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Price Formation and Liquidity in the U.S. Treasury Market: The Response to Public Information

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ABSTRACT

The arrival of public information in the U.S. Treasury market sets off a two-stage adjustment process for prices, trading volume, and bid-ask spreads. In a brief first stage, the release of a major macroeconomic announcement induces a sharp and nearly instantaneous price change with a reduction in trading volume, demonstrating that price reactions to public information do not require trading. The spread widens dramatically at announcement, evidently driven by inventory control concerns. In a prolonged second stage, trading volume surges, price volatility persists, and spreads remain moderately wide as investors trade to reconcile residual differences in their private views.

HOW DO FINANCIAL MARKETS FORM PRICES and provide liquidity when information arrives? Efforts to address this issue have led to an extensive microstructure literature on equity markets, and to a lesser extent on the foreign exchange (FX) market. Relatively little work has focused on the U.S. Treasury market, however, in spite of its importance in its own right and the advantages it offers as an alternative testing ground for microstructure hypotheses.

One of the most striking features of the Treasury market is the extent to which price movements are driven by public information.[1] Theory (e.g., French and Roll (1986)) identifies public information as that which affects prices before anyone can trade on it. However, no study has documented this mar-

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[1] Thus, although Cutler, Poterba, and Summers (1989) find it difficult to attribute sharp daily price moves in the stock market to important news, Andersen and Bollerslev (1998) link 15 of their 25 largest five-minute deutsche mark–dollar moves to just-released economic news, and Fleming and Remolona (1997) link all of their 25 largest five-minute U.S. Treasury price changes to just-released news.

ket behavior upon the observed arrival of such information.[2] Another implication of public information is that it does not confront marketmakers with the risk of trading with better informed investors. Liquidity surrounding sharp price changes can therefore be examined when market making is presumably driven by inventory control and not asymmetric information concerns.

The Treasury market also differs from other financial markets, particularly the New York Stock Exchange (NYSE) and the American Stock Exchange (AMEX), in its organization. Nearly all secondary trading in Treasury securities occurs over-the-counter in a dealer-driven market. Unlike the stock exchanges, dealer behavior in this market is not governed by rules that limit bid-ask spreads or price changes to specified minimums or maximums, so spreads and prices can adjust endogenously. This fact, combined with the tremendous level of trading activity in the market, allows powerful statistical tests of microstructure hypotheses.

This paper examines microstructure issues in the U.S. Treasury securities market by analyzing what happens when public information arrives. We focus on information contained in scheduled macroeconomic announcements, which are released widely at precisely identifiable times. Recently available high frequency data from the interdealer market allow us to examine not only the price response to announcements, as Ederington and Lee (1993) do for interest rate futures, but also the behavior of trading volume and bid-ask spreads. In characterizing the market's full response, we uncover two distinct stages of adjustment for price formation and liquidity provision.

A brief first stage is marked by an almost archetypal response to pure public information in which the release of a major macroeconomic announcement induces a sharp and nearly instantaneous price change with a reduction in trading volume. As theory predicts, price reactions to public information do not require trading. At the time of the sharp price change, the bid-ask spread widens dramatically. The finding that it is public information that drives prices at the time of the announcement suggests that it is inventory control that drives the spread. Marketmakers evidently widen or withdraw their quotes in response to the inventory risks of sharp price changes.

In a prolonged second stage, trading volume surges and then persists along with high price volatility and moderately wide bid-ask spreads. This extension of the adjustment process seems to be driven by a residual disagreement among investors about what precisely the just-released information means for prices. The disagreement may arise from investors' differential private views including those based on dealers' knowledge of their customer order flows. The adjustment process set off by public information is therefore extended by investors' private information.

[2] Jones, Kaul, and Lipson (1994) find that stock prices can change without trading, but they do not offer direct evidence of information arrival. Mitchell and Mulherin (1994) find that public information is correlated with stock price volatility although they do not identify an absence of trading at the time of information arrival. Hopewell and Schwartz (1978) find that prices change over exogenously imposed trading halts when information arrives.

The paper is organized as follows: In Section I, we describe the U.S. Treasury market, the data used in the analysis, and the nature of the public information. In Section II, we document the two-stage adjustment process of the Treasury market to the arrival of public information and discuss its implications for price formation and liquidity provision. In Section III, we summarize our findings.

I. The U.S. Treasury Market and Public Information

A. The U.S. Treasury Market

The secondary market for U.S. Treasury securities is a multiple-dealer over-the-counter market. Trading takes place around-the-clock during the week, although 95 percent of it occurs during New York trading hours, approximately 7:30 a.m. to 5:00 p.m. (Fleming (1997)). The predominant market-makers are the 30 primary government securities dealers—those dealers with whom the Federal Reserve Bank of New York interacts directly in the course of its open market operations. For the April to August 1994 period, the dealers traded an average of $125 billion per day: $67 billion with customers and $58 billion with other dealers. The core of the U.S. Treasury market and the source of our data is the interdealer broker market, which accounts for more than 90 percent of trading among dealers.

The primary dealers behave like informed investors through their trading activity and the manner in which trades are executed. In addition to making markets—buying and selling securities for their own account at bid and ask prices quoted to customers—the dealers also take positions. The positions are highly leveraged and financed in the overnight repo market. Moreover, dealers mask their identity by trading anonymously through one of six interdealer brokers: Cantor Fitzgerald Securities, Exco USA Securities, Inc., Garban GuyButler Inc., Hilliard Farber & Co., Inc., Liberty Brokerage Inc., and Tullett & Tokyo Securities, Inc. Trading anonymity suggests that dealers possess private information that could be revealed if dealers' identity were known. Such information may relate to dealers' customer order flows, private analyses of the market, or differing investment strategies.[3]

Trading in the interdealer broker market is conducted via direct phone lines between the dealers and the brokers. The brokers provide the dealers with proprietary electronic screens that post the best bid and offer prices called in by the dealers, along with the associated quantities bid or offered (minimums are $1 million for notes and bonds and $5 million for bills). The quotes are binding until and unless they are withdrawn. The dealers execute trades by calling the brokers, who post the resulting trade price and size on

[3] As in the FX market, each dealer has sole knowledge of its own-customer order flow. Lyons (1995) notes that "to the extent this flow conveys information it is private information, which can be exploited in interdealer trading." Ito, Lyons, and Melvin (1998) demonstrate empirically the existence of private information in the FX market.

their screens. Large trades go through a "work-up" stage in which a broker mediates an increase in the trade size beyond the amount quoted. For these trades the brokers' screens first indicate that a trade is occurring and then update the trade size until the trade's completion several seconds later. In compensation for their services, the brokers charge a small fee.

In contrast to the NYSE and the AMEX, the interdealer broker market is not subject to market presence or price continuity rules that limit bid-ask spreads or price changes to specified minimums or maximums.[4] Though Treasury notes and bonds are quoted in 32nds of a point (where one point equals one percent of par), the 32nds are split into halves and quarters, allowing price delineation to 1/128 of a point. For the most actively traded five-year Treasury note, for example, posted bid-ask spreads and trade-to-trade price changes of 1/64 and 1/128 of a point are quite common. However, the absence of market presence rules means that bid-ask spreads as wide as 1/16 of a point are not uncommon. Similarly, the absence of price continuity rules means that trade-to-trade price jumps as large as 1/4 of a point occur. The fine delineation of prices, the absence of rules that limit bid-ask spreads or price changes, and the high trading activity of the Treasury market combine to allow strong statistical tests even for one-minute time intervals.

B. Treasury Market Data

Our data cover one year of trading activity 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 prices. GovPX consolidates data from five of the six interdealer brokers, accounting for approximately two-thirds of the market, and transmits the data to subscribers in real time through on-line vendors. The posted data include the best bid and offer quotes and the price and size of each trade. The quotes are firm, as they are obtained directly from the broker screens.

Our sample period is August 23, 1993 to August 19, 1994. After excluding 10 days when the market was closed, we are left with a sample of 250 trading days. We focus our analysis on the *on-the-run* five-year Treasury note. On-the-run securities are the most recently issued securities of a given maturity and account for the majority of interdealer trading volume (Fleming (1997)). The five-year note is the most actively traded on-the-run security among the brokers reporting to GovPX. During our sample period, GovPX posted a daily average of 2,189 bid-ask quotations and 659 trades for this security. A detailed appendix describing the cleaning of the data is available from the authors.

[4] Hasbrouck and Sofianos (1993) provide a good recent discussion of specialist obligations on the NYSE. They note that the market presence rule "directs the specialist to maintain a meaningful (narrow) spread at all times" while the price continuity rule "limits most successive price changes to one tick" (1/8 of a dollar for most stocks at that time).

C. The Public Information

The arrival of public information is marked in this paper by the release times of scheduled macroeconomic announcements. These announcements are particularly useful for high frequency analysis because they are released widely and virtually instantaneously at precisely identifiable times. The government statistical agencies impose "lock-up" conditions to ensure that the information is released to the public at only the scheduled times.[5] Since the release times are known in advance, the whole market anticipates each release, and no investor is able to gain advantage from having seen the numbers first.

Our analysis relies on the consumer price index, employment, and producer price index announcements. These announcements significantly impact the Treasury market as indicated in numerous studies (Fleming and Remolona (1997)) and are used in other high-frequency analyses of information arrival (e.g., Ederington and Lee (1993)). The announcements are all released monthly and on separate days at 8:30 a.m. eastern time (ET). We retain 30 announcement days from our sample year after excluding six announcement days on which there are also confounding 9:15 a.m. or 10:00 a.m. announcements. We also retain 87 nonannouncement days with no 8:30 a.m., 9:15 a.m., or 10:00 a.m. announcements whatsoever. The full set of announcements we use to identify our announcement and nonannouncement days consists of the 18 morning announcements that regularly appear in "The Week Ahead" section of *Business Week*.

II. The Two-Stage Adjustment Process

We analyze price formation and liquidity in the U.S. Treasury market by examining the response of prices, trading volume, and bid-ask spreads to macroeconomic announcements. Ederington and Lee (1993) identify a price volatility spike in interest rate futures markets at the time of announcement followed by higher than normal volatility for several hours. Since their analysis is limited to price behavior, they do not address liquidity and can only speculate on the causes of the volatility pattern. Locke (1996) finds a significant increase in marketmaker activity in the first and several subsequent 15-minute intervals after announcement for a variety of futures markets.[6] Balduzzi, Elton, and Green (1997) examine cash market data on

[5] At the Bureau of Labor Statistics, for example, reporters enter a lock-up room at least 30 minutes before an 8:30 a.m. announcement. At 8:00 a.m., they receive the report and begin typing their stories into their computers. The computers have modems, but the phone lines remain dead. At 8:29 a.m., the reporters press their "reconnect" buttons and wait for a 10-second countdown. At precisely 8:30 a.m., the phone lines are turned on and the reporters are able to transmit their stories.

[6] Analysis of trading activity in the futures markets at frequencies higher than 15 minutes is problematic because of the way transaction times are imputed. Trade reconstruction data from the Chicago exchanges include an "imputed" time to the minute, but the imputation algorithm places an inordinate number of trades at the start of 15-minute brackets, creating volume spikes at each bracket's onset (we thank Peter Locke of the Commodities Futures Trading Commission for clarifying this issue).

prices, trading volume, and bid-ask spreads, but they limit their analysis of trading activity to five-minute intervals. If the initial market impact of public information is nearly instantaneous, however, then characterizing this impact requires a higher frequency analysis. In this paper, we use cash market data to analyze the interaction of prices, trading volume, and spreads at appropriately high frequencies. We are thus able to uncover two distinct stages of adjustment in the market's response.

A. The First Stage: The Immediate Impact of Public Information

We characterize the immediate impact of macroeconomic announcements through a minute-by-minute examination of market behavior. Panel A of Table I presents price volatility for every one-minute interval from 8:25 to 8:37 a.m., and includes the standard deviation for announcement and nonannouncement days, as well as the ratio between the two.[7] Price volatility is based on the change in log prices, with the price defined as the midpoint of the last bid and ask quotes posted during an interval.[8] Panels B and C of Table I present trading volume and bid-ask spread means, respectively, along with the differences between the two groups. Trading volume is measured as the face value of notes traded and the bid-ask spread as the mean proportional spread.

We find that the release of a major macroeconomic announcement induces a sharp and nearly instantaneous price change, a lull in trading volume, and a dramatic widening in the bid-ask spread. As shown in Panel A of Table I, price volatility starts to rise in the minute before the announcement. Volatility then spikes up in the next two minutes, reflecting the market's initial reaction to the announcement. At its peak, volatility is more than 13 times the volatility of nonannouncement days for the same interval. Trading volume tends to be less than normal during the same two minutes, as shown in Panel B, with a statistically significant difference in the 8:31–8:32 a.m. interval. Trading volume does surge after the announcement, but not until the third minute after the release.[9] As shown in Panel C, the spread starts to widen before the announcement. The most illiquid time then coincides with the volatility spike in the minute of the announcement, when the bid-ask

[7] The GovPX ticker feed records the time every 60 seconds. The time is not typically stamped at the start of a minute, however, but between minutes. We round the times forward so that a time stamp of 8:24:40 a.m., for example, is coded as 8:25 a.m.

[8] We also have data on transaction prices, but using bid-ask midpoints mitigates complications associated with the "bid-ask bounce" and provides more observations. The first-, second-, and third-order one-minute autocorrelations using bid-ask midpoints are 0.073, −0.001, and −0.020, respectively. The corresponding autocorrelations using transaction prices are 0.035, 0.000, and −0.021.

[9] As noted earlier (Section I.A), large trades typically go through a "work-up" stage in which a broker mediates an increase in the trade size beyond the amount quoted. Our data lack the interim stages of such trades, recording trade volume only when a trade is completed. This several-seconds volume delay does not account for our result. We conduct the same minute-by-minute analysis using actual transaction prices pulled from the same line of the GovPX ticker feed as volume, and therefore transmitted at *exactly* the same time as volume. We still find that price volatility spikes to its peak before trading volume starts to surge.

Table I

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

One-minute log price change standard deviations, trading volume means, and bid-ask spread means are reported and compared for announcement and nonannouncement days for the five-year U.S. Treasury note. 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, and the reported bid-ask spread is the actual mean proportional spread times 10^4. Announcement days are defined as those with a consumer price index, employment, or producer price index announcement but no 9:15 a.m. or 10:00 a.m. announcements. Nonannouncement days are those with no 8:30 a.m., 9:15 a.m., or 10:00 a.m. announcements. We report *p*-values from the Brown-Forsythe-modified Levene *F*-statistic comparing variances for announcement and nonannouncement days and *p*-values from the *t*-statistic comparing means for announcement and nonannouncement days assuming unequal variances. All one-minute intervals between 8:25 and 8:37 a.m. are examined. The period of analysis is August 23, 1993 to 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	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	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	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	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

* and ** indicate significance at the 0.05 and 0.01 levels, respectively.

spread is nearly six times wider than its average on nonannouncement days. Two minutes after the announcement the spread narrows sharply as price volatility falls and trading volume surges.

This brief first stage in which the market reprices with little trading activity demonstrates an almost archetypal response to pure public information. French and Roll (1986) state that public information "affects prices before anyone can trade on it." We not only find information affecting prices with little trading activity, but we find this market reaction only in the two minutes after the announcement, consistent with the near-instantaneous response predicted by theory.[10] Although equity market studies have shown that prices can change without trading (e.g., Jones, Kaul, and Lipson (1994)), we offer evidence of such a response at the very time that we observe the arrival of public information. It may be that private information plays a role in Treasury market price formation, but the behavior of prices and trading volume implies that such information plays a relatively minor role during the initial price adjustment.

The wide bid-ask spread and low trading volume at announcement reflect dealer reluctance to make markets at a time of sharp price changes. The spread's behavior is consistent with the inventory-control models of Amihud and Mendelson (1980), Ho and Stoll (1983), and O'Hara and Oldfield (1986), which emphasize the increased risk to marketmakers of high price volatility and low trading volume. In the Treasury market, the effort to control inventory risk at a time of extreme price volatility evidently causes some dealers to widen their quotes and others to withdraw quotes entirely.[11] At the same time, the wide spread and the price volatility inhibit dealers from taking new positions, keeping trading volume momentarily low.

In contrast to the pronounced widening of the bid-ask spread we find in the Treasury market, the strongest announcement effect on the spread we are aware of for equity markets is an 18.6 percent widening in the half-hour interval around earnings announcements (Lee, Mucklow, and Ready (1993)). Krinsky and Lee (1996) attribute this widening in stock market spreads to the effect of asymmetric information, with inventory control having the *opposite* effect. In one hypothesis, they suggest that marketmakers widen the spread to reflect the probability of facing informed traders with "advance knowledge of the earnings." Unlike earnings announcements, advance information about macroeconomic announcements is improbable given the "lock-up" conditions imposed by the government agencies.

Why do we find such a striking response to announcements in the Treasury market? In addition to being a market in which announcements exert rather strong effects, the market is one where marketmakers are not subject

[10] Moreover, an analysis of one-minute signed price changes reveals no significant autocorrelation after announcement. Ederington and Lee (1993) similarly find no return autocorrelation beyond the first minute in interest rate futures markets.

[11] Since the quotes we observe are a consolidation of the best ones, the withdrawal of quotes by individual dealers tends to widen the observed market spread. In practice, dealers routinely withdraw their quotes just before major announcements so that broker screens "go blank." Dealers find the commitment to fix quotes, even momentarily, to be excessively risky when prices are adjusting sharply.

to rules that deter large trade-to-trade price changes or wide bid-ask spreads and where prices and spreads can therefore adjust endogenously. In contrast, NYSE and AMEX specialists are subject to such price continuity and market presence rules (Hasbrouck and Sofianos (1993)). Hasbrouck (1991) notes that price continuity rules can blur the distinction between public and private information, and Jang and Venkatesh (1991) argue that minimum tick rules may explain why NYSE quote revisions do not conform to theoretical predictions. Note that the NYSE does afford an analogous adjustment to major new information—albeit an exogenously imposed one—by permitting a formal trading halt at the request of a specialist with an order imbalance or of a listed firm with an important announcement. Stock prices can and do jump over such halts (Hopewell and Schwartz (1978)).

B. The Second Stage: The Subsequent Adjustment Process

To analyze the subsequent adjustment to macroeconomic announcements, we also examine market behavior at five-minute intervals. Table II compares announcement and nonannouncement days for every five-minute interval from 8:15 to 8:45 a.m. and every third five-minute interval from 9:00 to 10:20 a.m., following the same format as Table I. Figure 1 compares announcement and nonannouncement days for every five-minute interval across the trading day, indicating the instances where the differences are significant. Since Fleming and Remolona (1997) document a significant market impact from announcements of federal funds target rates and U.S. Treasury coupon security auction results, the figures exclude the observations for the days of these announcements starting one-half hour before their release. The price volatility standard deviations are presented in Panel A, the trading volume means in Panel B, and the bid-ask spread means in Panel C.

We find that the sharp initial price change is followed by a surge in trading volume that persists along with high price volatility and moderately wide bid-ask spreads. As shown in Panel B of Table I, it takes about two minutes for volume to start to pick up after an announcement, by which time price volatility has already come down to one-third of its peak level. Between four and seven minutes after the announcement, volume surges to its highest levels when it averages about four times its average for nonannouncement days. Panels A of Table II and Figure 1 indicate that price volatility remains significantly higher than normal for at least an hour after the announcement, with intervals of significantly higher volatility common until noon. Panels B of Table II and Figure 1 show that trading volume remains significantly elevated for about 90 minutes, with intervals of significantly higher volume common until 1:00 p.m. Panel C of Table II and Panel C of Figure 1 show that bid-ask spreads tend to be wider than usual until noon, although significantly so only for occasional intervals.

The surge in trading volume, continued price volatility, and wider than usual bid-ask spread suggest a prolonged second stage in which differential private information plays a role. In the price formation literature, evidence

Table II

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

Five-minute log price change standard deviations, trading volume means, and bid-ask spread means are reported and compared for announcement and nonannouncement days for the five-year U.S. Treasury note. 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, and the reported bid-ask spread is the actual mean proportional spread times 10^4. Announcement days are defined as those with a consumer price index, employment, or producer price index announcement but no 9:15 a.m. or 10:00 a.m. announcements. Nonannouncement days are those with no 8:30 a.m., 9:15 a.m., or 10:00 a.m. announcements. We report *p*-values from the Brown-Forsythe-modified Levene *F*-statistic comparing variances for announcement and nonannouncement days and *p*-values from the *t*-statistic comparing means for announcement and nonannouncement days assuming unequal variances. All five-minute intervals between 8:15 and 8:45 a.m. are examined as are intervals from every 15 minutes between 9:00 and 10:30 a.m. The period of analysis is August 23, 1993 to 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	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	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	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	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

* and ** indicate significance at the 0.05 and 0.01 levels, respectively.

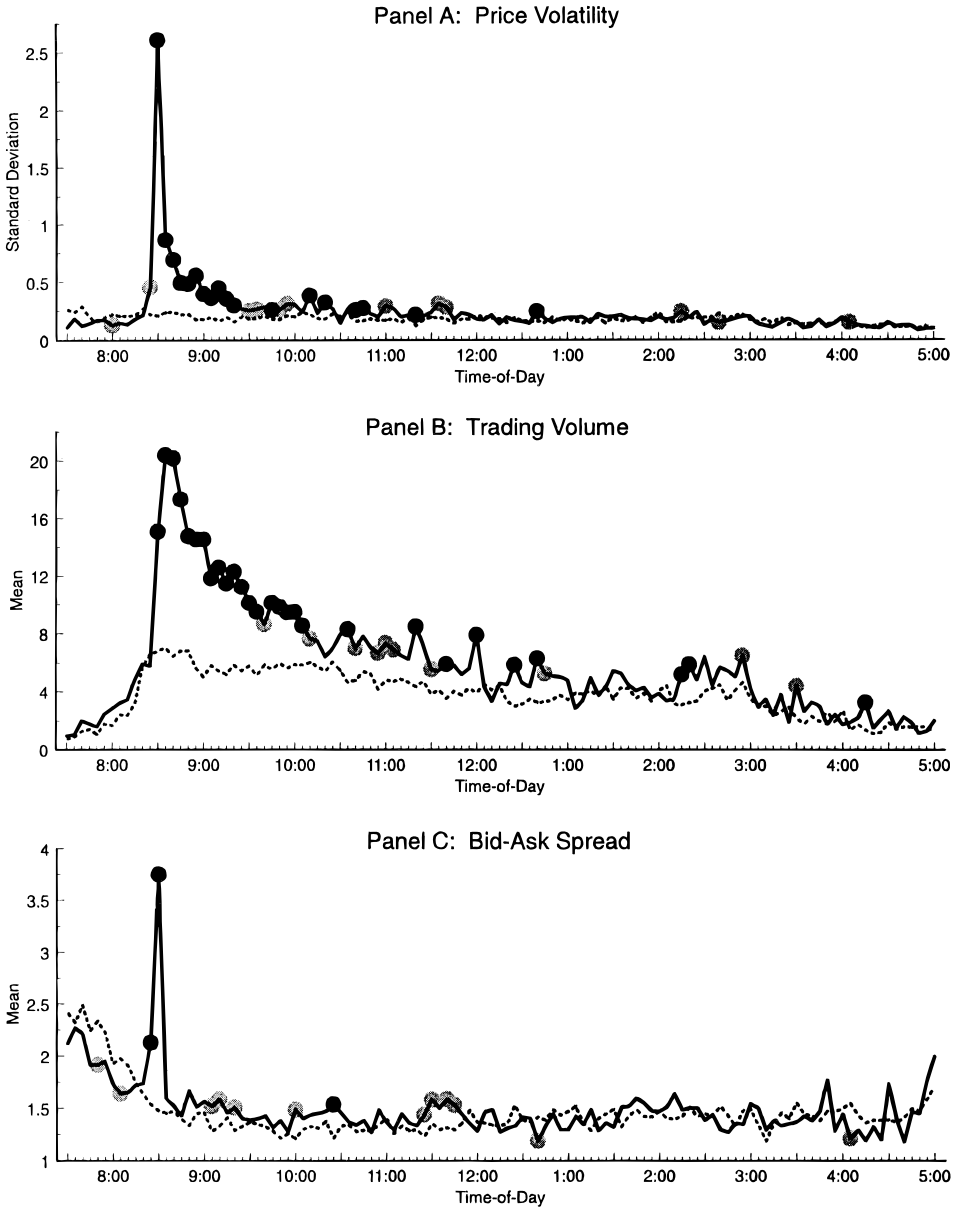

Figure 1. Intraday patterns on announcement and nonannouncement days. Intraday patterns for the five-year U.S. Treasury note are plotted by five-minute interval for days with major 8:30 a.m. announcements (solid line) and days with no announcements (dashed line). Standard deviations of log price changes times 1000 are reported in Panel A, means of interdealer trading volume in tens of millions of dollars are reported in Panel B, and means of interdealer bid-ask spreads in hundredths of one percent are reported in Panel C. Solid and shaded circles indicate statistically significant differences at the 1 percent and 5 percent levels, respectively. The period of analysis is August 23, 1993 to August 19, 1994 and the times shown are interval starting times (ET).

of an accompanying volume surge dates back to Beaver (1968), who attributes the rise in trading volume in the stock market in weeks of earnings announcements to "a lack of consensus regarding the price." In the Treasury market, most participants seem to draw rather similar price implications from the numbers in a major announcement so that the initial price adjustment reflects a large common component in the changes in market participants' expectations. The precise magnitude of the appropriate price change, however, is a matter of interpretation, which differs among dealers depending on their analyses and customer order flows. Some of them see the initial price change as an overreaction, others an underreaction. The dealers then take positions on the strength of their differential views and thus produce the volume surge along with the high volatility and wide spreads.

The process of reconciling the differential views is a protracted one. He and Wang's (1995) model of differentially informed investors is one that gives rise to persistence in both price volatility and trading volume in a slow convergence to a consensus price. In the model, investors trade for several rounds after they receive information, causing volume and volatility to persist even though the arrival of information does not. Persistence is possible because prices are noisy and not fully revealing of traders' private information. In Lyons' (1997) model of the FX market, individual dealers hold such information in the form of knowledge of their own-customer order flows and the aggregation of these flows matters for prices. Lyons (1995) shows that trades reflecting such differential information widen bid-ask spreads, and Lyons (1996) suggests that "hot-potato trading"—the passing around of inventory imbalances among dealers—obscures the information.

Note that our interpretation is an effort to explain the joint persistence of high price volatility, high trading volume, and moderately wide bid-ask spreads. A sequential arrival of public information may be expected to lead to high price volatility and a wide bid-ask spread, but not high trading volume.[12] The unwinding of speculative positions or portfolio rebalancing may be expected to lead to a trading volume surge, but not persistently high volatility. Our interpretation of differential private views that take time for the market to reconcile can explain the joint persistence of high price volatility, high trading volume, and moderately wide bid-ask spreads.

C. The Adjustment Process in One Episode

The two-stage adjustment process we describe above is discernible in a single episode. The largest five-minute price shock in our sample takes place at 8:30 a.m. on August 5, 1994 when the July employment report was released.

[12] Ederington and Lee (1993), for example, suggest that the persistence of price volatility after a major announcement may be attributable to the release of further details of a report beyond the headline number. However, our inspection of a Bloomberg feed on a major announcement day shows that all of a report's details along with preliminary analysis become available within one minute of the release time. This is possible because reporters have access to the report 30 minutes before its release (see footnote 5).

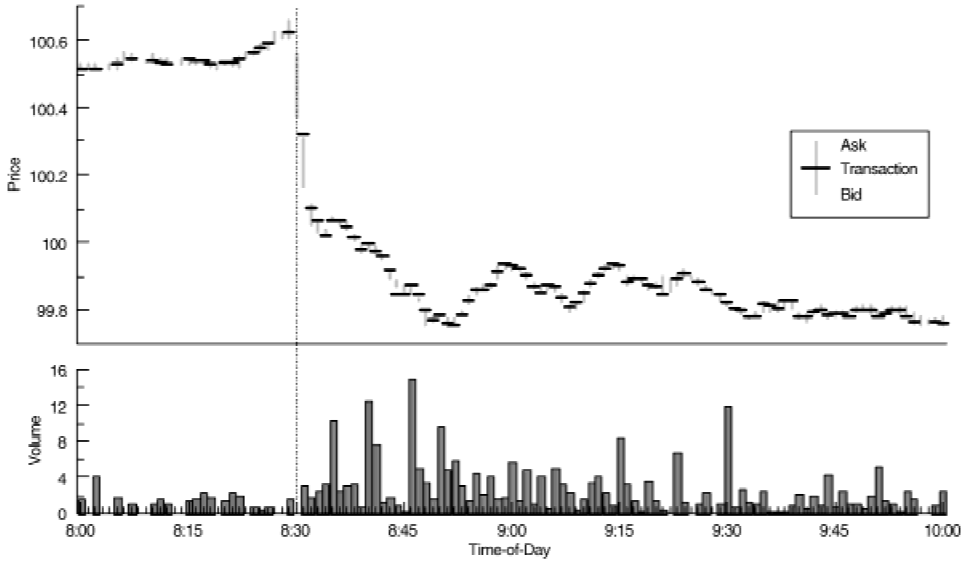

Figure 2. Market response to August 5, 1994 employment report. Means of interdealer bid, ask, and transaction prices, and interdealer trading volume for the five-year U.S. Treasury note are plotted for every one-minute interval between 8:00 a.m. and 10:00 a.m. on August 5, 1994. Trading volume is reported in tens of millions of U.S. dollars and the times shown are interval starting times (ET).

As shown in Figure 2, in the half hour before the announcement the price of the five-year note is relatively stable, the bid-ask spread is narrow, and the trading volume is low. The bid-ask spread then starts to widen in the minute before the announcement. Upon the report's release, the price of the five-year note falls about 1/2 point within three minutes of the announcement, with trading still relatively thin. In fact, there are no recorded trades in the minute of the announcement, when both bid and ask quotes are falling. The spread is at its widest in the first two minutes after the announcement, but it narrows quickly in the third minute as trading volume starts to pick up. Volume then surges as the price continues to fluctuate. For the next 90 minutes, both price volatility and trading volume persist at substantially higher levels than typically seen on nonannouncement days.

III. Conclusion

The recent availability of high frequency data on interdealer trading in the U.S. Treasury market allows us to examine in a new light how secondary markets form prices and provide liquidity. The Treasury market offers a setting for testing microstructure hypotheses where marketmakers are unhindered by price continuity or market presence rules, allowing prices and bid-ask spreads to adjust endogenously. We focus our examination on mar-

ket behavior around the release times of macroeconomic announcements because these times mark the arrival of public information precisely. We uncover a striking two-stage adjustment to such public information.

A brief first stage is marked by an almost archetypal response to pure public information. Prices adjust sharply to a just-released announcement and trading volume declines, demonstrating empirically that price responses to public information do not require trading. The moments in which prices adjust sharply to public information are accompanied by a marked disruption of liquidity. Marketmakers widen or withdraw their bid and ask quotes in response to the inventory risks of sharp price changes.

In a prolonged second stage, the initial sharp price change is followed by a surge in trading volume. High trading volume and price volatility then persist along with moderately wide bid-ask spreads. The persistence reflects a residual disagreement among investors about what the new information means for prices. The disagreement may arise from investors' differential private views including those based on dealers' knowledge of their customer order flows. The adjustment process set off by public information is therefore extended by investors' private information. Once a consensus price is reached, price volatility and liquidity return to their normal levels.

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