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Louis H. Ederington; Jae Ha Lee

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LOUIS H. EDERINGTON and JAE HA LEE*

ABSTRACT

We examine the impact of scheduled macroeconomic news announcements on interest rate and foreign exchange futures markets. We find these announcements are responsible for most of the observed time-of-day and day-of-the-week volatility patterns in these markets. While the bulk of the price adjustment to a major announcement occurs within the first minute, volatility remains substantially higher than normal for roughly fifteen minutes and slightly elevated for several hours. Nonetheless, these subsequent price adjustments are basically independent of the first minute's return. We identify those announcements with the greatest impact on these markets.

WE EXAMINE THE IMPACT on interest rate and foreign exchange markets of scheduled macroeconomic news releases such as the employment report, the consumer price index (CPI), and the producer price index (PPI). Many market participants believe that such announcements have a major impact on financial markets. Indeed, a small industry devoted to predicting the figures to be released in upcoming releases has evolved in recent years. With the exception of the weekly money supply figures, however, the impact of such announcements on financial markets has received scant attention.[1] This is doubly surprising given the considerable research interest in market volatility since these news releases are a potential source of much of this volatility. Consider, for instance, Figure 1. As shown there, prices in interest rate and foreign exchange futures markets are much more volatile between 8:30 and 8:35 A.M. eastern time (ET) than during any other five-minute trading period including

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[1] Exceptions are Dwyer and Hafer (1989), Hakkio and Pearce (1985), Cook and Korn (1991) and recent independent studies by Harvey and Huang (1992) and Savanayana, Schneeweis, and Yau (1992). The first two studies find little evidence that several announcements impact interest or exchange rates respectively but Cook and Korn (1991) find a strong interest rate reaction to the employment report. Harvey and Huang (1992) and Savanayana *et al.* (1992) observe that returns on interest futures markets are more volatile following some macroeconomic news announcements. In addition French, Leftwich, and Uhrig (1989) find that the volume of trading in agricultural futures markets declines prior to releases of U.S. Department of Agriculture crop forecasts and increases sharply following the release.

the open (8:20 A.M.) and close. In the two interest rate futures markets, the standard deviation of 8:30 to 8:35 returns is approximately two and a half times the next highest five-minute return standard deviation. In the deutsche mark market, the ratio is 1.9. Since several major macroeconomic statistical releases, including the employment report, the CPI and PPI, Gross National Product (GNP), the index of leading indicators, and the merchandise trade deficit, are released at 8:30 A.M. (ET), these releases are obvious candidates for explaining this phenomenon.

We examine the impact of the nineteen monthly announcements, listed in the Appendix, on the Treasury bond (T-bond), Eurodollar, and deutsche mark futures markets. We focus on these markets because they open before 8:30, are heavily traded, and provide tick-by-tick prices. Because the futures and spot instruments are close substitutes, we believe our results are generalizable to spot interest and exchange rate markets as well. Indeed, we feel many of our results are relevant to any scheduled announcement, i.e., one whose timing is known beforehand, such as earnings and dividend announcements.

Harvey and Huang (1991, 1992) observe that interest rate and foreign exchange futures prices are much more volatile during the first sixty to seventy minutes of trading on Thursdays and Fridays than during any other hour over the trading week. They hypothesize that this pattern is due to the fact that many macroeconomic announcements occur during the first hour of trading on these two days—it is not due to the opening itself. Our results support their hypothesis. We find that, within the first seventy minutes, volatility is not usually high at the opening (8:20) but at 8:30 when the announcements are made. More important, we find that, when we control for these announcements, volatility is basically flat both across the trading day and across the trading week.

In examining the importance of individual announcements, we find that the following seven announcements (listed in order of decreasing impact) have a significant (0.005 level) effect on T-bond futures prices: employment, the PPI, the CPI, durable goods orders, industrial production–capacity utilization, construction spending–National Association of Purchasing Managers (NAPM) survey, and the federal budget. Employment, the PPI, the CPI, durable goods orders, construction spending–NAPM survey and industrial production–capacity utilization have a significant impact on Eurodollar futures, while employment, the U.S. merchandise trade deficit, the PPI, durable goods orders, GNP, and retail sales significantly impact the dollar–deutsche mark rate.

We explore the speed at which the market adjusts to these news releases focusing on both market efficiency and volatility. We find that the major price adjustment occurs within one minute of the release and the direction of subsequent price adjustments is basically independent of the first minute's price change. Nonetheless, prices continue to be considerably more volatile than normal for roughly fifteen minutes and slightly more volatile for several hours. This is a considerably more rapid adjustment than that observed by

Patell and Wolfson (1984) in equity markets. They find that following dividend and earnings announcements, it takes five to ten minutes for trading profits in individual equities to disappear and that volatility may remain high even into the next day. Given our results, it appears that traders with immediate access to the market quickly form a basically unbiased estimate of the release's implications for market prices and that the price adjusts to this level almost immediately. Prices continue to adjust as details become available and as these and other traders reassess the news and its implications for prices. However, these subsequent adjustments are generally independent of the initial price change.

In the next section we explain our choices of news releases and markets; we also describe the news release procedures. In Section II, we examine the implications of these releases for intraday and day-of-the-week volatility. In Section III we turn to the question of the relative importance of these announcements. The efficiency of the markets in adjusting to this information is explored in Section IV and our results are summarized in Section V.

I. News Releases and Market Structure

We explore the impact on interest rate and foreign exchange futures prices of the nineteen macroeconomic news releases listed in the Appendix. These are the nineteen monthly announcements whose upcoming release is regularly covered in "The Week Ahead" section of *Business Week*.[2] Their release could affect interest and exchange rates either because they are viewed as signalling a likely change in the demand for credit or foreign exchange or because market participants believe these are important variables which the Federal Reserve considers in setting monetary policy. We examine only monthly announcements. Weekly news releases such as the money supply figures and Treasury bill auction results are excluded because (since they are always announced on the same day) their impact would be difficult to distinguish from day-of-the-week effects. Also, most (e.g., the money supply) are announced after the markets close. Because the number of data points is inadequate for individual analysis, purely quarterly announcements are excluded. While the GNP is a quarterly statistic, advance, preliminary, and final estimates are announced in successive months, so we include it in our set.

We examine the impact of these announcements on the T-bond, Eurodollar, and deutsche mark futures markets. The T-bond contract is traded on the Chicago Board of Trade (CBOT). The other two are traded on the Interna-

[2] A few other upcoming monthly announcements are occasionally reported in this column but not on a consistent basis. Consensus forecasts for most of our releases are tabulated by MMS International and these are reported in *Business Week*. The federal government's "Schedule of Release Dates" lists twenty-four monthly nonagricultural news releases. We include eighteen of these. We also include one release from a private agency, the National Association of Purchasing Managers.

tional Monetary Market (IMM) unit of the Chicago Mercantile Exchange (CME). These markets were chosen for three reasons. First, they open for trading at 8:20 A.M. (ET)—before the 8:30 announcements. This requirement rules out examination of stock index futures. Second, prices are available on a tick-by-tick basis. These two requirements preclude any examination of spot prices. However, since we always use prices for the nearby contract, these futures contracts are very close substitutes for the underlying spot instruments. Consequently, we feel that our results are generalizable to spot rates. Third, all are heavily traded. The T-bond contract, which calls for delivery of a U.S. Treasury bond with fifteen or more years to maturity, is the most heavily traded long-term interest rate contract in the world. The Eurodollar futures, which specifies cash delivery based on the three-month London interbank offered rate, is the most heavily traded short-term interest rate futures contract. While the Eurodollar rate is the rate paid on offshore interbank deposits (to avoid insurance fees and regulations) it is a dollar rate dependent on domestic monetary conditions and this contract is much more heavily traded than other short-term rate contracts. The dollar–deutsche mark contract is the most heavily traded foreign exchange contract in the United States. We require heavily traded contracts because we are interested in price adjustments over very short periods of time.

Our data consist of tick-by-tick data from the CBOT and CME. These are transaction prices, not bid-asked quotes, recorded by exchange personnel who observe the pits and post the most recent price.[3] Our data set begins November 7, 1988 when the CBOT switched its opening time from 9:00 A.M. (ET) to 8:20 and ends November 29, 1991.

As shown in the Appendix, nine of the announcements are released at 8:30 A.M. (ET), two at 9:15, six at 10:00, and one at 2:00. One, installment credit, does not occur at a set time, which limits our analysis of its impact. One, the NAPM survey, is released by a private agency, the National Association of Purchasing Managers. The other eighteen are government releases.

During the period of our study, slightly different release procedures were followed by the three government agencies. All provide the data to reporters with "a need for timely access" prior to the release time, e.g., at 8:00 for the 8:30 releases. At the Department of Commerce and Federal Reserve, reporters can write their reports but cannot leave the room, phone, or transmit until the scheduled release time. The Bureau of Labor Statistics (BLS) also currently follows this procedure. During our data period, however, the BLS allowed reporters to leave the room although the news was embargoed until the scheduled time. Broad tape reports on the announcements are shown on screens on the exchange floor. The T-bond market reaction to the May 8, 1992

[3] This is tick-by-tick data. The exchange's interest is to provide timely price information. Consequently, the observers record every change in price but do not separately record successive trades at the same price or trade volume.

employment report was directly observed from the CBOT trading pit.[4] Key figures appeared promptly at 8:30 and a paragraph of text was displayed on the screens within ten seconds or so. However, several traders said they don't normally watch the screen but simply react to the order flow. Also, the screens are not visible to all traders unless they turn their back on the trading pit. There appeared to be a flurry of phone orders within a few seconds of 8:30.

II. Volatility

A. Intraday Volatility

To examine intraday volatility, log returns, $\ln (P_t/P_{t-1})$, are calculated from prices on the nearby contract for each five-minute period over the trading day. Of course these "returns" measure price changes only. They are not returns in an investment sense since no money is actually invested up front. Standard deviations of these log returns calculated across all 775 trading days (November 7, 1988 to November 29, 1991) are shown in Figure 1. In this and other figures, the time on the horizontal axis indicates the end of the interval in eastern time, e.g., 8:35 for 8:30 to 8:35 returns. It is readily apparent that returns are much more variable over the 8:30 to 8:35 period than during any other five-minute period. In the T-bond market, the ratio of the 8:30 to 8:35 standard deviation to the next highest five-minute standard deviation is 2.4. In the Eurodollar and deutsche mark futures markets, this ratio is 2.6 and 1.9 respectively.

Of particular interest is volatility at the open. Note that if one examines periods of fifteen minutes or longer for our futures contracts (e.g., Harvey and Huang (1991, 1992) or Ekman (1992)), prices appear to be more volatile at the open. However, prices over the first ten minutes, 8:20 to 8:30, are not particularly volatile. It is between 8:30 and 8:35 that volatility is unusually high. Nine of our news releases occur at 8:30 including all three which several futures traders have told us are particularly important: the employment report, the CPI, and the PPI. To determine if the intraday volatility patterns observed in Figure 1 are indeed due to these new releases, we divide the sample into those days with at least one of our nineteen new releases, 457 days, and those with none, 318 days. As shown in Figure 2, in the nonannouncement day set, the 8:30 to 8:35 spike disappears.[5]

[4] The authors are grateful to Jerome Lacey and others at Prudential Securities for sharing their experiences on the market's reaction to these announcements and for arranging for one of the authors to visit the trading floor to observe the reaction to the May 8, 1992 employment report.

[5] The days and times of the announcements were primarily determined from *Business Week*'s "The Week Ahead" column. On the few occasions when an announcement was not reported in *Business Week* we use the government's "Schedule of Release Dates." Although the only major spike in Figure 1 is at 8:30, we include in our data set announcements at other times in order to determine if there is any impact on volatility at those times.

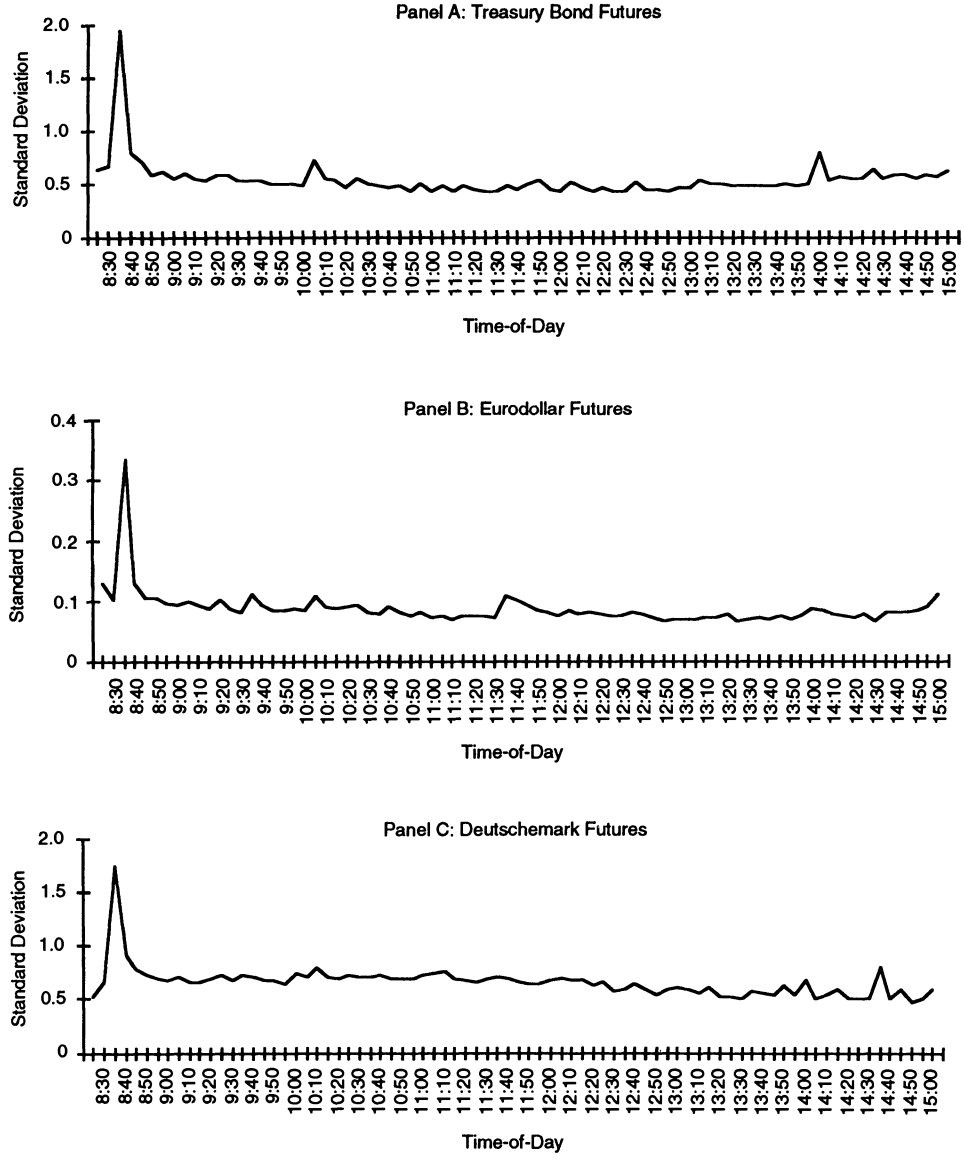

Figure 1. Intraday return volatility. Standard deviations of five-minute returns calculated across daily observations from November 7, 1988 through November 29, 1991 are reported. The reported standard deviations are the calculated value times 10^3 and the times shown are interval ending times in eastern time.

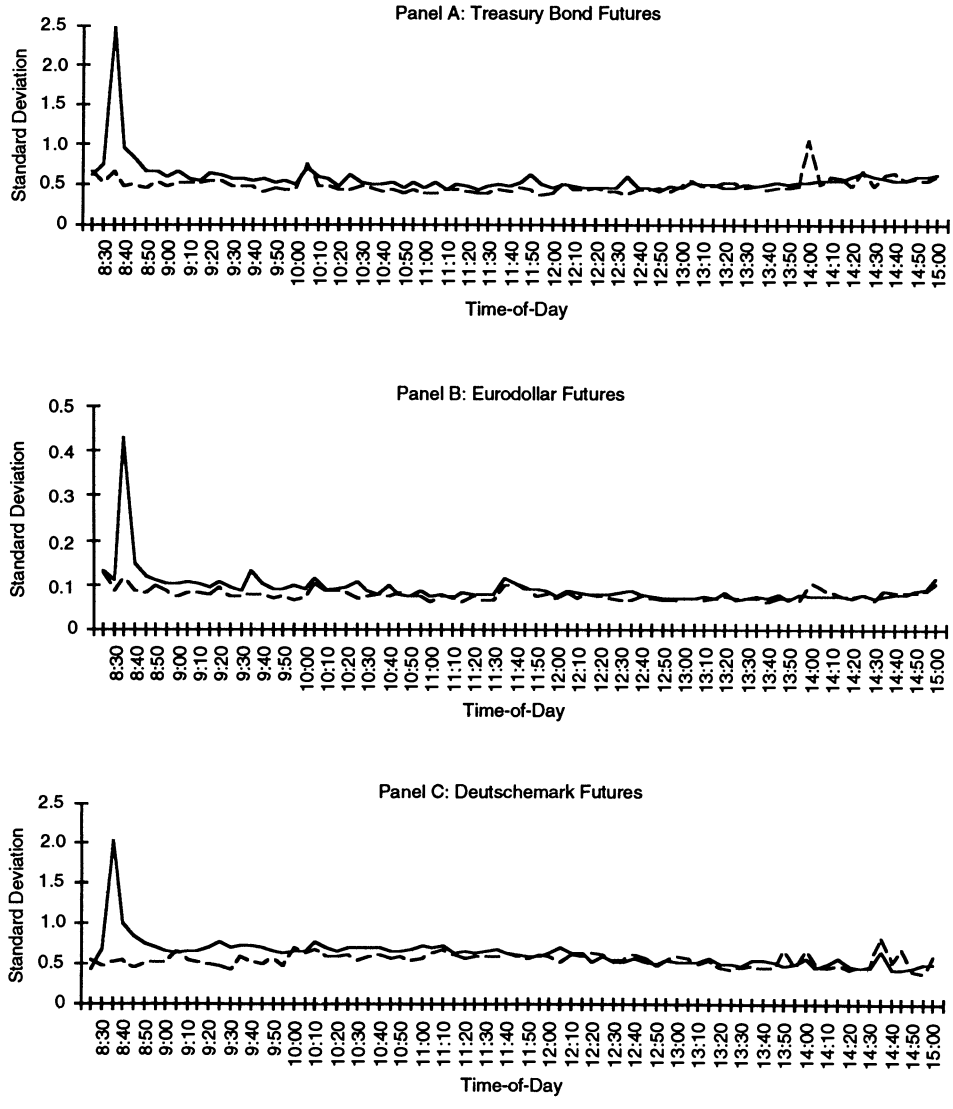

Figure 2. Intraday return volatilities on announcement and nonannouncement days. Standard deviations of five-minute returns are reported for days with at least one of the nineteen announcements listed in the Appendix (*solid line*) and days with none of these announcements (*dashed line*). Daily observations from November 7, 1988 through November 29, 1991 are utilized. The reported standard deviations are 10^3 times the calculated values and the times shown are interval ending times (ET).

Table I

Tests of Homoskedasticity of the Return Variates

Brown-Forsythe–modified Levene test statistics are reported; F_1 is the test statistic for equality of the variances across the 80 intraday five-minute intervals. F_2 is the test statistic for equality of the variances for the 8:30 to 8:35 period across days of the week, and F_3 is the test statistic for equality of the variances for the open to 9:30 period across days of the week. The Brown-Forsythe–modified Levene test statistic is

$$F = \frac{\Sigma_{j=1}^{J} n_j (\bar{D}_{\cdot j} - \bar{D}_{\cdot\cdot})^2}{\Sigma_{j=1}^{J} \Sigma_{t=1}^{n_j} (D_{tj} - \bar{D}_{\cdot j})^2} \frac{(N-J)}{(J-1)},$$

where $D_{tj} = |r_{tj} - \hat{M}_{\cdot j}|$; r_{tj} is the return for day t, interval j; $\hat{M}_{\cdot j}$ is the sample median return for interval j computed over the n_j days included in the test; $\bar{D}_{\cdot j} = \Sigma_{t=1}^{n_j} (D_{tj}/n_j)$ is the mean absolute deviation (from the median) for interval j; and $\bar{D}_{\cdot\cdot} = \Sigma_{j=1}^{J} \Sigma_{t=1}^{n_j} (D_{tj}/N)$ is the grand mean, and $N = \Sigma_{j=1}^{J} n_j$. The statistic is distributed $F_{J-1, N-J}$ under the null hypothesis. An asterisk indicates that the null hypothesis of homoskedasticity is rejected at the 0.01 percent level.

	Announcement Days	Nonannouncement Days	All Days
Panel A: Treasury Bond Futures			
F_1 :	39.57*	5.77*	35.86*
F_2 :	20.35*	2.79	31.73*
F_3 :	17.59*	0.21	24.54*
Panel B: Eurodollar Futures			
F_1 :	34.11*	6.11*	33.11*
F_2 :	17.59*	0.54	27.85*
F_3 :	13.37*	1.31	21.90*
Panel C: Deutsche Mark Futures			
F_1 :	22.25*	3.89*	18.62*
F_2 :	22.79*	2.43	36.69*
F_3 :	10.80*	1.61	13.91*

In Table I, we present the Brown-Forsythe–modified Levene test statistic (F_1) for the null hypothesis that the variance of returns is constant throughout the trading day.[6] This null is overwhelmingly rejected for days on which announcements occur and for the total data set. For the nonannouncement set, the homoskedasticity null is still rejected at the 0.0001 level. However, the F statistic is sharply reduced and there is no discernable intraday pattern on these days. In particular there is no evidence that volatility is particularly high at the open and close as observed in equity markets by

[6] Conover, Johnson, and Johnson (1981) compare over fifty methods of testing for homogeneity of variance and find that this test is among the most powerful and is robust to nonnormality. It is used by Lockwood and Linn (1990) to test for homogeneity of intraday return variances.

Wood, McInish, and Ord (1985), Lockwood and Linn (1990), and others. Indeed, one wonders if the high variance observed at the open in equity markets is partly due to the 8:30 news releases which occur shortly before the stock market opens. In the nonannouncement set, the highest variance in the T-bond market occurs at 1:55 to 2:00 (10:00 to 10:05 if a single outlier is removed).[7] For Eurodollars and deutsche marks, the high points are at 8:20 to 8:25 (the open) and 2:30 to 2:35, respectively. Harvey and Huang (1992) hypothesize and present evidence that interest rate volatility tends to be high between 11:35 and 12:15 (ET) when a uniquely informed trader, the Federal Reserve, is actively trading. While we do not explicitly test their hypothesis, no such increase in volatility is apparent in Figures 1 and 2. In summary, although the null of homoskedasticity is rejected for nonannouncement days, there is no clear pattern, i.e., volatility is basically flat across the trading day.

B. Day-of-the-Week Effects

Harvey and Huang (1991) observe that in the interest rate and foreign exchange futures markets, returns over the first sixty to seventy minutes of trading on Thursdays and Fridays are more volatile than during any other one-hour period during the week.[8] They hypothesize that this is due to the fact that many news releases take place during this time on these days and present evidence in a later paper (1992) that this is the case. Our results further support their hypothesis. The distribution of our announcements by day of the week is reported in the Appendix. Among our 8:30 announcements, the employment report is always released on Friday and the PPI is usually released on Thursday or Friday. In Figures 3 and 4 we show 8:30 to 8:35 and 8:20 to 9:30 standard deviations for each day of the week for announcement days, nonannouncement days, and our complete sample. Volatility is particularly high on Fridays on which announcements occur. On nonannouncement Fridays, there is no such pattern. In Table I, we present Brown-Forsythe–modified Levene tests of the null that the variance is the same for all days of the week. F_2 is the test statistic for the null that the 8:30 to 8:35 variance is the same on all five days and F_3 is the equivalent test statistic for the 8:20 to 9:30 variance. Both are clearly rejected for the announcement and total samples but cannot be rejected for the nonannouncement sample. In summary, intraday and interday volatility patterns in these markets appear to be due primarily to the timing of macroeconomic news releases.

[7] As shown in Figure 2, there is a "mini-spike" at 1:55 to 2:00 in the nonannouncement data set. This is due to a single outlier on January 9, 1991 when Secretary of State Baker emerged from a meeting with Iraqi Foreign Minister Aziz and reported there was no indication Iraq would leave Kuwait peacefully. To avoid distortion, this outlier is eliminated in our subsequent analysis.

[8] In a recent paper, Harvey and Huang (1992) calculate the variances of returns over the period from the open to 8:45 A.M. (ET) for days when at least one of six macroeconomic announcements occur and separately for days without any of the six. They observe a much higher variance on announcement days.

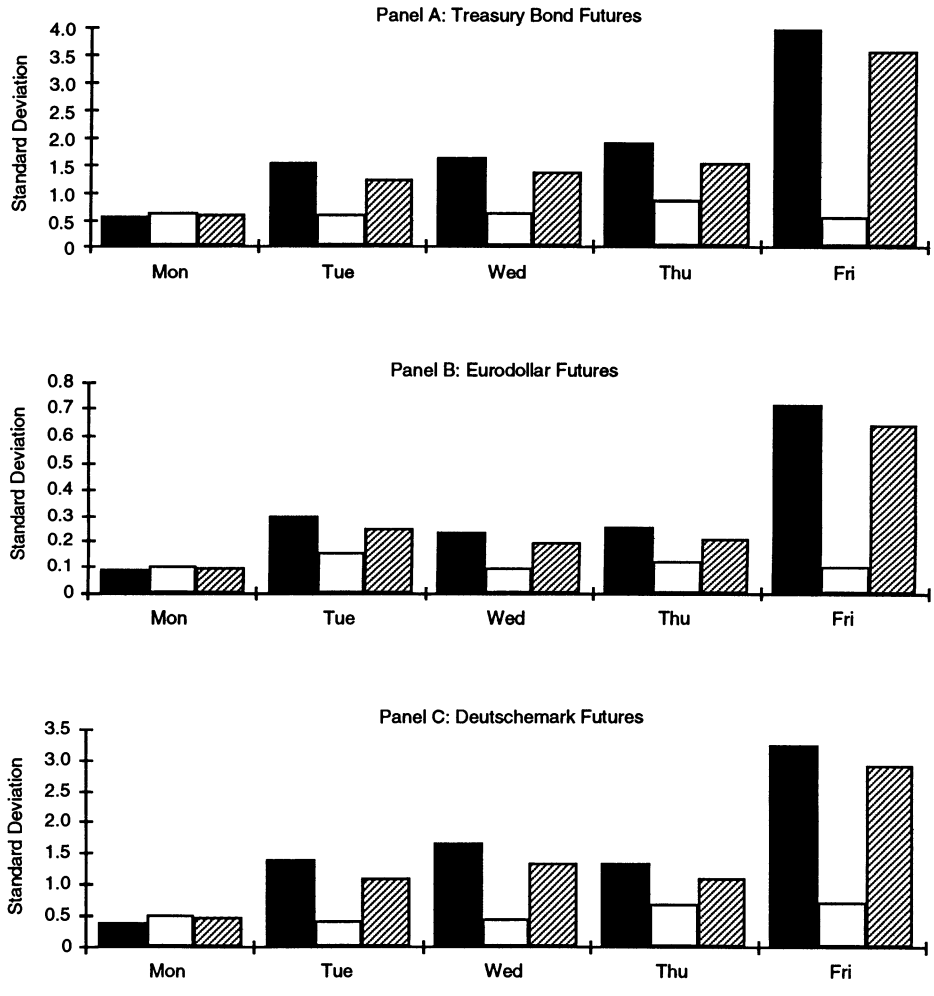

Figure 3. Day-of-the-week patterns in 8:30 to 8:35 (ET) return volatility. Standard deviations of 8:30 to 8:35 (ET) returns stratified by day of the week are reported for all days (*shaded bars*), days with at least one of the nineteen announcements in the Appendix (*solid bars*), and nonannouncement days (*open bars*). Daily observations from November 7, 1988 through November 29, 1991 are utilized and the reported standard deviations are the actual values times 10^3.

III. Which Announcements Move the Markets

We do not expect all nineteen announcements to have the same impact and indeed do not expect each announcement to necessarily impact prices. For one thing, several traders told us that the employment report, CPI, and PPI have the greatest effect on the interest rate markets. For another, little response to the 9:15, 10:00, and 2:00 announcements is apparent in Figures 1 and 2. Attention is now turned to the question of which announcements have the greatest impact.

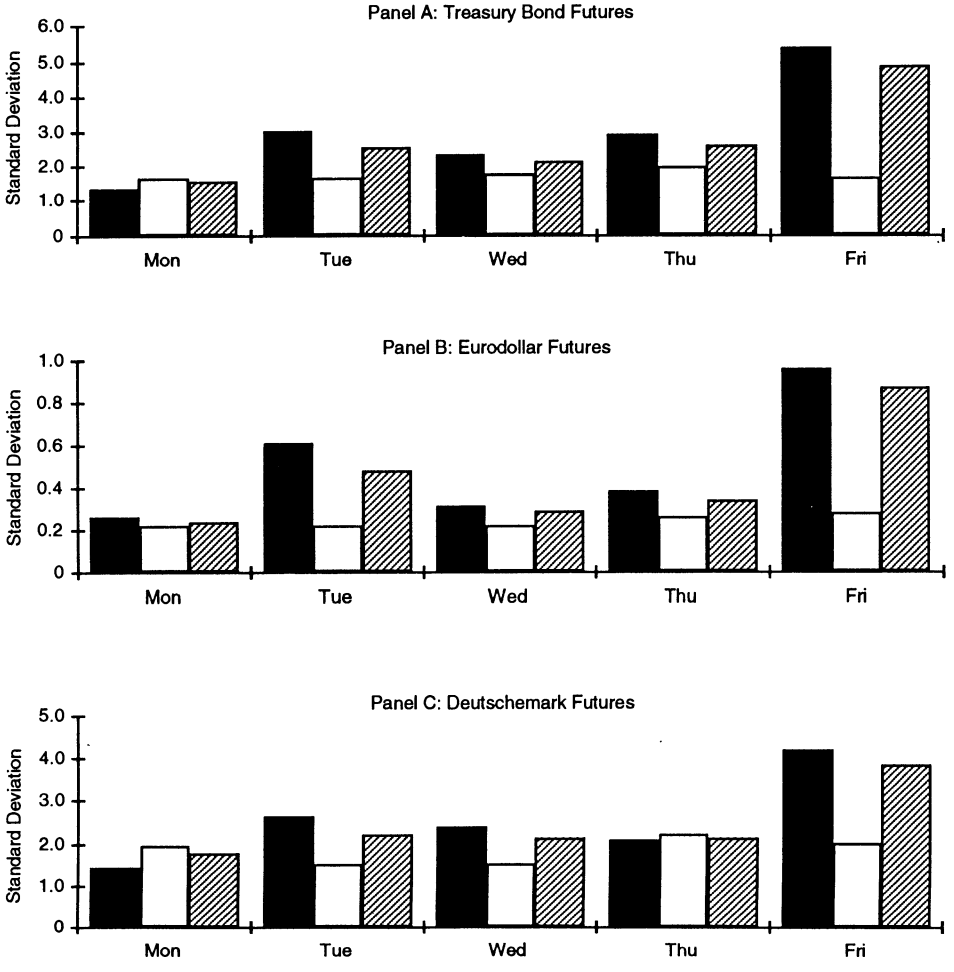

Figure 4. Day-of-the-week patterns in 8:20 to 9:30 (ET) return volatility. Standard deviations of 8:20 to 9:30 (ET) returns stratified by day of the week are reported for all days (*shaded bars*), days with at least one of the nineteen announcements in the Appendix (*solid bars*), and nonannouncement days (*open bars*). Daily observations from November 7, 1988 through November 29, 1991 are utilized and the reported standard deviations are the actual values times 10^3.

A. Previous Studies

While there have been numerous studies of the reaction of interest and exchange rates to weekly money supply announcements,[9] there have been

[9] The impact of money supply announcements on interest rates has been studied by Cornell (1983), Thorton (1989), and Stronglin and Tarhan (1990) among many others, and the impact on exchange rates has been studied by Hardouvelis (1984) and Thorton (1989). In general these studies find no reaction to the anticipated component of money supply announcements but a significant reaction to the unexpected component—at least during the period of money supply targeting October 1979 to October 1982.

only a few explorations of the monthly announcements which we consider. Using daily data, Dwyer and Hafer (1989) examine the reaction of interest rates (1980 to 1987) to surprise announcements regarding (1) the money supply, (2) the PPI, (3) the CPI, (4) the index of leading indicators, (5) the trade balance, and (6) the unemployment rate. They find an interest rate response to surprise changes in the money supply and a possible response to PPI surprises but no reaction to any of the other announcements. On the other hand, Cook and Korn (1991) find a strong reaction to the employment report.[10] Hakkio and Pearce (1985) find that exchange rates react to unanticipated changes in the money supply but find no reaction to unanticipated changes in (1) the CPI, (2) the PPI, (3) the unemployment rate, or (4) industrial production. While they do not examine individual announcements separately, Harvey and Huang (1992) find that returns on interest rate futures markets are more volatile on days when the PPI, CPI, retail sales, GNP, unemployment, or index of leading indicators are announced.

B. Procedure

In past studies, such as Dwyer and Hafer (1989) and Hakkio and Pearce (1985), the usual procedure is to use either a time series or a survey forecast to separate the announced figure into anticipated and surprise components. The change in interest or exchange rates, usually over a one-day period, is then regressed on the surprise or both the surprise and the expected change. The data set consists only of days on which the particular announcement occurred. While this procedure captures the impact of announcements on the level of rates, it does not delineate the effect on market volatility and does not allow us to compare the relative importance of various announcements. In addition, most of these announcements contain not one but several statistics which could be informative and the success of the procedure requires that the forecast accurately reflect the market's expectations.

In order to measure the impact of individual announcements on market volatility, our procedure is somewhat different. We define a series of dummy variables D_{kt} where $D_{kt} = 1$ if announcement k is made on day t and $D_{kt} = 0$ otherwise. The dependent variable in our regressions is the absolute value of the difference between the actual return R_{jt} for the five-minute interval j on day t and the mean return $\overline{R}_j$ for interval j over all 775 trading days. In summary, our regression format is

$$|R_{jt} - \overline{R}_j| = a_{oj} + \sum_{k=1}^{K} a_{kj} D_{kt} + e_{jt} \tag{1}$$

[10] This discrepancy may be due to the fact that Dwyer and Hafer examine only the reaction to innovations in one part of the employment report, the unemployment rate. Cook and Korn find some evidence to these innovations but find that the market is much more responsive to innovations in total nonagricultural employment.

Separate regressions for each five-minute interval j are estimated over 775 trading days. As noted in Schwert (1989) and Schwert and Seguin (1990), if log returns are normally distributed with constant mean but time-varying variance, $E|R_{jt} - \bar{R}_j| = (2/\pi)^{0.5}\sigma_{jt}$ where σ_{jt} is the standard deviation of returns in interval j on day t. Consequently, $(\pi/2)^{0.5}a_{oj} = 1.2533\ a_{oj}$ provides an estimate of the standard deviation of returns in interval j on nonannouncement days. Whether a particular surprise is good or bad news, a_{kj} should be positive if announcement k impacts the market. The estimated standard deviation of returns in interval j on days when k (and only k) is announced is given by $1.2533\ (a_{oj} + a_{kj})$. If an announcement is ignored by the market, a_{kj} should be approximately zero.

We are not able to define individual dummy variables for all nineteen announcements listed in the Appendix. In order to obtain meaningful estimates a_{kj} of the impact of an announcement on the standard deviation of returns, it is necessary that the announcement occur at a consistent time j and not always coincide with another announcement. Since the time of the installment credit release varies, no dummy for its release is calculated. There is considerable overlap between two pairs of announcements. Over most of our period (34 of 37 months), the Federal Reserve Board released the industrial production and capacity utilization simultaneously. However, in the first three months in our data set, capacity utilization was announced at a different time.[11] Consequently, we define a dummy variable for industrial production but not for capacity utilization. However, in interpreting its coefficient, a_{kj}, it must be recognized that since in most months both announcements are occurring simultaneously the coefficient probably reflects the impact of the capacity utilization announcement as well. In 32 of 37 months, two of the 10:00 announcements, construction spending and the NAPM survey, were released on the same day. For these we construct a combined dummy variable as follows: $D_{kt} = 1$ if both announcements are released on day t (32 days); $D_{kt} = 0.5$ if one, but not both, are released (10 days), and $D_{kt} = 0$ otherwise. No other pairs of announcements have more than 15 days in common. In total sixteen announcement dummies are calculated.

The set of announcements, K, differs somewhat between regressions. For j = 8:30 to 8:35, the absolute return deviation is regressed on dummies for the nine 8:30 announcements only. For later periods, we regress five-minute absolute return deviations on both the announcements that occur at that time and those that occur earlier. For instance, the 9:15 to 9:20 absolute return deviation is regressed on dummies for the nine 8:30 announcements as well as the industrial production–capacity utilization announcement at 9:15.[12]

[11] Two capacity utilization announcements were made at 10:30 (one on a different day than industrial production) and in one case the time of the release is unknown.

[12] Results are not changed substantially if we leave dummies for earlier announcements, e.g, 8:30 announcements in the 9:15 regression, out of the regressions. We also tried adding day-of-the-week dummies to test for day-of-the-week effects. They were not significant.

The reason for this cumulative approach is that earlier announcements may still contribute to higher than normal volatility in later periods.

C. Results: Interest Rates

Results for the T-bond, Eurodollar, and dollar–deutsche mark markets are shown respectively, in Tables II, III, and IV. Since there are many announcements and time periods, we require that the probability of Type I error be 0.005 or lower before clearly regarding an announcement as significant. On this basis, four 8:30 announcements are significant in explaining 8:30 to 8:35 volatility in both interest rate futures markets. In addition, if these four announcements are ranked in terms of their regression coefficients, which measure their impact on 8:30 to 8:35 volatility, the ranking is the same in both markets: the employment report, the PPI, the CPI, and durable goods orders. The 8:30 to 8:35 volatility spike in the interest rate futures markets is primarily due to these four announcements. On days when the employment report is released, the estimated standard deviation of T-bond returns is 1.2533 (3.576 + 0.499) (10^{-3}) = 5.107 (10^{-3}) versus only 1.2533 (0.499) (10^{-3}) = 0.625 (10^{-3}) on nonannouncement days. The impact of the PPI release on prices is only a little less on average than the impact of the employment report. Its announcement day standard deviation of 8:30 to 8:35 returns averages 7.2 (T-bond) and 6.6 (Eurodollar) times the nonannouncement day standard deviation. On days when the employment report or the PPI is released, the standard deviation of returns between 8:30 and 8:35 averages 38.6 percent of the total standard deviation of open to close returns in the T-bond market and 45.8 percent in the Eurodollar market. The 9:15 industrial production–capacity utilization report is significant in the 9:15 to 9:20 regressions in both markets as is the 10:00 construction spending–NAPM survey pair in the 10:00 to 10:05 volatility regressions. The 2:00 budget report is significant at the 0.005 level in the T-bond market but not in the Eurodollar market.

Among the other announcements, GNP is significant at the 0.02, but not the 0.005, level in both interest rate markets. Retail sales are significant at the 0.02 level in the T-bond, but not the Eurodollar, market. Only one announcement, Business Inventories, has a negative coefficient in the five-minute period in which it is released.[13] It is clearly ignored by these markets. The six others have positive but insignificant coefficients. While we cannot say that they are totally ignored by the two interest rate markets, their impact is clearly minor. It is also noteworthy that none of the announcements, even the employment report and the CPI, seem to have a significant impact on volatility in later periods' regressions, i.e., they do not cause volatility to stay high throughout the trading day. We shall return to this issue in Section IV. Finally it is interesting to note that the report with the

[13] We have been told by officials at the Bureau of the Census that most of the figures in this release have already been released as parts of other announcements such as factory inventories.

Table II

The Impact of Announcements on the Five-Minute Interval Return Volatilities for the Nearby T-Bond Futures Contract

Coefficients a_{kj} of the regression $|R_{jt} - \bar{R}_j| = a_{oj} + \sum_{k=1}^{K} a_{kj} D_{kt} + e_{jt}$ are reported. $R_{jt} = \ln(P_{jt}/P_{j-1,t})$ is the log return over the five minute interval j where P_{jt} is the price at the end of interval j on day t. $D_{kt} = 1$ if announcement k is released on day t. The regression is estimated for j intervals of 8:30–8:35, 9:15–9:20, 10:00–10:05, and 14:00–14:05 over 775 trading days, t, between 11/07/88 and 11/29/91. Of the sixteen announcements, k, only those issued in interval j or earlier are included in each regression. The reported coefficients are the actual coefficients times 10^3. One, two, and three asterisks indicate significance at the 2, 0.5, and 0.01 percent levels, respectively.

	8:30–8:35		9:15–9:20		10:00–10:05		14:00–14:05	
	Regression Coefficient	T-Value	Regression Coefficient	T-Value	Regression Coefficient	T-Value	Regression Coefficient	T-Value
Intercept	0.499***	8.909	0.352***	19.617	0.400***	14.824	0.337***	16.984
8:30 A.M. Announcements								
Consumer Price Index	1.656***	6.984	0.039	0.510	−0.070	−0.678	0.089	1.176
Durable Goods Orders	1.095***	5.066	0.038	0.550	−0.043	−0.453	0.112	1.663
Employment	3.576***	16.320	−0.009	−0.128	0.064	0.672	0.046	0.688
Gross National Product	0.530*	2.424	0.044	0.623	0.042	0.440	0.110	1.602
Housing Starts	0.399	1.701	0.154	2.028	0.033	0.320	0.018	0.238
Merchandise Trade Deficit	0.418	1.891	0.023	0.305	−0.062	−0.604	0.094	1.258
Leading Indicators	0.302	1.359	0.081	1.146	0.157	1.570	0.031	0.422
Producer Price Index	3.077***	13.247	0.170	2.258	0.001	0.009	0.065	0.905
Retail Sales	0.538*	2.341	−0.036	−0.483	0.109	1.075	0.015	0.211
9:15 A.M. Announcements								
Industrial Production–Capacity Utilization	N/A	N/A	0.685***	8.980	0.119	1.133	0.134	1.805
10:00 A.M. Announcements								
Business Inventories	N/A	N/A	N/A	N/A	−0.045	−0.465	−0.105	−1.539
Construction Spending–NAPM Survey	N/A	N/A	N/A	N/A	0.496***	4.957	−0.099	−1.409
Factory Inventories	N/A	N/A	N/A	N/A	0.076	0.780	0.005	0.076
New Single-Family Home Sales	N/A	N/A	N/A	N/A	0.215	2.173	0.045	0.645
Personal Income	N/A	N/A	N/A	N/A	0.137	1.429	0.098	1.412
2:00 P.M. Announcement								
Federal Budget	N/A	N/A	N/A	N/A	N/A	N/A	0.233**	3.399
Adjusted R^2	0.402		0.135		0.038		0.023	

Table III

The Impact of Announcements on the Five-Minute Interval Return Volatilities for the Nearby Eurodollar Futures Contract

Coefficients a_{kj} of the regression $|R_{jt} - \overline{R}_j| = a_{oj} + \sum_{k=1}^{K} a_{kj} D_{kt} + e_{jt}$ are reported. $R_{jt} = \ln (P_{jt}/P_{j-1,t})$ is the log return over the five-minute interval j where P_{jt} is the price at the end of interval j on day t. $D_{kt} = 1$ if announcement k is released on day t. The regression is estimated for j intervals of 8:30–8:35, 9:15–9:20, 10:00–10:05, and 14:00–14:05 over 775 trading days, t, between 11/07/88 and 11/29/91. Of the sixteen announcements, k, only those issued an interval j or earlier are included in each regression. The reported coefficients are the actual coefficients times 10^3. One, two, and three asterisks indicate significance at the 2, 0.5, and 0.01 percent levels, respectively.

	8:30–8:35		9:15–9:20		10:00–10:05		14:00–14:05	
	Regression Coefficient	T-Value	Regression Coefficient	T-Value	Regression Coefficient	T-Value	Regression Coefficient	T-Value
Intercept	0.081***	7.732	0.051***	13.885	0.057***	13.156	0.049***	13.410
8:30 A.M. Announcements								
Consumer Price Index	0.244***	5.483	−0.009	−0.581	0.003	0.170	−0.001	−0.094
Durable Goods Orders	0.175***	4.327	0.004	0.258	0.011	0.699	0.012	1.002
Employment	0.676***	16.474	0.024	1.687	−0.003	−0.189	0.014	1.102
Gross National Product	0.113*	2.760	0.002	0.117	0.003	0.189	0.001	0.105
Housing Starts	0.028	0.625	0.035	2.231	0.041*	2.472	0.008	0.592
Merchandise Trade Deficit	0.086	2.078	0.031	2.012	−0.006	−0.385	0.006	0.440
Leading Indicators	0.033	0.801	−0.004	−0.307	0.013	0.819	−0.020	−1.474
Producer Price Index	0.435***	10.004	0.032	2.079	−0.013	−0.785	−0.000	−0.025
Retail Sales	0.016	0.374	−0.013	−0.891	0.010	0.647	−0.013	−1.014
9:15 A.M. Announcements								
Industrial Production–Capacity Utilization	N/A	N/A	0.064***	4.076	−0.013	−0.748	0.004	0.330
10:00 A.M. Announcements								
Business Inventories	N/A	N/A	N/A	N/A	−0.012	−0.745	−0.020	−1.533
Construction Spending–NAPM Survey	N/A	N/A	N/A	N/A	0.073***	4.538	−0.006	−0.499
Factory Inventories	N/A	N/A	N/A	N/A	0.031	2.002	−0.021	−1.739
New Single-Family Home Sales	N/A	N/A	N/A	N/A	0.012	0.767	−0.006	−0.498
Personal Income	N/A	N/A	N/A	N/A	0.013	0.818	−0.003	−0.239
2:00 P.M. Announcement								
Federal Budget	N/A	N/A	N/A	N/A	N/A	N/A	0.023	1.876
Adjusted R^2	0.340		0.049		0.031		0.003	

Table IV

The Impact of Announcements on the Five-Minute Interval Return Volatilities for the Nearby Deutsche Mark Futures Contract

Coefficients a_{kj} of the regression $|R_{jt} - \bar{R}_j| = a_{0j} + \Sigma_{k=1}^{K} a_{kj} D_{kt} + e_{jt}$ are reported. $R_{jt} = \ln (P_{jt}/P_{j-1,t})$ is the log return over the five-minute interval j where P_{jt} is the price at the end of interval j on day t. $D_{kt} = 1$ if announcement k is released on day t. The regression is estimated for j intervals of 8:30–8:35, 9:15–9:20, 10:00–10:05, and 14:00–14:05 over 775 trading days, t, between 11/07/88 and 11/29/91. Of the sixteen announcements, k, only those issued in interval j or earlier are included in each regression. The reported coefficients are the actual coefficients times 10^3. One, two, and three asterisks indicate significance at the 2, 0.5, and 0.01 percent levels, respectively.

	8:30–8:35		9:15–9:20		10:00–10:05		14:00–14:05	
	Regression Coefficient	T-Value	Regression Coefficient	T-Value	Regression Coefficient	T-Value	Regression Coefficient	T-Value
Intercept	0.415***	9.362	0.375***	18.348	0.448***	20.168	0.329***	18.619
8:30 A.M. Announcements								
Consumer Price Index	0.397	2.116	0.242*	2.794	0.047	0.552	0.005	0.080
Durable Goods Orders	0.934***	5.458	−0.065	−0.825	−0.130	−1.668	−0.033	−0.548
Employment	3.481***	20.070	0.307***	3.837	0.164	2.084	−0.024	−0.405
Gross National Product	0.766***	4.424	0.075	0.945	0.054	0.682	0.005	0.083
Housing Starts	0.045	0.242	−0.082	−0.949	0.018	0.210	−0.071	−1.098
Merchandise Trade Deficit	2.002***	11.439	0.100	1.164	0.014	0.172	0.102	1.572
Leading Indicators	0.188	1.067	−0.043	−0.535	0.107	1.300	−0.040	−0.624
Producer Price Index	1.319***	7.176	0.325**	3.784	0.134	1.583	0.110	1.726
Retail Sales	0.662**	3.642	0.191	2.270	0.006	0.071	−0.038	−0.606
9:15 A.M. Announcements								
Industrial Production–Capacity Utilization	N/A	N/A	0.179	2.057	−0.056	−0.646	0.085	1.296
10:00 A.M. Announcements								
Business Inventories	N/A	N/A	N/A	N/A	0.007	0.091	0.054	0.882
Construction Spending–NAPM Survey	N/A	N/A	N/A	N/A	0.036	0.431	−0.026	−0.425
Factory Inventories	N/A	N/A	N/A	N/A	0.112	1.407	0.038	0.635
New Single-Family Homes Sales	N/A	N/A	N/A	N/A	0.003	0.035	−0.021	−0.336
Personal Income	N/A	N/A	N/A	N/A	0.129	1.639	−0.011	−0.179
2:00 P.M. Announcement								
Federal Budget	N/A	N/A	N/A	N/A	N/A	N/A	0.007	0.128
Adjusted R^2	0.439		0.068		0.004		0.001	

greatest impact, the employment report, is normally the first government release concerning economic activity in a given month. In addition, the PPI is released before the CPI. One can conjecture that later releases are less important because they are partially predictable based on the earlier releases.

D. Results: Exchange Rates

Results for the dollar–deutsche mark exchange rate, as shown in Table IV, are somewhat different from those for the two interest rate markets. Not surprisingly the merchandise trade announcement, which is insignificant in the interest rate markets, has a big impact on the exchange rate. Indeed, its coefficient is second only to the employment report in size. Retail sales and GNP are significant in this market while industrial production–capacity utilization, construction spending–NAPM, the federal budget, and the CPI are not. Otherwise the list of significant announcements matches that for the interest rate markets. There is also evidence that some 8:30 announcements, the employment report, the PPI, and even the CPI (which was insignificant at 8:30), continue to cause high volatility at 9:15.

IV. Market Efficiency, Volatility, and the Speed of Adjustment

A. The Issues

Attention is now turned to the question of how rapidly the markets adjust to this new information. There are two aspects to this adjustment: efficiency and volatility persistence. We expect the standard deviation of returns to increase when the information first arrives and to return to normal once the full implications of the information for market prices are worked out. We seek to measure how long it takes for the markets to fully incorporate the new information by measuring how long return volatility remains higher than normal.

A second issue concerns the efficiency of the market adjustment. If the price adjusts slowly to the new information, then it may be possible to earn excess returns based on the initial market reaction to the news release. If, for instance, market participants are slow to react or if there are a large number of open limit orders which are gradually worked through before the new equilibrium price is reached, then prices will tend to rise (or fall) for some period after bullish (or bearish) information is announced. In this case, returns in successive subperiods within the adjustment period will tend to be positively correlated and it will be possible to earn excess trading profits by buying (or shorting) futures if the initial price adjustment is positive (or negative). We test for market inefficiency by testing for serial correlation in returns and for the possibility of trading profits based on the initial market reaction.

Clearly volatility may remain high for some period after an announcement even if the market is efficient. If prices adjust immediately to the available information but the full information only arrives gradually, then volatility will remain high but returns over successive subperiods will be independent. There are two possible reasons why the full information in a report may not be available immediately. First, most of the reports are several pages in length with numerous statistics. Second, the implications of the released information for interest and exchange rates may only be known after a time-consuming analysis. If, on the other hand, the full implications of the report are quickly recognized by market participants but prices adjust slowly, then volatility will remain high *and* excess trading profits based on the initial price reaction will be possible.

Both the efficiency and volatility aspects of the adjustment process are examined by Patell and Wolfson (1984) in their study of the intraday adjustment of equity prices to earnings and dividend announcements. They find that trading profits disappear within five to ten minutes but both they and Jennings and Starks (1985) find that the variance remains high for several hours and even into the next trading day.

B. Volatility Persistence

We have already presented some evidence on volatility persistence in Tables II, III, and IV. There we observed that in the interest rate markets, 9:15 to 9:20 return volatility is not impacted by the 8:30 announcements. Indeed, no announcements have a significant impact on volatility in any of the later periods in Tables II and III. There is, however, evidence in Table IV that some of the 8:30 announcements are still contributing to exchange rate volatility at 9:15.

More precise evidence of the volatility adjustment is presented in Table V. We calculate successive five-minute return standard deviations for two subsets: (1) days when one of the four (six for deutsche mark) 8:30 announcements significant at the 0.005 level in Tables II, III, and IV occur and (2) days when none of our nineteen announcements occur. Five-minute standard deviations are reported successively from 8:30 to 9:30 and at fifteen-minute intervals from 9:30 to 12:20. We also report the ratio of these two standard deviations and Brown-Forsythe–Levene tests for homoskedasticity.

Table V yields three observations applicable to all three markets. First, the 8:30 to 8:35 standard deviation is at least five times as high on major announcement days as on nonannouncement days.[14] Two, the announcement day standard deviation falls quite rapidly over the next ten minutes but remains about double the nonannouncement day standard deviation. Three,

[14] In the interest rate futures markets on nonannouncement days, the 8:30 to 8:35 variance tends to be slightly higher than in later periods. This could be due to quarterly announcements at 8:30 which we don't consider.

Table V

Volatility Persistence Following Major Announcements

Five-minute return standard deviations are reported and compared for announcement (major) and nonannouncement days. All five-minute return standard deviations from 8:30 to 9:30 are reported. From 9:30 to 12:20 they are reported at fifteen-minute intervals.[a] The data period is 11/07/88 through 11/29/91.

	8:30–8:35	8:35–8:40	8:40–8:45	8:45–8:50	8:50–8:55	8:55–9:00	9:00–9:05	9:05–9:10	9:10–9:15	9:15–9:20	9:20–9:25	9:25–9:30
Panel A: Treasury Bond Futures												
Announcement day[b]	4.091	1.236	1.042	0.916	0.798	0.635	0.816	0.766	0.678	0.779	0.732	0.640
Nonannouncement day[c]	0.660	0.493	0.505	0.470	0.535	0.492	0.525	0.520	0.524	0.546	0.555	0.494
Standard deviation ratio[d]	6.195	2.506	2.062	1.951	1.491	1.291	1.556	1.474	1.294	1.427	1.318	1.297
B-F-L F ratio[e]	248.14***	139.49***	87.68***	69.16***	28.66***	5.65*	21.06***	15.27***	7.60*	5.74*	5.05	7.73*
Panel B: Eurodollar Futures												
Announcement day	7.101	2.015	1.533	1.390	1.236	1.459	1.369	1.421	1.196	1.387	1.098	0.900
Nonannouncement day	1.159	0.890	0.818	0.989	0.879	0.757	0.818	0.823	0.802	0.974	0.756	0.775
Standard deviation ratio	6.126	2.265	1.873	1.405	1.406	1.928	1.673	1.727	1.491	1.424	1.453	1.162
B-F-L F ratio	177.73***	61.75***	36.58***	23.36***	10.61**	25.49***	18.65***	14.87***	16.67***	4.26	10.32**	7.53*
Panel C: Deutsche Mark Futures												
Announcement day	2.960	1.400	1.124	0.913	0.847	0.831	0.773	0.718	0.786	0.903	0.868	0.789
Nonannouncement day	0.534	0.563	0.468	0.516	0.523	0.531	0.662	0.561	0.525	0.518	0.498	0.450
Standard deviation ratio	5.547	2.486	2.399	1.770	1.620	1.565	1.167	1.280	1.497	1.742	1.742	1.753
B-F-L F ratio	195.97***	102.45***	72.16***	48.96***	28.47***	19.10***	10.53**	10.75**	7.25*	19.55***	25.16***	16.88***

Table V—*Continued*

	9:30–9:35	9:45–9:50	10:00–10:05	10 15–10:20	10:30–10·35	10:45–10:50	11:00–11:05	11·15–11:20	11:30–11:35	11:45–11:50	12:00–12:05	12:15–12:20
Panel A. Treasury Bond Futures												
Announcement day	0.632	0.562	0.631	0.497	0.506	0.490	0.601	0.523	0.557	0.817	0.533	0.525
Nonannouncement day	0.492	0.469	0.759	0.450	0.462	0.396	0.402	0.419	0.445	0.431	0.532	0.466
Standard deviation ratio	1.286	1.198	0.831	1 105	1.096	1 236	1.496	1.247	1.252	1.896	1.001	1.127
B-F-L F ratio	6.44[b]	3.44	0.48	1.39	4.59	3 81	3.52	2.38	6.17[a]	7.45[b]	0.04	4.63
Panel B Eurodollar Futures												
Announcement day	1.185	1.004	0 961	1 009	0.965	0.851	0.863	0.740	1.338	1.168	0.861	0 977
Nonannouncement day	0 778	0.767	1.027	0.850	0 802	0 752	0.759	0.745	0.992	0.765	0.825	0.752
Standard deviation ratio	1.522	1.310	0.936	1.187	1.080	1.131	1.137	0.993	1.348	1.527	1.044	1.299
B-F-L F ratio	5.73[a]	6.32[a]	1 28	4.14	2.62	4 23	3.80	0.05	5.96[b]	8.22[b]	2.26	0.56
Panel C: Deutsche Mark Futures												
Announcement day	0.728	0.737	0 654	0 661	0 705	0.683	0.828	0 642	0 652	0.519	0.715	0.598
Nonannouncement day	0.601	0.575	0.658	0 597	0.609	0.608	0.644	0 573	0.611	0.582	0.527	0.648
Standard deviation ratio	1.210	1.281	0.994	1 107	1.158	1.122	1.286	1.120	1.067	0.892	1.356	0.923
B-F-L F ratio	2.87	9.94[a]	1.17	1.06	2.17	0.21	7.25[b]	0.91	0.02	0 36	1.85	0.79

[a]The reported standard deviation is the actual standard deviation times 10^3 for the T-bond and deutsche mark futures, and it is the actual standard deviation times 10^4 for the Eurodollar futures.

[b]For the two interest rate futures markets, announcement days are defined as days with at least one of the following announcements: employment, PPI, CPI, and durable goods orders. For the deutsche mark market, the major announcements are employment, merchandise trade deficit, PPI, GNP, durable goods orders, and retail sales. These are the announcements significant at the 0.005 level in Tables II, III, and IV.

[c]Nonannouncement days are defined as days when none of our nineteen announcements occur.

[d]The ratio of the announcement day standard deviation to the nonannouncement day standard deviation.

[e]The Brown-Forsythe–modified Levene test statistic for equality between the announcement day and nonannouncement day variances. One, two, and three asterisks denote significance at the 2, 0.5, and 0.01 percent levels, respectively.

the announcement day standard deviation remains slightly higher for several hours. The announcement day standard deviation is consistently and significantly (0.005 level) greater than the corresponding standard deviation on nonannouncement days until 9:10 for T-bonds and deutsche marks, and 9:15 for Eurodollars. Over the next three hours of trading, this ratio of five-minute variances is normally insignificant in individual five-minute periods but generally continues to exceed one. Of the 36 five-minute variance ratios from 9:30 to 10:30 for the three markets combined, 32 exceed 1.0, and eleven are significantly greater than 1.0 at the 0.005 level. Of 72 interval ratios from 10:30 to 12:30, 65 exceed 1.0, and seven are significantly greater than 1.0 at the 0.005 level. In summary, volatility is extremely high in the five minutes right after the announcement, declines quite sharply over the next 10 to 15 minutes, but remains slightly higher than normal for several hours.

Further evidence of the volatility adjustment is presented in Table VI where we show regression results for nine five-minute periods following the announcement. On the right-hand side of the table, we also show results for individual minutes within the first five. In each case, equation (1) is estimated using all of the independent variables listed in Tables II, III, and IV e.g., all of the 8:30 announcements for 8:35 to 8:40,..., 9:10 to 9:15. To conserve space, however, only the coefficients of announcements which are significant at the 0.005 level in the first five-minute announcement interval's regression are shown. These coefficients provide estimates of the standard deviation of returns following each announcement. Since the construction spending–NAPM variable can represent either one or two announcements, its coefficient is not shown.

Most announcements which are significant in the first five-minute interval have significant positive coefficients for 20 minutes or more. The coefficient of the employment report is still significant after 40 or 45 minutes though few others are after 25 or 30 minutes. This may reflect the fact that the employment report is an extremely important report or the fact that it is a particularly long one (nine double-sided pages with statistics on employment, unemployment, and hours worked in various sectors) with many details that market participants require time to absorb. Although most announcements are not significant after 30 minutes at the 0.005 level, most coefficients remain positive. It is clear from the coefficient pattern in Table VI that the largest return deviations occur in the first five minutes and that volatility declines fairly rapidly after that. The coefficients in the second five-minute period average only 31 percent of the coefficients in the first five-minute period. After thirty minutes the coefficients average only 8 percent of their values in the first five minutes. As in Table V, it appears that volatility declines quite sharply over the first 10 to 20 minutes of trading and only gradually after that.

It is also clear from the figures on the far right-hand side of Table VI that most of the volatility in the first five minutes is due to price changes that occur in the first minute of trading after the announcement. On average, the coefficients for the first minute of trading are more than two and a half

times the coefficients for the second minute and more than five times the coefficients for the third minute.

C. Market Efficiency

We now address the question of market efficiency. In particular, we ask whether it is possible to make excess profits by observing the initial price response and buying (or selling) if the initial return is positive (or negative) because of a gradual adjustment of the price to its new equilibrium level based on the information available at that time. If so, how long does it take for this trading opportunity to disappear? After we first analyzed the same five-minute intervals examined earlier, it quickly became apparent that any trading profits disappear well within the first five minutes so we switched to a one-minute framework for our analysis and only these results are presented here.

As discussed in Section IV.*A* above, if several minutes are required for the price to adjust to its new equilibrium level, then returns in successive minutes within this period will tend to be positively correlated. Once the adjustment to the new equilibrium level is reached, this correlation should disappear. It is clear from the one-minute results in Table VI that the major price adjustment occurs within the first minute after the announcement. However, it is also clear that volatility remains high for at least 10 to 20 minutes. Are these later price adjustments a continuation of the adjustment begun in the first minute or independent adjustments due to either new information or a refinement of the original information? If the former, it may be possible for a trader who can execute a trade quickly to profitably trade in later minutes based on this adjustment in the first minute.

Partial correlation matrices are shown in Table VII for successive one-minute periods after major announcements. The data set for Table VII consists of the minutes after the major announcements listed in Table VI, i.e., those which are significant at the 0.005 level in our earlier regressions. These are arranged in event, not clock, time. For instance, the first minute observations consist of the 8:30 to 8:31 returns observed after the 8:30 announcements and the 9:15 to 9:16 returns observed after the 9:15 industrial production–capacity utilization announcement, etc.

Consider particularly the correlation between the returns in the first and second minutes after the announcement, e.g., 8:30 to 8:31, and 8:31 to 8:32. There is no evidence in Table VII that the price adjustment which began in the first minute continues into the second minute. In the T-bond market, the correlation between returns in the first two minutes is an inconsequential 0.077. In the other two markets, this correlation coefficient is significant but negative. This negative correlation raises the possibility that the market may tend to overreact to the news in the first minute and then correct in later periods. This is particularly true in the Eurodollar market where returns in the third, fourth, and fifth minutes are also significantly negatively correlated with returns in the first minute. However, this result must be inter-

Table VI

The Speed of the Volatility Adjustment in Response to Major Announcements

Results of regressions in which the dependent variable is the absolute return deviation for the five-minute interval shown and the independent variables are dummies for all announcements occurring in that interval or earlier on that day are reported. Only coefficients of announcement dummies significant at the 0.005 level in the first-five minute interval following announcement are shown. The data from 11/07/88 through 11/29/91 are utilized. The reported coefficients are the actual coefficient times 10^3. One, two, and three asterisks indicate significance at the 2, 0.5, and 0.01 percent levels, respectively.

	Coefficients for Successive Five-Minute Intervals after Announcements									Coefficients for One-Minute Intervals				
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	1st	2nd	3rd	4th	5th
Panel A: Treasury Bond Futures														
8:30 Announcements														
Consumer Price Index	1.656***	0.312**	0.277**	0.190*	0.140	0.033	0.000	0.203**	0.127	1.462***	0.343**	0.284**	0.093	0.176**
Durable Goods Orders	1.095***	0.167	0.223*	0.190**	0.095	0.018	0.157	0.094	0.032	1.399***	0.265**	0.154	0.124	0.136*
Employment	3.576***	0.859***	0.590***	0.605***	0.372***	0.188**	0.341***	0.193**	0.143	3.819***	1.338***	0.450***	0.652***	0.464***
Producer Price Index	3.077***	0.547***	0.408***	0.311***	0.100	−0.055	0.247**	0.181*	0.146	2.372***	0.666***	0.505***	0.382***	0.427***
9:15 Announcements														
Industrial Production–Capacity Utilization	0.685***	0.312***	0.269**	0.084	0.137	0.086	0.047	0.050	−0.019	0.663***	0.289***	0.200***	0.123**	0.158**
2:00 Announcement														
Capital Budget	0.232**	0.122	0.127	0.261**	0.109	0.116	−0.008	0.036	0.058	0.087	0.069	0.142**	0.097	0.067

Table VI—*Continued*

Panel B: Eurodollar Futures														
8:30 Announcements														
Consumer Price Index	0.244***	0.050**	0.018	0.030	0.009	0.025	0.014	0.044**	0.024	0.312***	0.106***	0.031	0.024	0.041**
Durable Goods Orders	0.175***	0.013	0.022	0.022	−0.001	0 029	0.021	0.005	0.010	0.263***	0.071**	0.032*	0.040**	0.029*
Employment	0.676***	0 132***	0.088***	0.056***	0.052***	0.062***	0.057***	0.048**	0.056***	0.707***	0.200***	0 081***	0.108***	0.046***
Producer Price Index	0.435***	0.059**	0.029	0 037*	0.029	0.029	0.035*	0.033*	0.029	0.396***	0.190***	0.088***	0.038**	0.050***
9:15 Announcements														
Industrial Production–Capacity Utilization	0.064***	0.013	0.049***	0.005	0.005	0.009	0.009	0.028	−0.007	0.073***	0.058***	0.032***	0.017	0.013
Panel C: Deutsche Mark Futures														
8:30 Announcements														
Durable Goods Orders	0.934***	0.323**	0.207*	0.077	0.012	0.007	0.094	0.160	0.103	0.969***	0.255**	0.199*	0.137*	0.153**
Employment	3.481***	0.805***	0.869***	0.433***	0.306**	0.401***	0.381***	0.231**	0.280**	2.298***	0.937***	0.654***	0.453***	0.456***
Gross National Product	0.766***	0.481***	0.297**	0.117	0.143	0.062	0.031	0.067	−0.015	0.714***	0.254**	0.249**	0.121	0.115*
Merchandise Trade Deficit	2.002***	1.030***	0.325**	0.312**	0.386***	0.430***	0.271**	0.073	0.080	2.829***	1.049***	0.758***	0.746***	0.255***
Producer Price Index	1.319***	0.489***	0.336**	0.464***	0.295**	0.131	0.119	0.201*	0.355	0.857***	0.342***	0.156	0.271***	0.144**
Retail Sales	0.662**	0.401**	0.231*	0.114	0.142	0.026	0.034	−0.083	0.174	0.635***	0.314***	0.207*	0.210***	0.127**

Table VII

Serial Correlation Matrices

Pearson correlation coefficients between returns in the first ten minutes following the major announcements listed in Table VI. One, two, and three asterisks indicate significance at the 2, 0.5, and 0.01 percent levels, respectively. The data period is from 11/07/88 through 11/29/91.

	T-Bond Market			Eurodollar Market			Deutsche Mark Market		
	First Minute	Second Minute	Third Minute	First Minute	Second Minute	Third Minute	First Minute	Second Minute	Third Minute
First minute	1.000			1.000			1.000		
Second minute	0.077	1.000		−0.214**	1.000		−0.206**	1.000	
Third minute	−0.250**	−0.143	1.000	−0.276**	−0.017	1.000	−0.104	0.029	1.000
Fourth minute	−0.052	0.196*	−0.007	−0.319***	0.188*	−0.185*	0.049	0.131	0.052
Fifth minute	0.118	−0.167*	0.048	0.328***	−0.203*	−0.119	0.041	0.102	−0.057
Sixth minute	0.146	0.004	−0.033	0.111	−0.090	−0.016	−0.055	−0.070	−0.019
Seventh minute	−0.067	−0.025	−0.122	0.011	−0.179*	−0.059	−0.015	−0.047	−0.067
Eighth minute	0.048	0.082	−0.119	0.033	−0.024	0.183*	−0.262**	0.031	0.369***
Ninth minute	0.153	−0.101	0.025	0.080	−0.011	−0.075	0.004	−0.140	−0.072
Tenth minute	0.012	−0.008	−0.023	0.054	0.034	0.228**	−0.224**	0.053	−0.173*
Observations		217			183			200	

preted with caution. First, although several of the correlation coefficients in Table VII are significant, their predictive power is weak. A coefficient of -0.214 (the Eurodollar figure) implies that only 4.6 percent of the variation in returns in the second minute can be predicted based on returns in the first minute. Second, returns in successive minutes tend to be negatively correlated on nonannouncement days as well. On nonannouncement days the average correlation coefficient between successive minutes is -0.140 in the T-bond market, -0.241 in the Eurodollar market, and -0.059 in the deutsche mark market.[15] These nonannouncement correlations are consistent with a market in which actual prices fluctuate around an unchanged equilibrium price as buy and sell orders arrive.

Of course a negative serial correlation which does not represent a trading opportunity on nonannouncement days could represent a profitable trading opportunity on announcement days. On nonannouncement days, successive one-minute price changes will normally be small—primarily one-tick price fluctuations between effective bid and ask prices. From Table VI, we know that the price changes are much larger on announcement days. If a large rise in the first minute means that a large price decline is likely in the second minute, it could signal a profitable trading opportunity. To determine if this is the case, we examine separately the 15 largest negative and 15 largest positive first-minute returns following major announcements in each market—a total of 90—and then examine what happens in the second minute. While the second minute's returns are large, the direction appears unrelated to the first minute. Exactly half, 45, of the second-minute returns are the same sign as the first minute and exactly half are the opposite sign. In summary, the first minute's returns seem to have no meaningful ability to predict returns in the second minute.

D. Implications and Comparison with Previous Studies

The overall impression of the efficiency of the market in incorporating information that emerges from this evidence is quite impressive. Following an announcement, traders with immediate access to the market apparently form an estimate of the release's implication for market prices almost immediately and the actual price adjusts to this level within one minute. The price level at the end of one minute of trading is a relatively unbiased estimate of the final equilibrium price. In order to profitably trade on the market's initial reaction to the information release, one must be in a position to receive the information and place and execute an order within one minute. We doubt that anyone off the floor can do this effectively. This is a much more rapid adjustment than that observed by Patell and Wolfson (1984) who find that after dividend and earnings releases "trading profits largely disappear within

[15] To limit the data to a manageable size, we do not calculate these using all possible successive one minute pairs. They are calculated using data from 8:30 to 8:45 for the deutsche mark market, 8:30 to 8:45 and 9:15 to 9:30 for Eurodollars, and 8:30 to 8:45, 9:15 to 9:30, and 14:00 to 14:15 for T-bonds. These periods are analogous to those used in Table VII.

five to ten minutes (although we do detect significant mean returns in the overnight period and at the opening of trading on the following day)." There are several possible reasons we observe a more rapid adjustment. One, ours are more actively traded markets. Two, market microstructure differs. Three, these are widely anticipated announcements. Market participants know down to the second when the information will be released and are prepared to accept and analyze it.

While the largest price change occurs within the first minute following an information release, prices continue to be considerably more volatile than normal for fifteen minutes or so and slightly more volatile for several hours. There are at least two possible interpretations of this continued volatility. One, prices are adjusting to additional public information which only becomes available over time. While only a few summary figures are reported in the popular press, these reports usually contain much more information. For instance, the employment report is generally nine double-sided pages in length with data on employment, unemployment, and hours worked in various sectors. Prices may continue to adjust after the first minute of trading because these details are gradually becoming known. Two, the implications of the original information for prices may only become clear through trading. It is clear from the initial adjustment that traders with immediate access to the market quickly bid the price to a figure which is a relatively unbiased estimate of its final equilibrium level. However, those without such immediate access may have a better understanding of the implications of this information for interest and exchange rates so that further adjustments occur as they place their orders. This would appear to be a more satisfactory explanation for the observation that volatility remains slightly elevated for several hours after the release.

Both of these interpretations imply that it may be possible for some traders to trade profitably on the information more than one minute after its release. If a pertinent detail only becomes known ten minutes after the main release (the first hypothesis), it may be possible for those who receive this information first to trade on it. However, we suspect that in order to do so they must still be in a position to place and execute their order within one minute. The second hypothesis would imply that traders who are better informed about the implications of the announcement for interest and exchange rates than those who trade initially may be able to profitably trade later if in their view the market initially over- or underreacted.

There has been considerable debate, e.g., French and Roll (1986), over whether market volatility is due to public information or private information—the latter gathered through the costly search of individual market participants and only revealed through trading. Certainly our results emphasize the importance of public information. Moreover, we could not confirm Harvey and Huang's (1992) hypothesis that volatility is higher when a uniquely informed trader, the Federal Reserve, is active. If, however the continued volatility of these markets after the initial adjustment is due to our second reason, then private information may be important as well. The

volatility persistence in these markets may be due to the fact that the full implication of this information is only known after costly search and analysis and is only revealed through trading.

Having said this, it should be reemphasized that (1) most of the price adjustment occurs in the first minute and (2) the volatility persistence is relatively short lived. Although it remains slightly higher than normal for a couple of hours, the return variance declines quite rapidly over the first fifteen minutes or so of trading. This result also contrasts somewhat with Patell and Wolfson's (1984). They find that following dividend and earnings releases, returns continue to be more variable than normal for several hours and even into the next trading day. Again this difference may be due to the fact that ours are more heavily traded markets with a different microstructure or to the fact that these are widely anticipated announcements that market participants are prepared to analyze quickly.

V. Summary

This paper has covered considerable ground and touched on numerous issues. The conclusions and contributions which we regard as most important follow.

First, the observed intraday and day-of-the-week volatility patterns in interest rate and exchange rate futures market are mainly due to the timing of major macroeconomic announcements. When the impact of these announcements is removed, volatility is basically flat across the trading day and across the trading week.

Second, the monthly economic information releases with the greatest impact on interest rates in the 1988 to 1991 period were (in order of decreasing impact): the employment report, the PPI, the CPI, and durable goods orders. Those with the greatest impact on the dollar–deutsche mark exchange rate were: the employment report, the merchandise trade deficit, the PPI, durable goods orders, GNP, and retail sales.

Third, most of the price adjustment to these information releases occurs within one minute of the release and trading profits based on the initial reaction basically disappear within this period.

Fourth, while most of the price change occurs within one minute, volatility remains considerably higher than normal for another fifteen minutes or so and slightly higher for several hours. This can be explained as either continued trading based on the initial information as its implications for market prices are worked out or as price reactions to the details of the release as they become available.

Due to data availability, we have examined futures market prices. However, the nearby contract which we examine is a close substitute for the underlying spot market instrument and its price is known to be very highly correlated with spot prices. Accordingly, we think that our results are probably generalizable to spot interest and exchange rates as well.

Appendix: Macroeconomic Announcements

Time	Short Title	Full Title of Report	Reporting Agency	Day of the Week				
				Mon.	Tues.	Wed.	Thurs.	Fri.
8:30 A.M.	Consumer Price Index	Consumer Price Index	Bureau of Labor Statistics	1	12	9	8	7
8:30 A.M.	Durable Goods Orders	Advance Report on the Durable Goods Manufacturer's Shipments and Orders	Bureau of the Census	0	13	11	7	6
8:30 A.M.	Employment	The Employment Situation	Bureau of Labor Statistics	0	0	0	0	36
8:30 A.M.	Gross National Product	Gross National Product	Bureau of Economic Analysis	0	7	12	9	8
8:30 A.M.	Housing Starts	Housing Starts and Building Permits	Bureau of the Census	1	9	13	9	5
8:30 A.M.	Merchandise Trade Deficit	Advance Report of U.S. Merchandise Trade	Bureau of the Census	0	7	9	9	12
8:30 A.M.	Leading Indicators	Composite Indexes of Leading, Coincident, and Lagging Indicators	Bureau of Economic Analysis	0	3	14	2	17
8:30 A.M.	Producer Price Index	Producer Price Indexes	Bureau of Labor Statistics	0	0	1	6	30
8:30 A.M.	Retail Sales	Advance Retail Sales	Bureau of the Census	0	12	5	8	12
9:15 A.M.	Industrial Production	Industrial Production	Federal Reserve Board	1	10	8	4	14
9:15 A.M.[a]	Capacity Utilization	Capacity Utilization	Federal Reserve Board	1	9	9	4	14
10:00 A.M.	Business Inventories	Manufacturing and Trade: Inventories and Sales	Bureau of the Census	9	3	12	5	8
10:00 A.M.	Construction Spending	Value of New Construction Put in Place	Bureau of the Census	11	7	6	6	6
10:00 A.M.	Factory Inventories	Manufacturers' Shipments, Inventories, and Orders	Bureau of the Census	1	10	8	7	10
10:00 A.M.	NAPM Survey	NAPM Survey	National Association of Purchasing Managers	16	7	4	4	6
10:00 A.M.	New Single-Family Home Sales	New One-Family Houses Sold and For Sale	Bureau of the Census	4	10	10	7	5
10:00 A.M.	Personal Income	Personal Income and Outlays	Bureau of Economic Analysis	8	0	8	12	9
2:00 P.M.	Federal Budget	Treasury Statement (The Monthly Budget)	Department of the Treasury	9	6	8	4	10
No fixed time	Installment Credit	Consumer Installment Credit	Federal Reserve Board	8	7	6	5	11

[a] In two months the announcement was made at 10:30 and in one its timing was unclear.

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