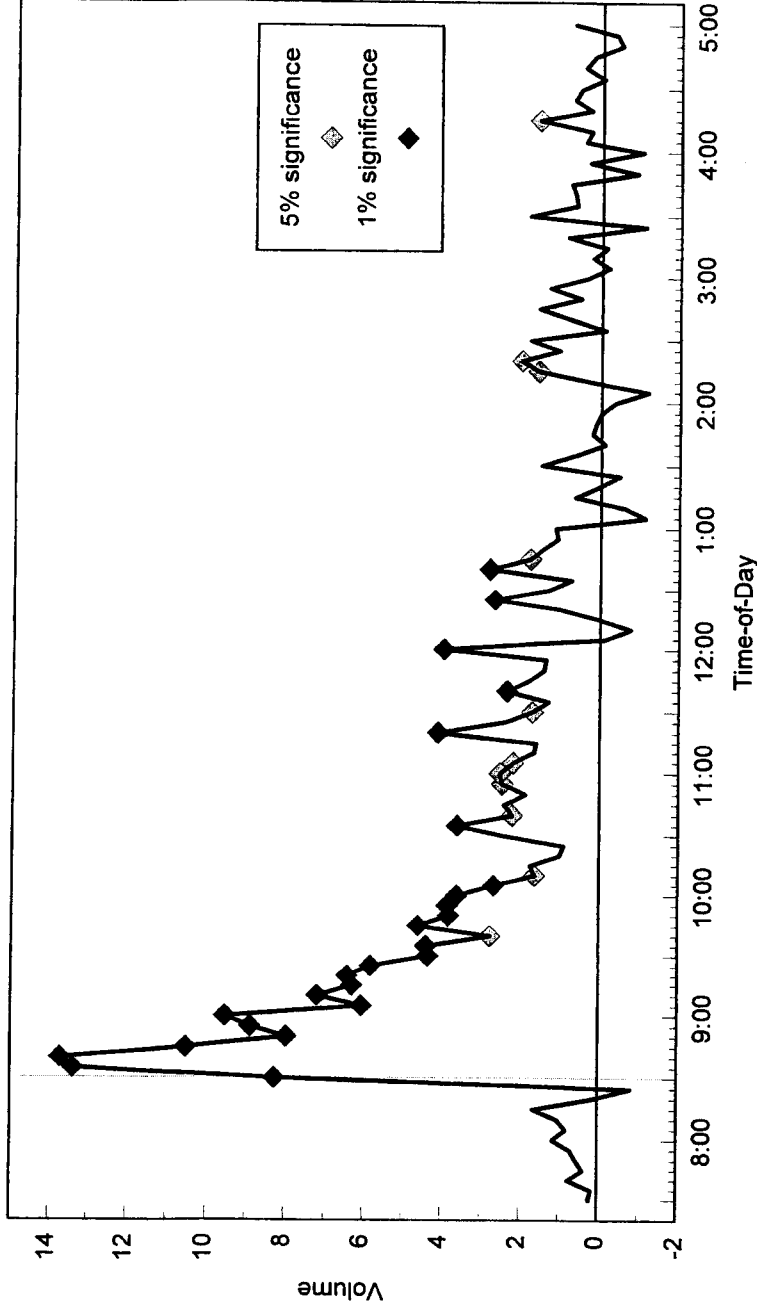
**Figure 3A. Intraday Bid-Ask Spread for the Five-Year Treasury Note.** Mean interdealer bid-ask spread by five-minute interval from August 23, 1993 - August 19, 1994. The spread is measured in hundredths of one percent and times shown are interval start times (ET).



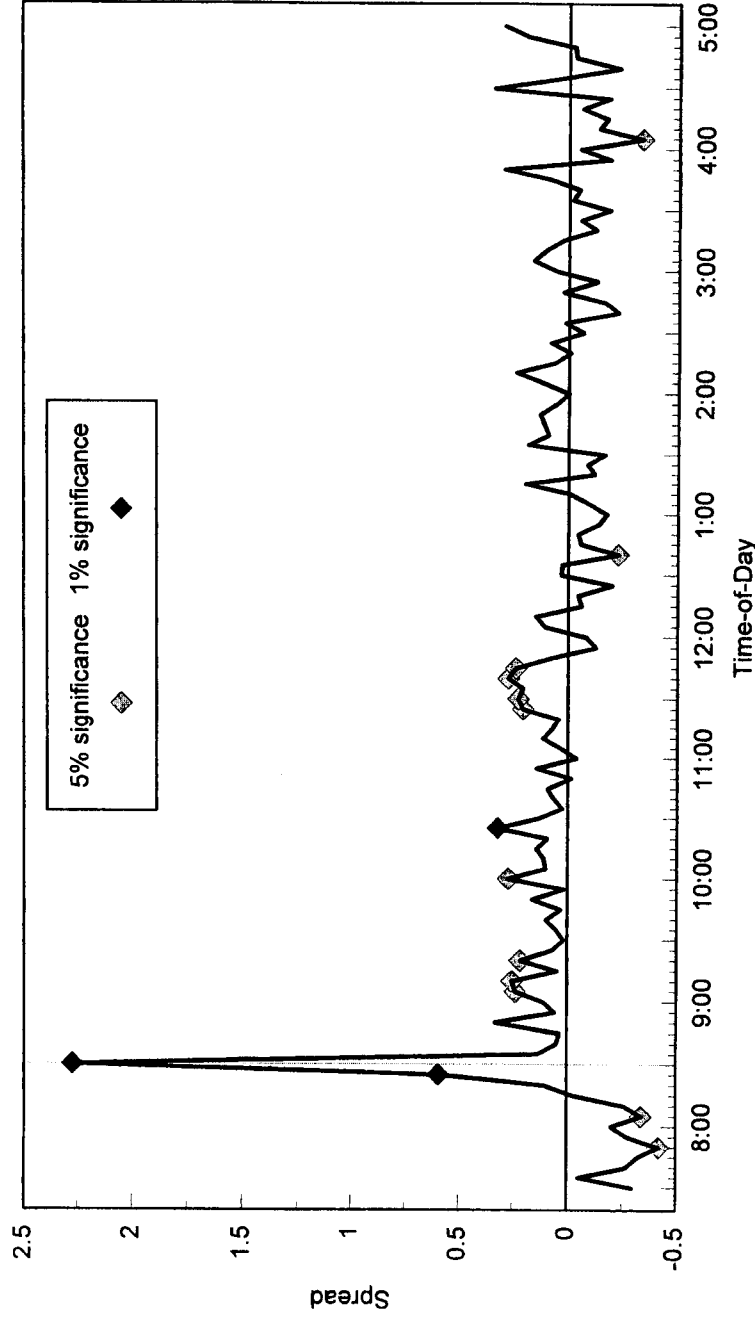
**Figure 3B. Intraday Bid-Ask Spread on Announcement and Nonannouncement Days.** Mean interdealer bid-ask spread for the five-year treasury note for days with at least one of our nineteen announcements listed in Table I and days with none of these announcements. The spread is measured in hundredths of one percent, the period of analysis is August 23, 1993 - August 19, 1994, and times shown are interval start times (ET).



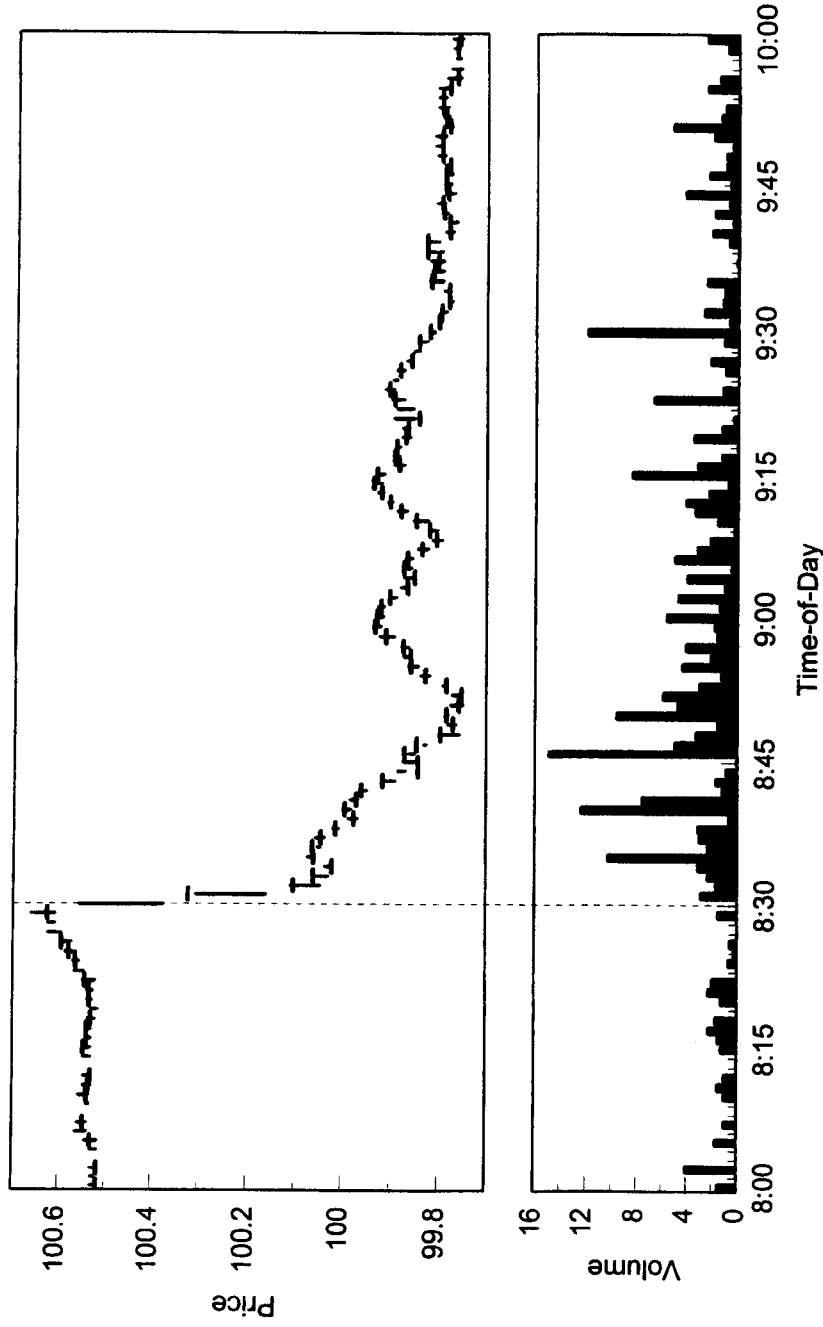
**Figure 4A. Persistence of Price Volatility After Major 8:30 AM Announcements.** Ratio of the standard deviation of log price changes on major 8:30 AM announcement days to nonannouncement days for the five-year treasury note by five-minute interval. Ratios significant at the five percent level or better are indicated by diamonds. The period of analysis is August 23, 1993 - August 19, 1994 and times shown are interval start times (ET).



**Figure 4B. Persistence of Trading Volume After Major 8:30 AM Announcements.** Difference in mean interdealer trading volume between major 8:30 AM announcement days and nonannouncement days for the five-year treasury note by five-minute interval. Differences significant at the five percent level or better are indicated by diamonds. The volume difference is reported in tens of millions of U.S. dollars, the period of analysis is August 23, 1993 - August 19, 1994, and times shown are interval start times (ET).



**Figure 4C. Persistence of Bid-Ask Spread After Major 8:30 AM Announcements.** Difference in mean interdealer bid-ask spread between major 8:30 AM announcement days and nonannouncement days for the five-year treasury note by five-minute interval. Differences significant at the five percent level or better are indicated by diamonds. The spread difference is measured in hundredths of one percent, the period of analysis is August 23, 1993 - August 19, 1994, and times shown are interval start times (ET).



**Figure 5. Market Response to August 5, 1994 Employment Report.** Mean interdealer bids, asks, and transaction prices, and interdealer trading volume for the five-year treasury note by one-minute interval between 8:00 AM and 10:00 AM on August 5, 1994. Trading volume is reported in tens of millions of U.S. dollars and times shown are interval start times (ET).