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Intraday periodicity, long memory volatility, and macroeconomic announcement effects in the US Treasury bond market

Tim Bollerslev [a,b,*], Jun Cai [c], Frank M. Song [d,e]

[a] *Department of Economics, Duke University, Durham, NC 27708-0097 USA*
[b] *National Bureau of Economic Research, USA*
[c] *Department of Economics and Finance, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong, People's Republic of China*
[d] *Department of Economics, Cleveland State University, Cleveland, OH 44115, USA*
[e] *School of Economics and Finance, University of Hong Kong, Pokfulam, Hongkong, People's Republic of China*

Abstract

In this paper, we provide a detailed characterization of the return volatility in US Treasury bond futures contracts using a sample of 5-min returns from 1994 to 1997. We find that public information in the form of regularly scheduled macroeconomic announcements is an important source of volatility at the intraday level. Among the various announcements, we identify the Humphrey–Hawkins testimony, the employment report, the producer price index (PPI), the employment cost, retail sales, and the NAPM survey as having the greatest impact. Our analysis also uncovers striking long-memory volatility dependencies in the fixed income market, a finding with important implications for the pricing of long-term options and other related instruments.

JEL classification: C14; C22; G14
Keywords: Treasury bonds; High-frequency data; Macroeconomic news announcements; Intraday volatility patterns; Long-memory volatility

* Corresponding author. Department of Economics, Duke University, Durham, NC 27708-0097, USA. Tel.: +1-919-660-1846; fax: +1-919-684-6974.
E-mail address: boller@econ.duke.edu (T. Bollerslev).

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1. Introduction

The US Treasury bond market is one of the largest and most active financial markets in the world. Unlike the stock and corporate bond markets, most of the information of direct relevance for the Treasury bond market are likely related to macroeconomic news. There appears to be little, if any, asset-specific information concerning Treasury bonds. Consistent with this view, a number of prior studies have documented a significant bond market impact from numerous macroeconomic announcements.[1] Meanwhile, the recent availability of high-frequency data has dramatically increased the power to identify and estimate such announcement effects.

In particular, Ederington and Lee (1993) examine the impact of monthly economic announcements on 5-min Treasury bond futures returns and find that the return volatility is much higher between 0830 and 0835 Eastern Standard Time (EST) than during any other 5-min trading period. Similarly, Fleming and Remolona (1997, 1999) report significant announcement effects in the return volatility, bid–ask spread, and trading activity of the 5-year US Treasury note. In a closely related context, Balduzzi et al. (1999) study the impact of macroeconomic announcements on the price, trading volume, bid–ask spread, and volatility of both short- and long-term US interest rate instruments.

Most of these earlier studies simply regress the absolute value of the change in log prices on announcement dummies, sometimes augmented with an additional set of dummy variables to control for intraday patterns in the price volatility. Although this approach has been quite successful in identifying the announcements with the greatest impact, it does not account for the complex volatility dynamics that exists at the low interdaily and high intradaily frequencies. However, the time-of-the-day patterns (intraday calendar effects), macroeconomic announcements (public information effects), and the well-documented interday volatility persistence (ARCH effects) all constitute an integral part of the overall volatility process, and should therefore be accounted for simultaneously, or distorted estimates for any one of the individual components may arise.

Building on the methodology in Andersen and Bollerslev (1997a,b, 1998), this paper offers a comprehensive study of the intraday patterns in the volatility for the US Treasury bond futures contracts that explicitly incorporate all the different volatility components in a coherent framework. Our analysis is based on a 4-year sample of 5-min returns from 1994 to 1997. Our main findings are as follows. First, there exist two spikes in the intraday volatility at 0830 and 1000 EST, respectively, corresponding to the regularly scheduled macroeconomic announcements in the US at these times. There is also an overall U-shaped pattern in the

[1] Fleming and Remolona (1997) provide a summary of the earlier literature.

volatility across the day, although this pattern is much less pronounced than what is typically observed in equity markets. This intraday periodicity in the volatility, in turn, gives rise to a strong daily pattern in the autocorrelation of the absolute 5-min returns. Appropriately filtering out this periodic pattern, a rapid initial decay in the autocorrelations, followed by an extremely slow rate of decay thereafter, becomes evident. This shape indicates the presence of long-memory volatility dependencies in the Treasury bond market, which we also confirm by more formal testing procedures. Our finding of long-memory, or fractionally integrated volatility dependencies in the fixed income market complements previous results related to the foreign exchange and equity markets in Dacorogna et al. (1993), Ding et al. (1993), and Baillie et al. (1996), among others. Moreover, the fact that the long-memory feature manifests itself in the high-frequency data over a relatively short time span suggests that it is an inherent property of the return process.

Second, we find that the largest returns in the US Treasury bond market are readily linked to the release of macroeconomic announcements. At both the daily and intraday frequencies, the announcement effects have the highest marginal explanatory power for the volatility among the three components (calendar, announcement, and ARCH effects). Most notably, the release of the Humphrey–Hawkins testimony and the employment report generates an average instantaneous jump in volatility of about 2100% and 1400%, respectively, along with a 93% and 75% increase in the cumulative absolute return for trading days that contain these two particular announcements. Moreover, the 15 most important regularly scheduled macroeconomic news reports all result in an increase in the daily cumulative absolute returns in excess of 10%. These effects are much larger than what have previously been documented for the foreign exchange and Japanese equity markets by Andersen and Bollerslev (1998) and Andersen et al. (2000a), respectively.[2] Moreover, we confirm the robustness of these findings by splitting the sample into two separate sub-periods. Using the first 2 years for model estimation and the second 2-year period for out-of-sample forecast evaluation, the results are virtually unaltered.

The remainder of the paper is organized as follows. Section 2 describes the data, summarizes the intraday return and volatility patterns, and estimates the intraday periodic and long-memory volatility components. Section 3 examines the implications of the major macroeconomic announcements, while Section 4 assesses the overall importance of the different volatility components at the intraday and interdaily level. Section 5 concludes the paper.

[2] Related studies concerning the effect of public information releases in the foreign exchange market include Ito and Roley (1987), Goodhart et al. (1993), DeGennaro and Shrieves (1997), and Payne (1996), while Cutler et al. (1989), Berry and Howe (1994), and Mitchell and Mulherin (1994) all study announcement effects in equity prices.

2. Modeling the intraday periodicity and long-memory volatility

2.1. Data

The intraday US Treasury bond futures data are provided by the Futures Industry Institute, and cover the period from January 1994 to December 1997. Treasury bond futures contracts are traded on the Chicago Board of Trade (CBOT). The contracts require delivery of a US Treasury bond with 15 or more years to maturity, and they are generally considered to be the most heavily traded long-term interest rate instruments in the world. The contracts mature in March, June, September, and December, and we always use the data for the nearby contracts. Each data record specifies the time to the nearest second and the exact price of the futures transaction. The intraday time series is partitioned into 5-min intervals. During each 5-min interval, the last recorded price for the nearby futures contract is employed to calculate the 5-min returns. The daily time interval covers the period from 0820 to 1500 EST, corresponding to the trading hours of the CBOT, thus resulting in a total of 80 5-min returns for each trading day. Occasionally, there can be no trading for more than 10 min. In these cases, the missing futures prices are determined by linear interpolation, leading to identical returns over each of the intermediate intervals. With 1001 trading days, each consisting of 80 intraday 5-min returns, this leaves us with a total of 80,080 observations, say $R_{t,n}$, where $n = 1,2,\ldots,80$, and $t = 1,2,\ldots,1,001$.

2.2. Intradaily patterns

Fig. 1a shows that the average raw returns across the day are centered around zero with little evidence for any systematic pattern.[3] On the other hand, the plot for the average absolute returns in Fig. 1b suggests an interesting regular pattern. The average absolute 5-min returns start at nearly 0.053% early in the morning, drop to a lower level of 0.029% in the middle of the day, and rise to about 0.058% towards the close. However, compared to equity markets, the general U-shaped pattern over the trading day is much weaker. Moreover, there are two distinct spikes at 0830 and 1000 EST, respectively.

This intraday periodicity, in turn, gives rise to a striking repetitive pattern in the autocorrelations of the absolute returns in Fig. 2a.[4] The slowly declining U-shape occupies exactly a 1-day interval. Even at the 10-day, or 800th 5-min lag, there is a clear U-shape in the autocorrelations. This pattern mirrors equally pronounced

[3] The sample mean of the 5-min raw returns equals 0.000152%, which is not significantly different from zero when judged by the sample standard deviation of 0.060%. Meanwhile, the sample skewness of -0.758 and the sample kurtosis of 54.0 both suggest that the returns are not normally distributed.

[4] The autocorrelations for the 5-min raw returns are numerically small, and resemble the realizations of a white noise process.

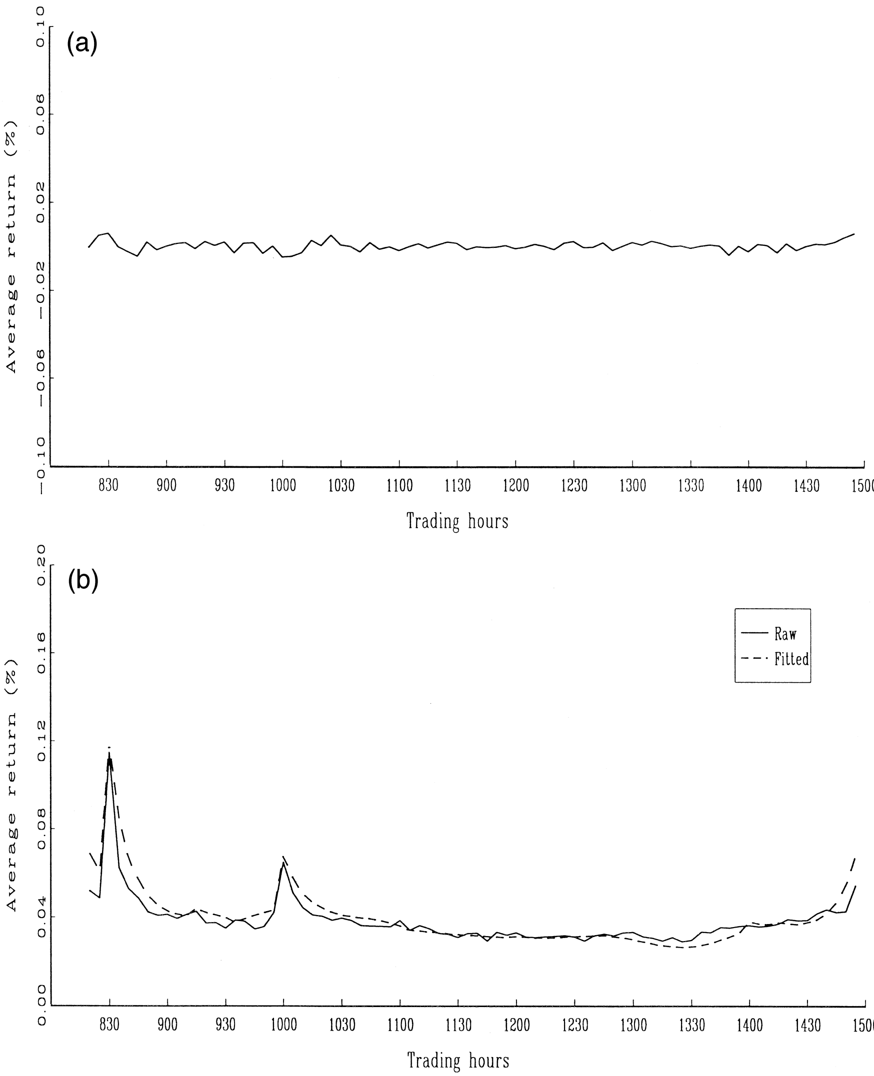

Fig. 1. (a) Treasury bond futures intraday 5-min average, *R.,n*. (b) Treasury bond futures intraday 5-min average, |*R.,n*|.

periodic dependencies in high-frequency foreign exchange and equity returns documented by Dacorogna et al. (1993), Payne (1996), Andersen and Bollersev (1997b, 1998), and Andersen et al. (2000a). The standard ARCH, GARCH and stochastic volatility models, originally designed to capture the slowly decaying interdaily volatility dependencies, are ill suited for modeling such patterns.

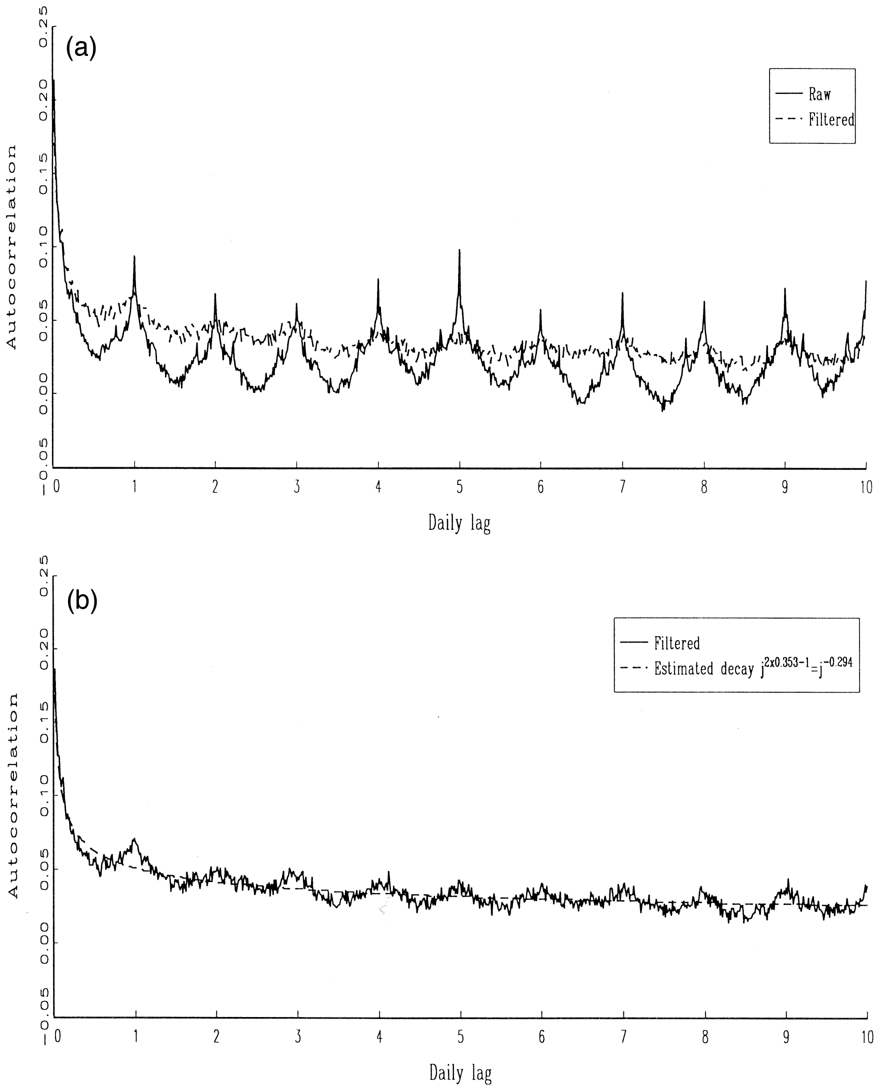

Fig. 2. (a) Ten-day correlogram for raw and filtered $|R_{t,n}|$. (b) Actual correlogram for filtered $|R_{t,n}|$ and estimated decay.

2.3. Flexible Fourier form (FFF) estimates

In order to explicitly model the periodic volatility component in the high-frequency returns, we apply the general framework developed by Andersen and Bollerslev (1997b). Specifically, on decomposing the 5-min returns as:

$$R_{t,n} - E(R_{t,n}) = s_{t,n}\sigma_{t,n}Z_{t,n},$$

where $\sigma_{t,n}$ denotes a daily volatility factor and $Z_{t,n}$ is an i.i.d. mean zero unit variance innovative term, the logarithmic seasonal component, $\ln(s_{t,n}^2)$, which may be conveniently estimated from the following FFF regression:[5]

$$2\ln\frac{|R_{t,n}-\overline{R}|}{\hat{\sigma}_t/N^{1/2}} = c + \sum_{k=1}^{D}\lambda_k I_k(t,n) + \delta_{0,1}\frac{n}{N_1} + \delta_{0,2}\frac{n^2}{N_2} + \sum_{p=1}^{P}\left(\delta_{c,p}\cos\frac{2\pi p}{N}n + \delta_{s,p}\sin\frac{2\pi p}{N}n\right) + \theta_0 D(t,n) + \varepsilon_{t,n}, \quad (1)$$

where $\overline{R}$ denotes the sample mean of the 5-min returns, $\hat{\sigma}_t$ is an a priori estimate of the daily volatility factor, N refers to the number of return intervals per day (here $N = 80$), the tuning parameter P determines the order of the expansion, and $N_1 = (N+1)/2$ and $N_2 = (N+1)(N+2)/6$ are normalizing constants. The $I_k(t,n)$ indicator variable for event k during interval n on day t allows for the inclusion of specific weekday and news announcement dummies, while the $D(t,n)$ dummy variable equals unity for expiration days.

The actual estimation of Eq. 1 involves a two-step procedure. First, we employ a fractionally integrated GARCH (FIGARCH) model to capture the daily volatility clustering.[6] The resulting 5-min volatility estimator is simply given by $\hat{\sigma}_{t,n} = \hat{\sigma}_t/N^{1/2}$. However, for some of the comparisons reported below, we shall ignore the temporal variation in σ_t, replacing it by the sample mean estimate, $\overline{\sigma}$.

The second step of the procedure involves estimating the parameters in Eq. 1 via ordinary least squares. The actual estimation is based on all 4 years of 80,080 intraday 5-min returns, as opposed to a simple estimate of the average pattern across the trading day. The advantage of the log transformation is that it helps to eliminate the extreme outliers in the 5-min return series, rendering the regression more robust. This two-step procedure is not fully efficient, but, as argued by Andersen and Bollerslev (1998), given correct specification of the second-step FFF regression, the parameter estimates are generally consistent. Thus, asymptotically, the heteroskedasticity correction in the first stage merely serves to enhance the efficiency of the parameter estimates, although the small sample performance

[5] The FFF regression was originally introduced by Gallant (1981, 1982). The trigonometric functions are ideally suited for modeling the smooth periodic intraday patterns across trading days.

[6] The MA (1)–FIGARCH (1,d,1) model specifies that $R_t = \mu_0 + \mu_1\varepsilon_{t-1} + \theta_1 D_t + \varepsilon_t$ and $\sigma_t^2 = \omega + \beta_1\sigma_{t-1}^2 + [1-\beta_1 L - (1-\phi L)(1-L)^d]\varepsilon_t^2 + \theta_2 D_t$, where the dummy variable, D_t, equals unity on futures expiration days. The actual QMLE estimates used below are obtained under the auxiliary assumption of conditionally normal standardized innovations, $\varepsilon_t\sigma_t^{-1}$, and rely on the longer sample of 3002 daily returns from January 2, 1986 to December 31, 1997, excluding the period from October 15, 1987 to November 13, 1987. Details concerning the parameter estimates are available upon request.

of the procedure can be very sensitive to this correction, as illustrated by Andersen et al. (2000b).

After some experimentation, we found that $P=6$ was sufficient to capture the basic shape, and that the parameter estimates from higher-order terms were also not significant. While the actual parameter estimates are difficult to interpret, it is clear from the corresponding plot in Fig. 1b that the fitted values provide a close approximation to the general intradaily volatility pattern in the US Treasury bond market.[7]

2.4. Dynamic dependencies

While the first stage, fractionally integrated volatility process, $\hat{\sigma}_t$, that underlies these estimates may successfully capture the volatility clustering in the daily returns, it is not obvious that it is a good model for $\hat{\sigma}_{t,n}$. In order to address this question, we filter away the estimated calendar and announcement effects in the high-frequency 5-min returns. Fig. 2a plots the autocorrelation for the raw absolute returns, $|R_{t,n}|$, and the filtered absolute returns, $|R_{t,n}|/\hat{s}_{t,n}$, where $\hat{s}_{t,n}$ denotes the normalized estimate for the periodic component from the FFF regression.[8] The former autocorrelogram is obviously dominated by the strong periodicity at the daily frequency, while the latter exhibits a strictly positive and slowly declining correlogram. Thus, by annihilating the intraday patterns, the long-memory dependencies stand out as an inherent feature of the returns process.

The autocorrelogram for the filtered returns also allows for an intuitive time-domain-based estimate for the degree of volatility persistence, or the fractional integration d. In particular, the autocorrelations, ρ_j, of a long-memory process are eventually all positive, and for large lags j, behave as $\rho_j \approx cj^{2d-1}$, where c is a factor of proportionality. Thus, taking the logarithm on both sides yields:

$$\log(\rho_j) \approx \log(c) + (2d-1)\log(j),$$

and by replacing the autocorrelations by their sample analogues an OLS estimate for d, say $\hat{d}_{\mathrm{AC}}$, is easily obtained. Applying this estimator to the sample autocorrelations for the filtered 5-min absolute returns yields $\hat{d}_{\mathrm{AC}} = 0.353$. This particular value of $\hat{d}$ is consistent with the estimates obtained for other markets based on longer time spans of daily returns, as reported by Granger et al. (1997),

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[7] The estimated pattern depicted in Fig. 1b pools all of the 27 news announcements discussed below. When the individual announcement effects are estimated separately, there is a tendency for the largest absolute returns, directly associated with the most important news releases, to result in an overfit at 0830 EST.

[8] Let $\hat{x}_{t,n}$ denote the estimated value of the right-hand side of Eq. 1. The standardized periodic component is then given by $\hat{s}_{t,n} = TN\exp(\hat{x}_{t,n}/2)/\Sigma_{t=1}^{T}\Sigma_{n=1}^{N}\exp(\hat{x}_{t,n}/2)$, where now $\Sigma_{t=1}^{T}\Sigma_{n=1}^{N}\hat{s}_{t,n} \equiv 1$.

among others.[9] The implied hyperbolic rate of decay depicted in Fig. 2b, $j^{2\times 0.353-1} = j^{-0.294}$, is also in close accordance with the actual shape of the autocorrelogram. It should be noted that this relatively simple time domain procedure for estimating d is not applicable with the autocorrelations for the raw absolute returns. Only by annihilating the intraday dependencies does the long-memory feature clearly stand out.

3. Macroeconomic announcement effects

3.1. Important announcements

One of the distinguishing features of the Treasury market concerns the extent to which prices react to the arrival of public information. To illustrate, Table 1 displays the 25 largest absolute 5-min returns over the 4-year sample period. The evidence is striking. All of the returns are directly associated with the release of economic news in the same 5-min interval. For example, 22 of the 25 largest absolute returns occur at 0830 EST, corresponding to the regularly scheduled US macroeconomic announcements at that time. The employment reports alone account for more than one half (13) of the largest absolute returns in the table, followed by producer price index (PPI) (four), retail sales (three), GDP (two), and employment costs (two). These results directly mirror the findings in earlier studies on news announcement effects in the Treasury market. In particular, Fleming and Remolona (1997) examine the 25 largest price changes in the 5-year US Treasury note from 1993 to 1994 and conclude that all of them occur on announcement days and all but one come within 15 min of an announcement.

In order to analyze more formally the actual impact of the news announcements, we collected the data on the dates and release times of 27 different macroeconomic news releases from the ‘‘The Week Ahead’’ section of *Business Week* during the 1994–1997 sample period and Bloomberg News Service. Most of these announcements are released widely and virtually instantaneously at a precise time. The government statistical agencies impose ‘‘lock-up’’ conditions to ensure that the information is not released to the public before the scheduled time (see, e.g., Fleming and Remolona, 1999).[10] While the actual release times vary for some of the news, the following list summarizes the typical announcement times. Among the 27 regularly scheduled news releases, 12 are made at 0830 EST. This

[9] The corresponding Geweke and Porter-Hudak (1983) frequency domain log periodogram regression estimates for d based on the 80,080 absolute 5-min returns and the longer time span of 3002 daily returns equal 0.308 and 0.289, respectively; see also Andersen and Bollerslev (1997a).

[10] For example, at the Bureau of Labor Statistics, reporters receive the announcements half an hour before the scheduled time in a lock-up room. The reporters are allowed to type stories into their computers, but the phone lines and modems will not be activated until precisely 0830 EST.

Table 1
Largest absolute 5-min return from US Treasury bond futures contract from 1994 to 1997
The absolute returns are based on the raw 5-min returns on US Treasury bond futures. The sample period is from January 2, 1994 to December 31, 1997. The daily time interval is between 0820 and 1500 EST, which corresponds to the trading hours of Treasury bond futures contracts on the CBOT, thus resulting in 80 5-min intervals during each trading day. Over the 4-year sample period, there are 1001 trading days, for a total of 80,080 observations. For each 5-min interval, we subjectively indicate if a US macroeconomic announcement contributed to the return.

Absolute return (%)	Date	Time (EST)	Weekday	Macroeconomic announcement
1.962	June 7, 1996	0830	Friday	Employment report
1.588	March 8, 1996	0830	Friday	Employment report
1.557	July 5, 1996	0830	Friday	Employment report
1.361	April 29, 1997	0830	Tuesday	Employment costs, Durable goods orders
1.229	June 2, 1995	0830	Friday	Employment report, leading indicators
1.166	August 5, 1994	0830	Friday	Employment report
1.082	August 1, 1996	1000	Thursday	NAPM survey, construction spending
1.040	May 12, 1994	0830	Thursday	PPI, retail sales
1.028	December 5, 1997	0830	Friday	Employment report
0.971	April 1, 1994	0830	Friday	Employment report, personal income
0.926	August 2, 1996	0830	Friday	Employment report, personal income
0.924	September 13, 1996	0830	Friday	CPI, retail sales
0.898	January 7, 1994	0830	Friday	Employment report
0.879	October 3, 1997	0830	Friday	Employment report
0.841	October 10, 1997	0830	Friday	PPI
0.790	October 13, 1994	0830	Thursday	PPI
0.777	August 13, 1997	0830	Wednesday	PPI, retail sales
0.757	July 7, 1995	0830	Friday	Employment report
0.746	May 2, 1996	0830	Thursday	GDP
0.739	June 29, 1995	1000	Thursday	New single family homes sales
0.731	January 10, 1997	0830	Friday	Employment report
0.709	January 28, 1997	0830	Tuesday	Employment costs
0.703	April 5, 1996	0830	Friday	Employment report
0.696	July 29, 1994	0830	Friday	GDP
0.694	October 8, 1997	1000	Wednesday	Wholesale trade

list includes the employment report, CPI, durable goods orders, housing starts, leading indicators, initial jobless claims, trade balances, PPI, retail sales, personal income, employment costs, and GDP. Nine of the announcements are made at 1000 EST, covering the Humphrey–Hawkins testimony, business inventories, construction spending, consumer confidence, NAPM surveys, new single-family home sales, factory inventories, existing home sales, and productivity costs. The remaining six announcements are industrial production (0915 EST), the Beige book (1200 EST), the federal budget and 10-year treasure note auction results (1400 EST), FOMC meetings (1415 EST), and consumer installment credit (1500 EST).[11] All of the announcements are monthly, except for the semiannual Humphrey–Hawkins testimony, the quarterly announcements of employment costs, the 10-year Treasury note auction results, the FOMC meetings, and the weekly announcements of initial jobless claims.[12]

3.2. FFF estimation

Given the limited number of occurrences of each type of news announcement and the inherent noise in the return process, it is not possible to estimate simultaneously separate coefficients for each event and time interval following the news releases. Instead, we impose a reasonable decay structure on the volatility response pattern and simply estimate the degree to which the event ''loads onto'' this pattern. This approach may be justified by the earlier evidence in Ederington and Lee (1993) and Fleming and Remolona (1999), indicating that while the largest price change generally occurs within the first few minutes following an information release, prices tend to be considerably more volatile for up to an hour. Following Andersen and Bollerslev (1998), we choose the dynamic response pattern to be of the form $\lambda(k,i) = \lambda_k \gamma(i)$, $i = 0,1,2,\dots,12$, where the pre-specified $\gamma(i)$ coefficients are determined by a third-order polynomial, the general shape of which is given in Fig. 3.[13] This approach restricts the response horizon to be 1 hour, except for the Humphrey–Hawkins testimony and employment report, where we explicitly double the response horizon to 2 hours.[14] Through translation of the resulting estimates for λ_k from Eq. 1, the immediate response in the absolute returns is then given by $\exp(\hat{\lambda}_k \gamma(0)/2) - 1$, while the response at the ith

[11] Employment costs include wage and benefit costs for civilian employees. The Beige book surveys business conditions of the Federal Reserve's 12 districts, and it is prepared a few weeks before each policy meeting. Industrial production and capacity utilization are always released together.

[12] With the notable exception of the Humphrey–Hawkins testimony, the employment cost, and the Beige book figures, all of which turn out to have a highly significant impact, this set of announcements corresponds fairly closely to the ones analyzed by Fleming and Remolona (1997, 1999) and Balduzzi et al. (1999).

[13] Specifically, the third-order polynomial representation of the volatility pattern following a news release is determined by $\gamma(i) = 2.47789[1-(i/13)^3] - 0.84927[1-(i/13)^2]i + 0.11986[1-i/13]i^2$ $= 0,1,2,\dots,12$, where by construction, $\gamma(13) = 0$. We calibrated this pattern by fitting all three parameters for the 27 announcements combined in Eq. 1, without the λ_k coefficient. For the rest of the announcement effects, we then fix the response pattern and estimate the λ_k coefficient that loads onto this pattern.

[14] In that case, the volatility response approaches zero in the 25th 5-min interval. In order to retain the same benchmark pattern as the 1-h response horizon, we let the i variable progress only a $(13/25)$ fraction of a unit per 5-min interval, rather than a full unit interval. This time deformation ''stretches'' the event time scale so that it conforms to the desired 2-h horizon.

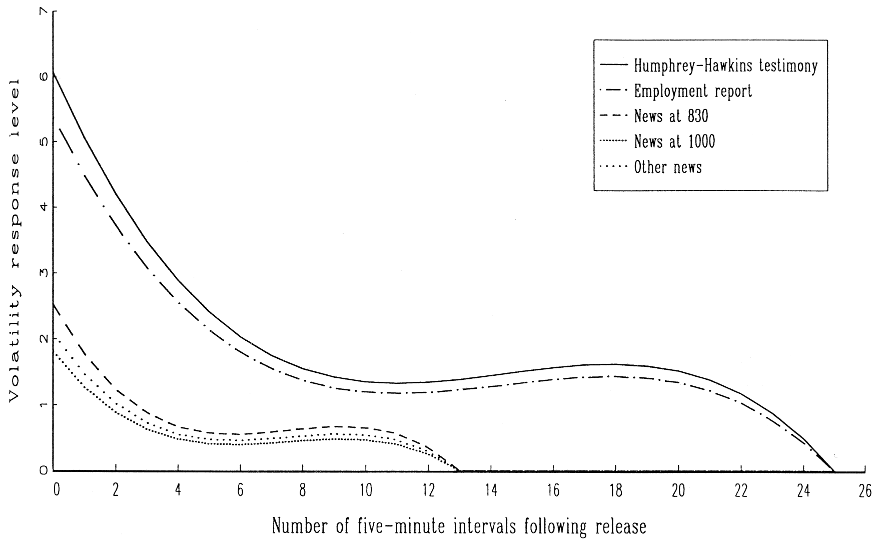

Fig. 3. Estimated announcement response patterns.

lag equals $\exp(\hat{\lambda}_k \gamma(i)/2) - 1$. Similarly, the cumulative response measure over the entire event window is given by $M(k) = \sum_{i=0}^{D}[\exp(\hat{\lambda}_k \gamma(i)/2) - 1]$, where $D = 12$ for all but the Humphrey–Hawkins testimony and the employment report, for which $D = 24$.

Table 2 summarizes the empirical results. In order to conserve space, we report only the estimated loading coefficients for each of the 27 announcements ranked according to $\hat{\lambda}_k$. The estimation is based on the full system in Eq. 1 including the time-varying daily volatility factor, the intradaily volatility pattern, and simple day-of-the-week dummies. In addition, we control for the average impact of all the remaining announcements while estimating the marginal impact of the particular announcement under investigation. Fig. 3 displays the corresponding volatility response levels, $\hat{\lambda}(k,i) = \hat{\lambda}_k \gamma(i)$, for each of the five categories of announcements over the relevant response horizons that form the basis for this set of controls. All together, 19 out the 27 announcements are significant, with the Humphrey–Hawkins testimony, the employment report, the PPI, the employment cost, retail sales, and the NAPM survey having the largest impact. With the exception of the Humphrey–Hawkins testimony, the employment cost, and the Beige book, this set of important announcements corresponds closely with those found in previous studies. As noted by Ederington and Lee (1993) and Fleming and Remolona (1997), the employment report is the first government report with information about the economic activity in a given month.

In order to clarify the economic impact of the different announcements, we report in columns three and four in Table 2 the implied instantaneous jump in the

Table 2

Macroeconomic news announcement effects on the US Treasury bond return volatility

The dependent variables are based on raw 5-min returns on the US Treasury bond futures. The sample period is from January 2, 1994 to December 31, 1997 for a total of 80,080 observations. The regression takes the form of Eq. 1, where $R_{t,n}$ denotes the 5-min returns for interval n on day t, $\overline{R}$ is the sample mean of the 5-min returns, and $\hat{\sigma}_t$ is an a priori estimate of the overall daily volatility estimated from a MA (1)–FIGARCH $(1,d,1)$ model fitted to a longer sample of daily returns. The $I_k(t,n)$ regressors refer to the dummies for either weekdays or prespecified volatility response patterns associated with the news announcements. The volatility response pattern is approximated by a third-order polynomial restricted to reach zero at the end of the response horizon of 1 h, or the 13th 5-min interval, except for the Humphrey–Hawkins testimony and employment report, where the response horizon is set to two h, 25 5-min intervals. The announcement coefficients measure the extent to which the absolute returns load into this pattern. Announcements made at 0830 EST include the employment report, CPI, durable goods orders, housing starts, leading indicators, initial jobless claims, trade balances, PPI, retail sales, personal income, employment costs, and GDP. Announcements made at 1000 EST cover Humphrey–Hawkins testimony, business inventories, construction spending, consumer confidence, NAPM surveys, new single-family home sales, factory inventories, existing home sales, and productivity costs. Announcements made at other times include industrial production (0915 EST), the Beige book (1200 EST), the federal budget and 10-year treasury bond auction results (1400 EST), FOMC meetings (1415 EST), and consumer installment credit (1500 EST). The instantaneous jump in volatility measures the estimated increase in the 5-min absolute return for the interval when the announcement is made; the estimated total cumulative absolute return induced by the announcement over the assumed horizon is measured relative to the median cumulative absolute return over the sample period, which equals 2.90% per day.

Announcements	Coefficients	Robust *T*-statistics	Instantaneous jump in volatility (%)	Impact on daily cumulative absolute return (%)
Humphrey–Hawkins testimony	2.507	10.91	2133	93.2
Employment reports	2.174	19.56	1378	75.1
PPI	2.057	14.96	1179	39.7
Employment costs	1.687	7.30	709	26.9
Retail sales	1.667	7.53	689	26.3
NAPM survey	1.647	9.42	670	23.2
FOMC meetings	1.641	8.04	664	24.3
CPI	1.593	10.63	620	24.2
Treasury note auction results	1.306	4.34	404	16.1
Beige book	1.242	4.51	366	11.4
Industrial production	1.085	6.60	284	12.1
Housing starts	1.038	7.00	262	12.3
GDP	0.986	4.34	239	11.4
Consumer confidence	0.967	4.35	231	10.0
New single-family home sales	0.964	5.33	230	10.0
Trade balance	0.846	5.31	185	9.3
Business inventory	0.732	3.70	148	6.9
Durable good orders	0.701	3.90	138	7.3
Existing home sales	0.590	2.71	108	5.3
Construction spending	0.479	1.50	81	4.1
Personal income	0.195	1.02	27	1.7
Productivity and costs	0.180	0.64	25	1.4

(continued on next page)

Table 2 (*continued*)

Announcements	Coefficients	Robust T-statistics	Instantaneous jump in volatility (%)	Impact on daily cumulative absolute return (%)
Initial jobless claims	−0.077	−0.40	−9	−0.6
Consumer credit	−0.139	−0.36	−16	−0.8
Federal budget	−0.151	−0.78	−17	−1.1
Leading indicators	−0.159	−0.70	−18	−1.2
Factory inventories	−0.250	−1.11	−27	−1.7
Announcements at 0830 EST	1.017	14.49	252	11.9
Announcements at other times	0.842	8.85	184	8.1
Announcements at 1000 EST	0.729	8.24	147	6.9

volatility and the cumulative impact over the day. For illustration, consider the employment report. The estimate implies $\hat{\lambda}_k \gamma(0) = 2.174 \times 2.478 = 5.387$, which is equivalent to an impact on the absolute 5-min return of $\exp(5.387/2) = 14.78$, or an instantaneous jump in the volatility of 1378%. The corresponding cumulative response $M(k)$ amounts to 53.05. Since the average 5-min absolute return over the 2-h response horizon from 0830 to 1030 EST equals 0.041%, the overall effect is an elevation of the volatility by a total of 53.05×0.041, which equals 2.18%. This translates into a 75.1 $(2.18/2.90)$% average increase in the cumulative absolute return for trading days on which the employment report is released. Similarly, the 15 most important announcements all imply an increase in the daily cumulative absolute returns in excess of 10%. These announcement effects for the US Treasury bond market are much greater than what have been observed for other markets.[15]

Even though Monday through Friday account for a disproportionate 10.1%, 23.4%, 23.2%, 20.6%, and 22.3% of the announcements in our sample, including all of the announcement coefficients in the regression in Eq. 1, the day-of-the-week dummies remain highly significant. Specifically, the $\hat{\lambda}_k$ Tuesday through Friday estimates (t-statistics) for the weekday dummies are 0.19 (3.28), 0.36 (6.42), 0.66 (11.74), 0.61 (10.87), respectively. As such, these results point toward underlying institutional features in the Treasury bond market as the source behind the systematic differences in the volatility across trading days. We shall not pursue this any further here, however.

[15] For instance, in their analysis of a 1-year sample of 5-min Deutschemark–US dollar exchange rates, Andersen and Bollerslev (1998) found that the employment report creates an instantaneous jump in the volatility of ‘‘only’’ 576%, while the average increase in the cumulative absolute return for trading days that contain a scheduled employment report is just 15%.

4. The relative importance of different volatility components

4.1. Model evaluation

In this section, we provide a direct assessment of the joint and marginal predicative power of each of the three volatility components — calendar effects, announcement effects, and the daily volatility factor. The basic idea is to construct a series of volatility forecasts that in turn leave out the contribution from each of the three components.

Formally, this comparison is based on the 1-day-ahead 5-min absolute return forecasts obtained as:

$$\upsilon(I:t,n) = N^{-1/2}\left[\hat{\sigma}_t I_\sigma + \bar{\sigma}(1-I_\sigma)\right] \times \exp\left(\frac{\hat{f}_c(t,n)I_c + \hat{f}_a(t,n)I_a + \hat{f}_w(t,n)I_w}{2}\right), \quad (2)$$

where $f_c(t,n)$, $f_a(t,n)$, and $f_w(t,n)$ denote the estimated calendar, announcement, and day-of-the-week effects from the regression in Eq. 1. The indicator variables I_c, I_a, and I_w signify whether the calendar, announcements, and day-of-the-week effects are accounted for in the particular forecast. Also, I_σ is set to unity if the time-varying daily volatility factor from the MA (1)–FIGARCH $(1,d,1)$ model, $\hat{\sigma}_t$, is included in the construction of the forecast, while I_σ equals zero if the daily volatility factor is assumed to be constant, $\bar{\sigma}$. In order not to obscure the comparisons, the highly significant day-of-the-week effects are incorporated in all of the forecasts. The joint and marginal contributions of the three volatility components at the daily and intraday frequencies are then measured by the coefficient of explained variation, R^2, from the regressions of the realized cumulative absolute returns, $\sum_{n=1}^{N}|R_{t,n} - \bar{R}|$, and the realized 5-min absolute returns, $|R_{t,n} - \bar{R}|$, on the corresponding volatility forecasts, $\sum_{n=1}^{N}\upsilon(I:t,n)$ and $\upsilon(I:t,n)$, respectively.

4.2. In-sample results

Table 3 summarizes the results for the eight possible model configurations as indicated by the triplet (I_σ, I_c, I_a). The in-sample calculations in the first two data columns are based on the full 4-year sample. The numbers in the first data column refer to the degree of explained variation in the daily cumulative absolute returns. The complete model explains 33.9% of the total variation. The number is only slightly reduced when the calendar effects are removed from the forecast. In contrast, the number drops to 20.6% and 25.3%, respectively, when either the announcement effect or the daily volatility factor is omitted. Interestingly, the benchmark day-of-the-week effects alone explain about 12.4%, which is virtually

Table 3

Explained variation (R^2) for US Treasury bond volatility based on alternative absolute return forecasts

The sample of 5-min returns on the US Treasury bond futures covers the period from January 1994 to December 1997 for a total of 80,080 observations. The 1-day-ahead 5-min absolute return forecasts are obtained as:

$$\upsilon(I:t,n) = N^{-1/2}\left[\hat{\sigma}_t I_\sigma + \bar{\sigma}(1 - I_\sigma)\right]\exp\left(\frac{\hat{f}_c(t,n)I_c + \hat{f}_a(t,n)I_a + \hat{f}_w(t,n)I_w}{2}\right),$$

where $N = 80$, $f_c(t,n)$, $f_a(t,n)$, and $f_w(t,n)$ denote the estimated calendar, announcement, and day-of-the-week effects from a regression of the normalized, log-squared, demeaned 5-min US Treasury bond futures returns on calendar, announcement, and day-of-the-week regressors. The indicator variables I_c, I_a, and I_w signify whether the calendar, announcements, and day-of-the-week effects are accounted for in the particular forecast. For example, $(I_c, I_a, I_\sigma) = (1,1,0)$ corresponds to the model where both the calendar and announcement effects are included, but the daily volatility factor is assumed to be constant. The day-of-the-week effects are always included in the regressions. For the in-sample results, the daily volatility, $\hat{\sigma}_t$, is estimated from an MA (1)–FIGARCH $(1,d,1)$ model fitted to a sample of 3002 daily returns from January 2, 1986 to December 31, 1997. The sample mean of $\hat{\sigma}_t$ is denoted by $\bar{\sigma}$. The table reports the coefficients of explained variation, or R^2, from regressing the daily cumulative absolute returns, or $\sum_{n=1}^{80}|R_{t,n} - \bar{R}|$, on $\sum_{n=1}^{80}\upsilon(I:t,n)$, $t = 1,2,\ldots 1001$, and from regressing the 5-min absolute returns, or $|R_{t,n} - \bar{R}|$, on $\upsilon(I:t,n)$, $t = 1,2,\ldots 1001$, and $n = 1,2,\ldots,80$. For the out-of-sample results, the 4-year sample is split into two 2-year sub-samples, corresponding to the 1994–1995 and 1996–1997 periods. The estimates from the 1994–1995 sample are used to predict the intraday patterns in the 1996–1997 sample. The daily volatility for the 1996–1997 period is predicted using the MA (1)–FIGARCH $(1,d,1)$ estimates from January 2, 1986 to December 29, 1995.

Model	In-sample		Out-of-sample	
	Daily cumulative absolute return	5-min absolute return	Daily cumulative absolute return	5-min absolute return
Complete model, $(I_c, I_a, I_\sigma) = (1,1,1)$	0.339	0.156	0.331	0.144
No calendar effects $(I_c, I_a, I_\sigma) = (0,1,1)$	0.333	0.139	0.326	0.123
No announcements $(I_c, I_a, I_\sigma) = (1,0,1)$	0.206	0.053	0.197	0.048
No daily volatility $(I_c, I_a, I_\sigma) = (1,1,0)$	0.253	0.144	0.253	0.139
Calendar effects only $(I_c, I_a, I_\sigma) = (1,0,0)$	0.124	0.046	0.130	0.042
Announcements only $(I_c, I_a, I_\sigma) = (0, 1,0)$	0.246	0.126	0.242	0.117
Daily volatility only $(I_c, I_a, I_\sigma) = (0, 0,1)$	0.206	0.017	0.197	0.015
Day-of-the-week effects only $(I_c, I_a, I_\sigma) = (0,0,0)$	0.124	0.010	0.130	0.010

the same as that from adding the calendar effects. This indicates that the strong intraday patterns are effectively annihilated when aggregating to the daily level. On the other hand, the R^2 increases to 24.6% when the announcement effects are included. Compared to the results for the foreign exchange market in Andersen and Bollerslev (1998) or the results for the Japanese equity market in Andersen et al. (2000a), the impact of the macroeconomic announcements is much larger for the bond market. In fact, among the three distinct components in the model, the announcement effects are the most important source of the overall volatility at the daily level.

Turing to the degree of explanatory power for the high-frequency 5-min absolute returns, the explained variation for the full model drops to ''only'' 15.6%. The announcement effects again stand out as the most important component, explaining an impressive 12.6% alone. The calendar effects are secondary, explaining 4.6% by themselves. Not surprisingly, the daily volatility factor adds little explanatory power at the highest frequencies.

4.3. Out-of-sample results

The last two columns in Table 3 report the results from a similar out-of-sample forecast evaluation. Specifically, we first split the full 4-year sample into two 2-year sub-samples, i.e., 1994–1995 and 1996–1997, respectively. We then re-estimate the MA (1)–FIGARCH $(1,d,1)$ model using daily returns from January 2, 1985 to December 29, 1995 only. Next, the resulting daily volatility factor is used to estimation a new set of FFF coefficients and announcement effects for 1994–1995. These estimates for the first sub-sample are in turn used to predict the daily volatility, the intraday patterns, and announcement effects for the second sub-sample. Finally, the corresponding out-of-sample R^2 values are calculated as outlined above. The results are striking. The out-of-sample forecasting performance of the model is remarkably close to the in-sample results, with most of the differences in the numbers only manifesting themselves at the third decimal point. Thus, from a true forecasting perspective, the announcement effects remain the most important source of volatility at both the intraday and interdaily frequencies.

5. Concluding remarks

This paper provides a detailed characterization of US Treasury bond futures return volatility based on a 4-year sample of 5-min returns from 1994 to 1997. Consistent with previous findings, we find two spikes in the intraday absolute 5-min return, corresponding to the regularly scheduled US macroeconomic announcements at 0830 and 1000 EST, respectively. The volatilities at the open and close are also higher than in the middle of the day, although the corresponding U-shape is less pronounced than the typical pattern in equity markets. The strong intraday periodicity leads to equally strong patterns in the autocorrelation of the absolute returns, which in turn overshadows the longer-run dynamic dependencies. However, when explicitly adjusting for the repetitive pattern, a striking long-memory hyperbolic rate of decay becomes evident in the autocorrelations.

Our analysis also details the impact of regularly released US macroeconomic announcements. Among the 27 different announcements that we investigate, the Humphrey–Hawkins testimony and the employment report are by far the most important, followed by the PPI, the employment cost, retail sales, and the NAPM survey. Although this list corresponds fairly closely to previous results in the literature, our approach provides new evidence for the incremental explanatory power afforded by each of the announcements, both at the daily and intradaily levels. In contrast to prior results for the foreign exchange and equity markets, we find that the macroeconomic announcement effects constitute an important source of bond market volatility, even at the daily horizon.

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