INFORMATION CONTENT OF THE FED FUNDS RATES

JAHANGIR SULTAN

This study shows that the Fed Funds spot rate mostly affects the level of key interest rates while the Fed Funds futures rate tends to affect both the level and the volatility. Such effects are more concentrated on the shorter segment of the yield curve. In addition, only an unexpected change in the target rate affects both the level and the volatility of interest rates. Finally, the FOMC's increased disclosure of its policy stance has a calming effect on the volatility of key interest rates. © 2005 Wiley Periodicals, Inc. Jrl Fut Mark 25:753–774, 2005

INTRODUCTION

Innovations in the Fed Funds spot and the CBOT 30-day Fed Funds futures[1] rates are expected to affect the level and the volatility of short- and long-term interest rates (Krueger & Kuttner, 1996). Such predictions

[1]The CBOT 30-day Fed Funds futures contract calls for delivery of the interest paid on $5 million overnight fed Funds held for 30 days. The contract is cash settled against the monthly average of the daily Fed Funds effective rate. Currently, 1 through 5-month contracts are traded, in addition to a "spot" month contract that is based on average Funds rate in the current month. Since its introduction, the Fed Funds futures contract has become popular for hedging and speculation.

Many thanks to an anonymous referee, the editor of this journal, David Gulley, David Simon, James Zeitler, and seminar participants at the FMA Annual Meeting, Denver, for their insightful comments.
For correspondence, Department of Finance, Bentley College, 175 Forest Street, Waltham, Massachusetts 02154; e-mail: jsultan@bentley.edu

Received November 2003; Accepted October 2004

■ *Jahangir Sultan is a Professor of Finance and Founding Director of the Hughey Center for Financial Services in the Department of Finance at Bentley College in Waltham, Massachusetts.*

The Journal of Futures Markets, Vol. 25, No. 8, 753–774 (2005)

Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/fut.20162

are based on the notion that the Fed Funds rates offer information to predict the Fed's near-term target[2] and its stance on monetary policy. The extent to which monetary information flows simultaneously affects the level and the conditional volatility of key interest rates has not been adequately addressed in the literature. In this article, using the multivariate GARCH model, the effects of changes in the Fed Funds spot and futures rates on *both* the level and the conditional volatility of the eurodollar and the 30-year Treasury bond futures yields are compared. The use of the short- and long-term rates in a multivariate GARCH model is new and offers an innovative framework to examine the effects of monetary policy on interest rate volatility.

The results in this study indicate that despite popular belief that the Fed Funds spot rate has nothing to do with monetary policy, key interest rates do respond to changes in this rate. Its impact on volatility, however, is insignificant. Compared to the Fed Funds spot rate, the Fed Funds futures rate has a more pronounced effect on both the level and the volatility of interest rates; however, its effects on the interest rate volatility are not always consistent. It has also been found that an unexpected change in the target rate leads to lower interest rate volatility, supporting the notion that actions by the Federal Reserve (Fed) resolve uncertainty in the market. Along the same line, the results suggest that the Fed's decision to announce rate actions immediately following Federal Open Market Committee (FOMC) meetings has led to lower interest rate volatility. This would confirm the notion that since 1994 federal policymaking has become more transparent.

THE INFORMATION CONTENT HYPOTHESIS

The hypothesis that the Fed Funds spot rate offers information on federal policy matters is grounded in the ways the Fed changes the target rate for the Fed Funds spot market and the manner in which the commercial banks respond to such changes. A commercial bank can raise the required reserves when it fails to meet the Fed's reserve requirement, for example, by liquidating existing portfolio investment, borrowing excess reserves (Federal Funds) in the reserves market, and borrowing from the Fed. The Fed uses the Fed Funds rate to control liquidity in the market.

[2]The frequency of target rate changes has varied over the years. For example, during the 1974–79 period, the Fed changed its Funds rate target 98 times, but the number of changes during 1984–89 was substantially less—only 32 times (Thornton, 2004). In recent days, the frequency of Funds target changes has accelerated with a sharp downturn in the economy. For example, there were 14 changes in the Funds target rate during January 2001 to July 2004. The sample period in this study (October 3, 1988 to July 7, 2004) contains 68 changes in the Federal funds target rate.

For example, the Fed reduces the supply of reserves by conducting open market sale of securities when the Funds rate target is raised. In contrast, when the Funds rate target is lowered, the Fed is believed to have been conducting open market purchase of securities, which adds reserves to the banking system, and subsequently leads to lowering of the Fed Funds rate (Taylor, 2001). As Bernanke and Blinder (1992), Bernanke and Mihov (1998), and Goodfriend (1991) among others claim, the long-term interest rate is based upon the average expected level of the Fed Funds spot rate over the relevant holding period, so the Fed Funds spot rate can predict future monetary policy. Ho and Saunders (1985) claim that the size of the positive spread between the Fed Funds spot rate and short-term money market rates is due to the Fed's operating policies.

Critics note that the daily changes in the Fed Funds spot rate have little to do with monetary policy, and therefore are not useful predictors of the Fed's actions. For instance, it is widely believed that the Fed Funds spot rate generates noisy signals due to many stylized features[3] in the Fed Funds markets. Some of these features have very little to do with monetary shocks. In addition, the Fed is known to adopt indirect channels—borrowed reserves and both technical and nontechnicalchanges in the discount rate[4]—to affect the Fed Funds market. This supports the notion that the Fed Funds spot rate may not be an important indicator of monetary policy, as it has been suggested. Bernanke (1990) and Garfinkel and Thornton (1995) suggest that the Fed Funds rate does not contain unique information about monetary policy; rather almost any other short-term interest rates such as the overnight repo rate or the 3-month T-bill rate would be just as good as the Fed Funds spot rate in conveying information about the Fed's policy action. Similarly, Stock and Watson (1988) and Friedman and Kuttner (1993) find the spread between 6-month T-bill and the 6-month commercial paper to be good predictors of most macroeconomic variables.

[3]The Fed requires periodic settlement (currently, every other Wednesday) of surplus and deficit positions of commercial banks' reserves with the Fed. For each bank, the Fed calculates the daily closing balances and at settlement the cumulative total is compared against the required reserves. Deficit banks receive a penalty and are forced to borrow the reserves from the Fed. Several studies exist that concentrate on empirical regularities such as the day-of-the-week effects in the level and daily variability of the Funds rate (for example, Cyree & Winters, 2001; Dyl & Hoffmeister, 1985, Griffith & Winters, 1995; Saunders & Urich, 1986). Spindt and Hoffmeister (1988) analyze the effects of institutional regularities such as the reserve maintenance and reserve settlement feature on the Fed Funds market. Using data for the period 1984–1986, Spindt and Hoffmeister show that the daily variance of the Fed Funds rate increases towards the end of day because of end of the day accounting of closing balances; the variance is also highest on settlement Wednesdays.

[4]Changes in the discount rate that are due to institutional reasons, rather than due to monetary policy.

In contrast, the Fed Funds *futures* rate is considered by many to be a better predictor of the Fed's policy actions. In particular, the spot month contract is a good proxy to predict near-term Fed Funds rate (Kuttner, 2001). Additionally, Krueger and Kuttner (1996), Kuttner (2001), and Rudebusch (1998) find that 1-month, 2-month, and 3-month future rates are all accurate predictors of subsequent Fed Funds rate movements. Carlson, McIntire, and Thomson (1995) find that the Fed Funds futures contracts are good predictors of future Fed Funds rate changes and Fed policy moves only for shorter forecast horizons. Finally, according to Pakko and Wheelock (1996), during 1994 and 1995 the Fed Funds futures market provided good information to predict Fed policy actions.

Overall, as an overnight rate, the Fed Funds spot reacts mostly to stylized institutional features in the market for excess funds and should not be expected to provide meaningful information about future monetary policy. However, one cannot completely disregard innovations in the Fed Funds spot market affecting key interest rates. The extent to which these innovations signal expected policy innovations in the near future deserves further examination. In contrast, one would expect the Fed Funds futures market to have significantly more pronounced effects on the level of market interest rates. Finally, very little has been done to discriminate between the Fed Funds spot and the futures markets in terms of their effects on the volatility of interest rates. Any difference in the way market interest rates respond to these two indicators would suggest that the strength and quality of monetary policy information signals differ across markets. Such differences could be a manifestation of the way information is generated in the Fed Funds spot and futures markets and is subsequently interpreted by market participants. One obvious method of testing this hypothesis is to link this information to the statistical distributions of key interest rates.

Therefore, an important contribution of this study stems from the application of a time series model to document the effects of monetary policy in contributing to stylized features such as the time varying volatility of the eurodollar and the T-bond futures yield. Prior research linking information and asset returns has shown that the assumption of normality and constant volatility in high frequency financial data is inappropriate. The multivariate GARCH method is suited for modeling the distribution of high frequency financial market data that are non-normal with fat tails and volatility clustering. Furthermore, the use of the Fed Funds spot and futures rates as sources of information is strongly grounded in the literature that emphasizes the link among information flow, asset price volatility, and volume of trading (see, for example, Admati & Pfleiderer, 1988; Karpoff, 1987). In this strand of the literature, the effect of information flows on asset volatility and volume increases with the degree of heterogeneous expectations, subsequently, asset returns are modeled as a mixture of normal distribution with information (or the volume) as the mixing variable. In this study, the inclusion of the Fed Funds spot and the futures rates offers an opportunity to examine if they affect the level and the volatility of key interest rates.

EMPIRICAL ANALYSIS

In this section, an empirical analysis of the effects of changes in the Fed Funds spot and futures rates on the level and the volatility of short- and long-term interest rates is provided.

The Data

The daily data for the period October 3, 1988 to July 7, 2004 are collected from the Datastream. The Fed Funds spot rate is the effective Fed funds rate, calculated by the Board of Governors. The Fed Funds futures rate is based on the nearby contract. The yield on the 3-month eurodollar contracts is a simple add-on yield. For the T-bond futures, the daily yield is calculated as the internal rate of return on a 30-year T-bond with a 6% coupon. To avoid expiration related problems all futures contracts are rolled over to the next nearest contract 2 weeks prior to expiration.

Figures 1 and 2 display the above interest rates. In Figure 1, both the Fed Funds spot and futures rates are on a downward trend, suggesting that the rates may not be stationary over the sample period. In addition, the Fed Funds spot rate seems to track the futures rate well, although the spot rate appears to be more volatile than the futures rate. If one assumes that innovations in both markets may be interrelated, it is possible that innovations in the spot rate also signal monetary policy. Therefore, by tracking the Fed Funds futures market, innovations in the spot market may be useful in conveying information on the Fed's policy stance.

In Figure 2, the 3-month eurodollar and the 30-year T-bond futures rates demonstrate a declining trend over the sample. Both figures suggest that all four interest rates may be nonstationary. To confirm nonstationarity, diagnostic tests are performed. In Panel A, Table I, the Phillips-Perron unit root test results are shown. All variables are nonstationary in the levels; the t statistics are below the critical value of 3.96 at

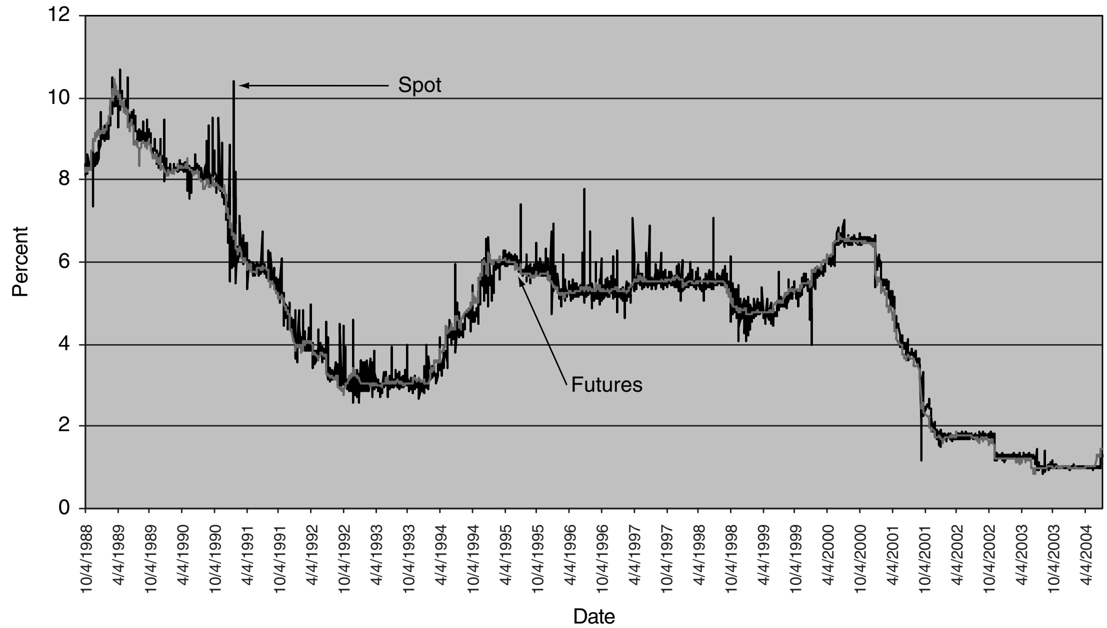

FIGURE 1
Daily Fed Funds spot and futures rates.

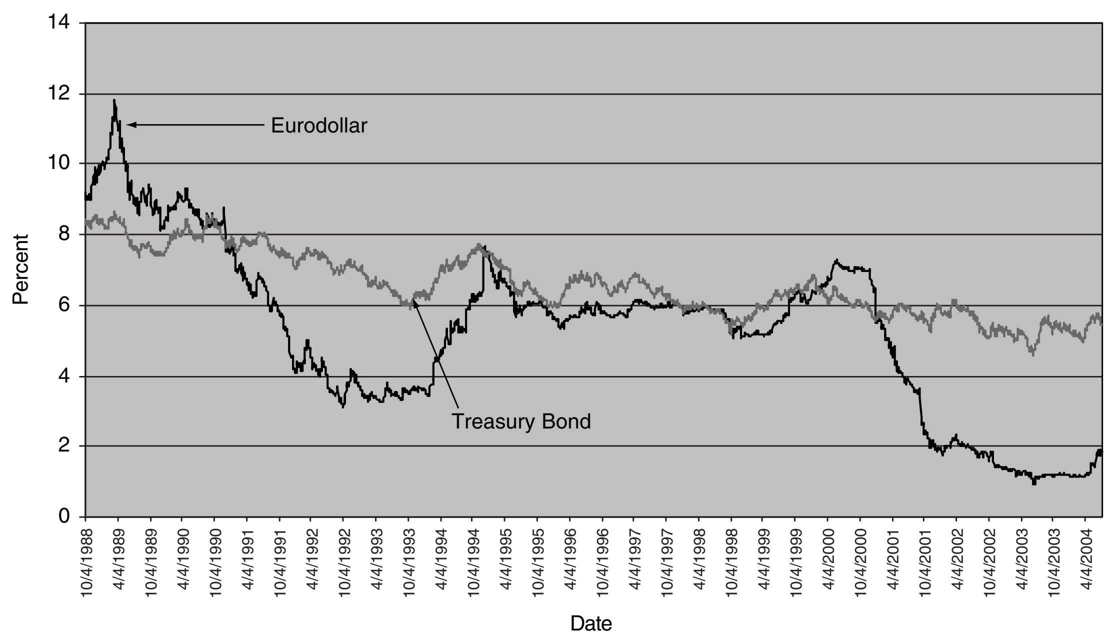

FIGURE 2
Daily eurodollar and Treasury bond futures rates.

TABLE I

Descriptive Statistics

Panel A: Phillips–Perron Unit Root Test

	Level	*First differenced*
Variable	*t-Stat*	*t-Stat*
Fed Funds Spot rate	−2.40	−138.88
Fed Funds Futures rate	−0.98	−59.93
Eurodollar Futures rate	−1.37	−58.95
Treasury Bond Futures rate	−3.69	−62.48
Target rate	−0.87	−63.18

Note. T-stats are reported above. MacKinnon's critical value for the *t*-stat for rejection of a hypothesis of a unit root (with trend and a constant) is −3.96 at the 1% level.

Panel B: Descriptive statistics (First differenced data)

	Mean	*SD*	*Skewness*	*Kurtosis*	*Jarque-Bera*
Fed Funds Spot rate	−0.05	5.44	0.67	21.68	3657.74
Fed Funds Futures rate	−0.04	1.09	0.10	79.21	44721.18
Eurodollar Futures rate	−0.04	1.33	.92	26.23	5483.70
Treasury Bond Futures rate	−0.01	0.70	0.44	1.81	149.89
Target rate	−0.01	0.04	−2.10	102.93	78541.11

Note. Jarque-Bera is a test for normality. The critical value of this chi-square for rejecting the hypothesis of normality is 36.39 at the 1% level.

Panel C: Johansen's Cointegration Test

	LR	*Critical value (1%)*
Fed Funds Spot, Fed Funds Futures	359.90	30.45
Eurodollar, Treasury Bond	18.22	30.45

Note. LR is the log-likelihood ratio statistics for cointegration. The LR indicates that the Fed Funds spot and Fed Funds futures rates are cointegrated.

Panel D: Granger Causality Test

	F
Fed Funds spot rate does not Granger cause Fed Funds futures rate	1.35
Fed Funds futures rate does not Granger cause Fed Funds spot rate	14.23
Eurodollar does not Granger cause Treasury Bond	1.16
Treasury Bond does not Granger cause eurodollar	0.81

Note. Critical value for the *F*-ratio is 3.98 at the 1% level (24 lag).

the 1% level. These tests are repeated using first differenced data and the results suggest that first differencing induces stationarity. In Panel B of Table I, descriptive statistics are reported. Among the interest rates, the Fed Funds spot rate appears to be most volatile. Panel B also shows that the first differenced variables are skewed and kurtotic. The Jarque–Bera statistic indicates that these variables are not normally distributed.

Since the dependent variables in this study are changes in the eurodollar and the T-bond futures yields, Panel C reports Johansen's test for cointegration between them.[5] The results suggest that these two rates are not cointegrated, so there is no need to include an error correction term to model the short- and long-run relationship between them. The results also suggest that the Fed Funds spot and futures rates are cointegrated, further supporting the notion that innovations in both markets are linked. A causal relationship between these interest rates is examined. In Panel D, Granger causality tests indicate that the eurodollar and the T-bond rates do not Granger-cause one another. This particular test is important as it demonstrates that the eurodollar and the T-bond futures yields are not endogenously linked to one another. Therefore, these rates are modeled in a seemingly unrelated regression setting.[6] On the other hand, there is evidence that the Fed Funds futures rate Granger-causes the Fed Funds spot rate. While I do not make use of the Granger causality between the Fed Funds spot and the futures rates in this study, it does offer support to the notion that the spot rate reacts to the information embedded in the Fed Funds futures rate. This may also suggest that volatility spillover maybe unidirectional—from the Fed Funds futures rate to the Fed Funds spot rate.[7] Finally, there is an examination of Granger causality among the Fed Funds spot, futures, and the daily target rate. Though not reported, the results indicate that these three variables Granger-cause one another, although the strength of the

[5]Cointegration is indicative of a fundamental relationship between two variables. An evidence of cointegration would indicate that as these two rates deviate from one another, arbitrage using the eurodollar and the T-bond would force these rates to return to a long-run equilibrium. As Engle and Granger (1987) note, if two variables are cointegrated, then omitting the error correction term amounts to a model misspecification.

[6]It is also critical to note that the purpose of this study is not to present a complete econometric model of interest rate determination. As such, many important macroeconomic variables such as inflation, payroll data, industrial production, trade balance, for example, are omitted from the model. Also, the convergence of a full-blown econometric model with a large number of explanatory variables is problematic. Therefore, the model presented here offers a partial glimpse on the interaction between information flow and interest rate volatility.

[7]Several bivariate GARCH models were estimated to examine the extent of volatility spillovers between the Fed Funds spot and the futures markets. The results, not reported, confirm the intuition that spillover is unidirectional—from futures to the spot rate. Statistical reliability of the results, however, is poor because of serial correlation in standardized residuals.

causality tends to vary. Overall, both the cointegration result and the Granger causality tests reveal important dynamics between the Fed Funds spot, the Fed Funds futures, and the target rate for the Fed Funds market.

The Effects of Changes in the Fed Funds Spot and Fed Funds Futures Rates

The following bivariate GARCH model, similar to the one reported in Kroner and Sultan (1993) is used:

$$\begin{aligned} \Delta \ln ED_t &= \alpha_0 + \alpha_1 \Delta \ln Fed_t + \varepsilon_1 \\ \Delta \ln TB_t &= \beta_0 + \beta_1 \Delta \ln Fed_t + \varepsilon_2 \end{aligned} \tag{1}$$

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix} \Bigg| \psi_{t-1} \sim N(0, H_t) \tag{2}$$

$$\begin{aligned} H_t = \begin{bmatrix} h_{1,t} \\ h_{12,t} \\ h_{2,t} \end{bmatrix} = \begin{bmatrix} \tau_1 \\ \tau_{12} \\ \tau_2 \end{bmatrix} + \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} \varepsilon^2_{1,t-1} \\ \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon^2_{2,t-1} \end{bmatrix} \\ + \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} h_{1,t-1} \\ h_{12f,t-1} \\ h_{2,t-1} \end{bmatrix} \end{aligned} \tag{3}$$

where $\Delta \ln ED_t$ and $\Delta \ln TB_t$ in the mean equations are changes in the natural log of the implied yields based upon the eurodollar and the T-bond futures, respectively. Daily changes in the natural log of the Fed Funds spot/Fed Funds futures rate, depending upon model specification, are defined as $\Delta \ln Fed_t$.[8] The terms ε_1 and ε_2 are the residuals from the mean equations.[9] Equation (2) describes their joint density function which is time varying, and in Equation (3), $h_{1,t}$ ($h_{2,t}$) is the conditional variance of the eurodollar (T-bond) yields and the term $h_{12,t}$ is the conditional covariance between the rates. In Equation (3), τs are constant terms in the H_t matrix, $a_{11} \ldots a_{33}$ are ARCH coefficients, and $b_{11} \ldots b_{33}$ are GARCH coefficients. To examine the effects of changes in the Fed

[8]Based upon the cointegration results, I did not include an error correction term ($\ln ED_{t-1} - \ln TB_{t-1}$) in the mean equations.
[9]Note that the variable Fed_t may also refer to the Fed Funds futures rate in subsequent estimations.

Funds spot/futures rate on the volatility of key interest rates, the modified variance equation [Equation (4)] is:

$$H_t = \begin{bmatrix} h_{1,t} \\ h_{12,t} \\ h_{2,t} \end{bmatrix} = \begin{bmatrix} \tau_1 \\ \tau_{12} \\ \tau_2 \end{bmatrix} + \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & 0 \\ 0 & 0 & a_{33} \end{bmatrix} \begin{bmatrix} \varepsilon^2_{1,t-1} \\ \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon^2_{2,t-1} \end{bmatrix} + \begin{bmatrix} b_{11} & 0 & 0 \\ 0 & b_{22} & 0 \\ 0 & 0 & b_{33} \end{bmatrix} \begin{bmatrix} h_{1,t-1} \\ h_{12,t-1} \\ h_{2,t-1} \end{bmatrix} + \begin{bmatrix} \theta_1 \\ \theta_{12} \\ \theta_2 \end{bmatrix} [\Delta \ln Fed_t] \quad (4)$$

where θ_is are coefficients of $\Delta \ln Fed_t$. For example, a positive and significant value for θ_1 (θ_2) implies that $\Delta \ln Fed_t$ is directly associated with the volatility of the implied yield on the eurodollar futures (T-bond futures). Similarly, θ_{12} measures the impact of $\Delta \ln Fed_t$ on the covariance between the eurodollar and the T-bond futures rates. Note that to avoid convergence problems, the [a] (ARCH) and [b] (GARCH) matrices are assumed to be diagonal. This implies that volatility is determined by the lagged squared residuals as well as past volatility.[10] The robustness of these results depends on postestimation diagnostics using the standardized residuals $(\varepsilon_{ij,t}/\sqrt{h_{ij,t}})$ and $(\varepsilon^2_{ij,t}/\sqrt{h_{ij,t}})$. If the errors from a GARCH model are biased due to excess kurtosis (Bollerslev & Wooldridge, 1992), then the normal t test may be inappropriate for making statistical inferences. Therefore, a conditional bivariate elliptical t distribution (Muirhead, 1982, pp. 48–49) is assumed for the residuals. The likelihood function is:

$$f(\varepsilon_t) = \frac{\Gamma\frac{(n+v)}{2}}{\Gamma(\frac{v}{2})(\sqrt{\pi(v-2)})^n} |H_t|^{-\frac{1}{2}} \left[1 + \frac{1}{v-2} \varepsilon_{\tau'} H_t^{-1} \varepsilon_t \right]^{-\frac{n+v}{2}} \quad (5)$$

where n is the number of equations and v is the degrees of freedom. The bivariate GARCH models are estimated using the Berndt, Hall, Hall, and Hausman (BHHH) (1974) procedure.

The primary focus in this study is on the link between information and interest rate volatility. However, predicting the impact of the Fed

[10]The bivariate GARCH model offers a convenient way to measure volatility spillover. In particular, some of the off-diagonal coefficients in [A] and [B] matrices detect volatility spillover. For example, a13 measures the impact of the volatility of the T-bond futures rate on the volatility of the eurodollar futures rate, while a31 measures the effects of changes in the volatility of the eurodollar futures on the volatility of the T-bond futures rate. In the [B] matrix, a similar analysis can be performed. The coefficient b13 measures the impact of lagged conditional volatility of the T-bond futures rate on the volatility of the Eurodollar futures rate and b31 measures the effects of lagged volatility of the Eurodollar futures rate on the volatility of the T-bond rate.

Funds spot/futures rate on conditional interest rate volatility may be difficult, absent prior studies in this area. Suppose an increase in the Fed Funds spot/futures rate leads to an increase in the level of key interest rates. To the extent to which the volatility changes, however, depends upon the way such actions in the Fed Funds markets are interpreted by market participants. If increases in the Fed Funds rates are perceived to be conveying a pessimistic message that inflation is rising, the volatility of key interest rates may *increase.* In contrast, suppose innovations in the Fed Funds market offer hints on the Fed's future monetary stance as well as the likelihood of additional rate changes. Hence, an increase in the Funds rates could actually resolve uncertainty in the market and subsequently *reduce* interest rate volatility. A similar logic can be applied to address interest rate cuts. Rate cuts may be perceived as conveying a pessimistic outlook on the economy. Under this scenario, market rates are expected to decline but the volatility should *increase,* indicating additional uncertainty in the market. In contrast, if the Fed actions are expected to resolve uncertainty in the market regarding the likelihood of future changes in the target, then the volatility may actually *decline.*

In Table II (Model 1), $\Delta \ln Fed_t$ refers to the daily changes in the Fed Funds spot rate and is included simultaneously in the mean and the variance equations. In the mean equations, the intercept term (β_0) is negative[11] and significant at the 5% level. The parameters α_1 and β_1 measure the effects of changes in the Fed Funds spot rate on the eurodollar and the T-bond yields, respectively. The results indicate that daily changes in the Fed Funds spot rate have a positive and significant impact on the level of eurodollar rate. α_1 is statistically significant at the 1% level. Therefore, innovations in the Fed Funds spot market should not be disregarded as useless.

In the variance equations, the intercept terms (τ) are generally significant at varying levels. The ARCH coefficients measure the impact of each market's lagged innovation on its own current volatility and are significant at the 1% level. The GARCH coefficients measure the impact of lagged conditional volatility on the current volatility and are positive and significant at the 1% level. The effects of the exogenous variable in the variance equations are insignificant, suggesting that $\Delta \ln Fed_t$ does not affect the level of uncertainty in the market.

[11]This could be a reflection of the uniqueness of the sample that includes the longest economic expansionary period, several stock market crashes, and wars in Afghanistan and Iraq. Also during this period, interest rates fell sharply due to a culmination of several events ranging from the aftermath of the Gulf War to the Fed's easing of monetary policy to help bail out the Savings and Loans Banks (S&Ls).

TABLE II

The Effects of the Fed Funds Market on the Eurodollar and the Treasury Bond Futures

$$\Delta \ln ED_t = \alpha_0 + \alpha_1 \Delta \ln Fed_t + \varepsilon_{ED}$$

$$\Delta \ln TB_t = \beta_0 + \beta_1 \Delta \ln Fed_t + \varepsilon_{TB}$$

$$H_t = \begin{bmatrix} h_{1,t} \\ h_{12,t} \\ h_{2,t} \end{bmatrix} = \begin{bmatrix} \tau_1 \\ \tau_{12} \\ \tau_2 \end{bmatrix} + \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & 0 \\ 0 & 0 & a_{33} \end{bmatrix} \begin{bmatrix} \varepsilon^2_{1,t-1} \\ \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon^2_{2,t-1} \end{bmatrix} + \begin{bmatrix} b_{11} & 0 & 0 \\ 0 & b_{22} & 0 \\ 0 & 0 & b_{33} \end{bmatrix} \begin{bmatrix} h_{1,t-1} \\ h_{12,t-1} \\ h_{2,t-1} \end{bmatrix} + \begin{bmatrix} \theta_1 \\ \theta_{12} \\ \theta_2 \end{bmatrix} [\Delta \ln Fed_t]$$

Model 1 is a bivariate GARCH model where Fed_t refers to changes in the Fed Funds spot rate. In Model 2, Fed_t refers to changes in the Fed Funds futures rates. The results are robust to fat tails and non-normality in the standardized residuals. Convergence criteria was set at .0001. Robust t-statistics are reported in parentheses. Significance level is denoted as follows: * (5%) and ** (1%). The critical values of t-statistics are: 1.98 (5%) and 2.64 (1%) level. The log-likelihood ratio statistic is a test of significance of exogenous variables in the variance equations. The critical value at the 5% level is 7.82 with 3 degrees of freedom.

	Model 1: Fed Funds Spot	*Model 2: Fed Funds Futures*
Mean equations constant		
α_0	−0.008	−0.012
	(−1.268)	(−2.223)*
β_0	−0.019	−0.016
	(−2.508)*	(−2.070)*
Exogenous variables in mean equations changes in Fed Funds rate		
α_1	0.004	0.940
	(2.714)**	(100.591)**
β_1	0.001	0.289
	(0.434)	(27.134)**
Variance equations constant		
τ_1	0.007	0.003
	(3.962)**	(5.909)**
τ_{12}	0.006	0.002
	(2.963)**	(3.383)**
τ_2	0.009	0.005
	(1.964)*	(2.652)**
ARCH coefficients		
a_{11}	0.155	0.047
	(5.122)**	(8.405)**
a_{22}	0.124	0.043
	(4.714)**	(6.478)**
a_{33}	0.123	0.052
	(4.076)**	(5.371)**
GARCH coefficients		
b_{11}	0.907	0.946
	(197.557)**	(260.566)**
b_{22}	0.933	0.956
	(150.035)**	(168.812)**
b_{33}	0.954	0.963
	(134.547)**	(150.297)**

TABLE II (*Continued*)

	Model 1: Fed Funds Spot	Model 2: Fed Funds Futures
Exogenous variables in variance equations changes in Fed Funds rate		
θ_1	0.004	−0.007
	(1.266)	(−2.498)*
θ_{12}	−0.005	0.001
	(−1.042)	(0.243)
θ_2	−0.003	0.000
	(−0.588)	(0.079)
1/*df*	0.425	0.353
	(28.819)**	(27.239)**
Log-L	−7819.322	−6720.133
−2 Log L	10.880*	10.020*

	Post-estimation diagnostics with standardized residuals			
Residuals	*Skewness*	*Kurtosis*	*Q(24)*	$Q^2(24)$
Model 1				
Eurodollar	2.176	45.328	28.328	4.702
T-bond	0.290	4.496	22.380	17.974
Model 2				
Eurodollar	3.048	58.457	14.068	2.775
T-bond	0.461	5.992	28.085	17.271

In Model 2, the independent variable in the mean and variance equations ($\Delta \ln Fed_t$) captures information from the Fed Funds futures market. Therefore, α_1 and β_1 now measure the effects of changes in the Fed Funds futures rate on the eurodollar and the T-bond futures yields, respectively. In the mean equations, the intercept terms are negative and significant at the 5% level. Consistent with prior existing studies, the parameters α_1 and β_1 are now positive, large, and significant at the 1% level. The results suggest, for instance, that a percentage increase in the Fed Funds futures rate leads to a .94% increase in the eurodollar futures rate and a corresponding .289% increase in the T-bond rate.[12]

These results indicate that while the Fed Funds futures rate affects the level of both the eurodollar and the T-bond futures rates, there is a significant difference in the ways the effects are distributed. The results

[12]These results are somewhat similar to those reported in the literature. Cook and Hahn (1989) and Radecki and Reinhart (1994) show that the 10-year T-bond yield increases by 12 to 13 basis points for each percentage increase in the Fed Funds target rate. They also indicate that longer maturity bond rates are less responsive to changes in the Fed Funds target rate. Roley and Sellon (1995) find that for a percentage increase in the target, the 30-year T-bond yield rises by 10 basis points. The authors note that if one includes 2–3 days before the change in policy, long-term rates change by 38 basis points for each percentage change in the Fed Funds rate.

imply that a tightening of the monetary policy leads to an almost equivalent increase in the short-term segment of the yield curve, but its impact on the long-run segment of the yield curve is much smaller. Mehra (1996) uses quarterly data during 1957 to 1995 to study the link between the nominal yield on 10-year U.S. Treasury bonds and the Fed Funds rate. He also finds that the Fed Funds rate has a significant effect on the bond rate

> and that the magnitude of its near-term effect on the bond rate has increased . . . since 1979. In the pre-1979 period, the bond rate rose anywhere from 14 to 29 basis points whenever the Funds rate spread widened by one percentage point. In the post-1979 period, however, the estimate of its near-term response ranges from 26 to 50 basis points.[13] (p. 28)

The fact that the bond market is cool to the information signals from the Fed Funds market is consistent with the hypothesis that much of the policy impact has already affected bond prices. Poole (2000) suggests that the process of conveying information about monetary policy changes tends to favor the bond market dealers who routinely participate in open market operations under special arrangements with the Fed. Poole's comment suggests that perhaps the bond market participants can correctly forecast Fed policy actions ahead of the FOMC meetings (policy anticipation hypothesis). In contrast, Rolley and Sellon (1995) suggest bond prices are forward-looking and therefore will be more sensitive to policy surprises and not to expected changes in the Fed Funds rate.

In the variance equations, the constant, ARCH, and GARCH terms are similar to the ones reported in Model 1. The coefficient of $\Delta \ln Fed_t$ in the eurodollar variance equation is negative and significant at the 5% level, which implies that changes in the Fed Funds futures rate reduce the volatility of the eurodollar futures rate. As noted earlier, perhaps market participants view rate hikes as the appropriate policy tool to combat increasing inflationary pressure. So, a rate hike may be seen as optimistic, suggesting a decline in expected inflation, thus leading to a fall in the volatility. Furthermore, to the extent that the Fed's policy shocks in general resolve uncertainty in the market, one can expect the volatility of key interest rates to decline following such rate changes.

Finally, it seems odd that changes in the Fed Funds spot rate do not affect the volatility of the interest rates while changes in the Fed Funds

[13]According to the author, the year 1979 marks the beginning of the Fed's attempts to bring down the trend rate of inflation and therefore the response of the long-term bond rates to the Fund rates is lower. Mehra (1996) considers this partly due to the anticipation of policy ahead of actual policy moves.

futures rate have the reverse effect. As noted earlier, the Fed Funds spot rate is more prone to generating noisy signals because some of the changes in the spot rate are due largely to institutional features and less to do with monetary policy. In contrast, the Fed Funds futures rate is offering a direct glimpse on what the market participants expect the near-term Fed policy to be. Such policy expectations can lead to a resolution of uncertainty in the market. Hence, the volatility of key rates declines.

For both models, the term $1/v$ is large, suggesting an absence of normality in the residuals.[14] The significance of the models is further indicated by the log-likelihood ratio statistic (-2 Log L) with 3 degrees of freedom that tests the hypothesis that the exogenous variable does not belong to the variance equation. The critical value is 7.82 at the 5% level. Therefore, in Model 1, the effects of the Fed Funds spot market rate in the variance equations, though insignificant, cannot be omitted. For Model II, the log-likelihood ratio is significant at the 5% level. Finally, postestimation diagnostics using the standardized residuals (ε_{it}/h_{tt} and $\varepsilon^2_{it}/h_{it}$) reveal that the GARCH model fits the data well. The residuals are close to being white noise. While kurtosis values are quite high, the estimated standard errors are robust to high kurtosis because of prior assumption of elliptical t distribution. The Ljung-Box Q shows that the residuals are not serially correlated.

The Effects of Expected and Unexpected Changes in the Fed's Target Rate

In this section, whether policy surprises matter in affecting the level and the volatility of interest rates is tested. Much of this analysis is motivated by Kuttner (2001) who uses the daily near-term Fed Funds futures rates to derive expected and unexpected changes in the target rate for the Fed Funds market. In particular, he defines unexpected change in the target to be equal to the difference between the conditional expectation of the average Funds rate for the spot month (which is the spot futures rate) and the conditional expectation of the average Funds rate one period earlier. He defines expected change in the target to be equal to actual target rate change minus the unexpected change in the target rate.

Kuttner finds that T-bills, notes, and long-term bonds respond significantly to changes in the unexpected component of the Fed's target rate changes. Estimates of the response vary. For a 100 basis points increase in the target, the responses are: 50 basis points (3-month bill),

[14]Traditional GARCH models that fail to take account of this non-normality therefore would produce spurious results. In particular, statistical inferences using the normal t test would be inappropriate if there is excess kurtosis in the standardized residuals. Such non-normality must be addressed, as it is done in this study, using robust models that can correct for such a bias in the data.

73 basis points (1-year note), 48 basis points (5-year note), and 19 basis points (30-year bond). As expected, these securities do not respond significantly to anticipated Fed Funds rates. In particular, the 30-year bond rate's response to anticipated change in the Fed's target rate is approximately zero. Finally, Kuttner also documents that bills and bonds do not respond to lagged surprise changes.

It is also examined if timing of the Fed's announcement of rate changes has any effect on the way the market responds to such policy actions. Since February 1994, the Fed's decisions to change the target rate are disclosed on the same day, immediately after the FOMC meeting. This is in sharp contrast to the earlier practices of announcing the decision a day after the FOMC meeting (Kuttner, 2001). Poole (2000) also notes that beginning February 1994, the Fed policymaking has become more transparent. He further notes that before February 1994, the Fed was following a complex signaling method of open market operations to convey its policy changes. These comments suggest that either some of these signals were not understood in a timely fashion, or that market participants did not correctly interpret the information. It is assumed that, given the same day announcement of monetary policy in recent years, the market participants are now more aware of the Fed's policy stance, and hence key interest rates may respond immediately to these changes. In fact, the decision to announce rate actions should lead to lower interest rate volatility, indicating that an increased disclosure promotes a resolution of uncertainty. To test this hypothesis, a dummy variable F representing the FOMC's policy change regarding disclosure of its monetary policy is included. The dummy takes a value of 1 after January 1994, and 0 otherwise. The new model is:

$$\begin{aligned}\Delta \ln ED_t &= \alpha_0 + \alpha_1 T_{expected} + \alpha_2 T_{unexpected} + \alpha_3 F + \varepsilon_{ED}\\ \Delta \ln TB_t &= \beta_0 + \beta_1 T_{expected} + \beta_2 T_{unexpected} + \beta_3 F + \varepsilon_{TB}\end{aligned} \tag{6}$$

$$\begin{aligned}H_t = \begin{bmatrix} h_{1,t} \\ h_{12,t} \\ h_{2,t} \end{bmatrix} &= \begin{bmatrix} \tau_1 \\ \tau_{12} \\ \tau_2 \end{bmatrix} + \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & 0 \\ 0 & 0 & a_{33} \end{bmatrix} \begin{bmatrix} \varepsilon^2_{1,t-1} \\ \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon^2_{2,t-1} \end{bmatrix}\\ &+ \begin{bmatrix} b_{11} & 0 & 0 \\ 0 & b_{22} & 0 \\ 0 & 0 & b_{33} \end{bmatrix} \begin{bmatrix} h_{1,t-1} \\ h_{12,t-1} \\ h_{2,t-1} \end{bmatrix} + \begin{bmatrix} \theta_1 \\ \theta_{12} \\ \theta_2 \end{bmatrix} [T_{expected}]\\ &+ \begin{bmatrix} \gamma_1 \\ \gamma_{12} \\ \gamma_2 \end{bmatrix} [T_{unexpected}] + \begin{bmatrix} \rho_1 \\ \rho_{12} \\ \rho_2 \end{bmatrix} [F]\end{aligned} \tag{7}$$

where measures of expected and unexpected rate changes (in basis points) are included as additional explanatory variables. Note that measures of expected and unexpected rate changes are obtained from Kuttner (2001) and are kept in their original form (in basis points) to facilitate a comparison to the results therein.

In Table III, expected changes in the target have no significant effect on the level and the volatility of the interest rates. In contrast,

TABLE III

The Effects of Expectations of Changes in the Fed Funds Target and FOMC Disclosure

$$\Delta \ln ED_t = \alpha_0 + \alpha_1 T_{expected} + \alpha_2 T_{unexpected} + \alpha_3 F + \varepsilon_{ED}$$

$$\Delta \ln TB_t = \beta_0 + \beta_1 T_{expected} + \beta_2 T_{unexpected} + \beta_3 F + \varepsilon_{TB}$$

$$H_t = \begin{bmatrix} h_{1,t} \\ h_{12,t} \\ h_{2,t} \end{bmatrix} = \begin{bmatrix} \tau_1 \\ \tau_{12} \\ \tau_2 \end{bmatrix} + \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & 0 \\ 0 & 0 & a_{33} \end{bmatrix} \begin{bmatrix} \varepsilon^2_{1,t-1} \\ \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon^2_{2,t-1} \end{bmatrix} + \begin{bmatrix} b_{11} & 0 & 0 \\ 0 & b_{22} & 0 \\ 0 & 0 & b_{33} \end{bmatrix} \begin{bmatrix} h_{1,t-1} \\ h_{12,t-1} \\ h_{2,t-1} \end{bmatrix}$$

$$+ \begin{bmatrix} \theta_1 \\ \theta_{12} \\ \theta_2 \end{bmatrix} [T_{expected}] + \begin{bmatrix} \gamma_1 \\ \gamma_{12} \\ \gamma_2 \end{bmatrix} [T_{unexpected}] + \begin{bmatrix} \phi_1 \\ \phi_{12} \\ \phi_2 \end{bmatrix} [F]$$

This model has expected and unexpected changes in the Fed Funds target rate, along with the FOMC dummy variable in the mean and variance equations. The results are robust to fat tails and non-normality in the standardized residuals. Convergence criteria was set at .0001. Robust t-statistics are reported in parentheses. Significance level is denoted as follows: * (5%) and ** (1%). The critical values of t-statistics are: 1.98 (5%) and 2.64 (1%) level. The log-likelihood ratio statistic is a test of significance of exogenous variables in the variance equations. The critical value at the 5% level is 21.03 with 12 degrees of freedom.

	Model 1
Mean equations constants	
α_0	−0.036
	(−1.985)*
β_0	−0.030
	(−2.520)*
Exogenous variables in mean equations expected change in Fed Funds target rate	
α_1	0.473
	(1.460)
β_1	−0.344
	(−1.056)
Unexpected Change in Fed Funds Target Rate	
α_2	10.422
	(13.021)**
β_2	1.917
	(2.695)**
FOMC Dummy	
α_3	0.031
	(1.607)
β_3	0.008
	(0.524)

(*Continued*)

TABLE III (*Continued*)

The Effects of Expectations of Changes in the Fed Funds Target and FOMC Disclosure

	Model 1
Variance equations constant	
τ_1	0.072
	(4.949)**
τ_{12}	0.028
	(3.666)**
τ_2	0.016
	(2.572)*
ARCH coefficients	
a_{11}	0.134
	(6.047)**
a_{22}	0.109
	(5.283)**
a_{33}	0.104
	(4.367)**
GARCH coefficients	
b_{11}	0.890
	(145.814)**
b_{22}	0.916
	(98.778)**
b_{33}	0.944
	(97.821)**
Exogenous variables in variance equations expected change in Fed Funds target rate	
θ_1	0.683
	(1.513)
θ_{12}	0.498
	(1.200)
θ_2	0.676
	(1.820)
Unexpected change in Fed Funds target rate	
γ_1	−3.101
	(−2.118)*
γ_{12}	−1.160
	(−1.283)
γ_2	−1.137
	(−1.697)
FOMC dummy	
ϕ_1	−.063
	(−4.721)**
ϕ_{12}	−0.017
	(−2.877)**
ϕ_2	0.007
	(1.597)
$1/df$	0.410
	(28.494)**
Log L	−7734.759
−2 Log L	116.282**

	Post-estimation diagnostics with standardized residuals			
Residuals	*Skewness*	*Kurtosis*	*Q(24)*	*Q^2(24)*
Model 1				
Eurodollar	1.797	43.057	25.880	4.494
T-bond	0.330	4.437	22.748	16.962

unexpected changes in the target are associated with large and positive effects on both the eurodollar and the T-bond rates (measured by α_1 and β_2 coefficients, respectively). Consistent with earlier results in this study and Kuttner (2001), there is evidence that the response to the monetary policy shock is more concentrated in the short-term segment of the market. The magnitude of the impact varies across the curve. For example, a one basis point increase in the unexpected change in the target leads to a 10.42% increase in the eurodollar yield. The impact on the T-bond yield is much smaller. A one basis point increase in the unexpected change in the target leads to only 1.91% increase in the T-bond yield. In the variance equations, the results suggest that unexpected changes in the target affect only the short-term interest rate volatility. This supports the claim that any policy move resolves uncertainty at least in the short-term segment of the market. Finally, the FOMC dummy (F) is insignificant in the mean equations but has negative coefficients in two out of three instances (measured by ϕ_1 and ϕ_{12} coefficients) in the variance equations. A reduction in the volatility of the eurodollar rate and its covariance with the T-bond rate due to timely disclosure of policy actions supports the resolution of the uncertainty hypothesis. It further supports the notion that an increased transparency of the Fed's policymaking is good for the market in general.

CONCLUSIONS

In this article, the effects of the Fed Funds spot and the CBOT 30-day Fed Funds futures rates on the level and the volatility of the short- and long-term interest rates are examined. Empirical analysis of the daily data for the period October 3, 1988 to July 7, 2004 uncovers several interesting results:

			Effects on				
			Level		*Volatility*		
Table	*Model*	*Information source*	*ED*	*T-Bond*	*ED*	*Cov*	*T-Bond*
2	1	Fed Funds Spot Rate	+	NS	NS	NS	NS
2	2	Fed Funds Futures	+	+	−	NS	NS
3	1	Expected change in target	NS	NS	NS	NS	NS
3	1	Unexpected change in target	+	+	−	NS	NS
3	1	FOMC	NS	NS	−	−	NS

where cov implies the covariance term and NS implies that the impact is not significant at least at the 5% level.

Overall, the study offers some interesting results on the alleged information content of the Fed Funds markets in affecting the level and the volatility of the short- and long-term interest rates. Compared to the Fed Funds spot rate, information generated in the futures market appears to have a more significant impact on the level of interest rates, though the effects on the volatility are mixed. There is evidence that changes in the Fed Funds futures rate have a more pronounced effect on the eurodollar yield than the 30-year T-bond yield. The evidence of such asymmetric effects could imply that monetary policy tends to have a more pronounced effect on the short-term rates. Finally, unexpected changes in the Fed's target rate have a significant impact on the level of interest rates. Overall, the preceding results provide additional support to the importance of the Fed Funds futures rates for predicting key interest rates.

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