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Monetary policy surprises and interest rates: Evidence from the Fed funds futures market ☆

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Abstract

This paper estimates the impact of monetary policy actions on bill, note, and bond yields, using data from the futures market for Federal funds to separate changes in the target funds rate into anticipated and unanticipated components. Interest rates' response to anticipated target rate changes is small, while their response to unanticipated changes is large and highly significant. These responses are generally consistent with the expectations hypothesis of the term structure. Surprise target rate changes have little effect on expectations of future actions, however, which helps to explain the lack of empirical support for the expectations hypothesis at the short end of the yield curve. © 2001 Published by Elsevier Science B.V.

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1. Introduction

How market interest rates respond to Federal Reserve actions is a topic of great interest to financial market participants and policymakers alike. Bondholders, naturally, are concerned with the effects of Fed policy on bond prices. Since the first link in the transmission of Federal Reserve policy is from the Fed funds target to other interest rates, the issue is an important one for assessing the likely effectiveness of monetary policy.

Conventional wisdom is that an increase in the target Fed funds rate leads to an immediate increase in market interest rates, and a fall in bond prices; yet evidence for this view is elusive. Cook and Hahn (1989) documented a strong response in the 1970s, but regressions using data from the 1980s and 1990s show little, if any, impact of Fed policy on interest rates. Roley and Sellon (1995), for example, conclude that "although casual observation suggests a close connection …, the relationship between Fed actions and long-term interest rates appears much looser and more variable". These studies did not distinguish between anticipated and unanticipated actions, however, and it turns out that the failure to do so accounts for the apparent lack of a close link.

Using Fed funds futures rates to disentangle expected from unexpected policy actions, this paper shows that interest rates' response to the "surprise" component of Fed policy is significantly stronger than the response to the change in the target itself; in fact, rates' response to the anticipated component of policy actions is minimal, and consistent with the expectations hypothesis of the term structure. The response of Fed funds futures rates themselves to unexpected policy actions is fairly uniform across the one- to five-month horizon, supporting the view that the short end of the yield curve contains little information about future movements in short-term rates.

2. A review of earlier studies

The first paper to assess markets' reaction to monetary policy actions is Cook and Hahn (1989), who examined the one-day response of bond rates to changes in the target Fed funds rate from 1974 through 1979. Their procedure was to regress the change in the bill, note and bond rates (denoted as R) on the change in the target Fed funds rate (denoted as $\tilde{r}$),

$$\Delta R_t = \alpha + \beta \Delta \tilde{r}_t + \varepsilon_t, \tag{1}$$

for a sample consisting of 75 days on which the Fed changed the funds rate target.

The response to target rate increases was positive and significant at all maturities, but smaller at the long end of the yield curve: a one percentage point increase in the Fed funds target led to an increase of 55 basis points in the three-month T-bill rate, but only a 10 basis point increase in the 30-year bond yield. A significant response of bill rates to *lagged* target rate changes was also detected, suggesting some delay in market participants' recognition of certain actions. Cook and Hahn also examined the relationship between changes in interest rates and *future* changes in the target, but found little evidence that the target rate changes were anticipated at a one- to two-day horizon.

Results for more recent periods show a much weaker relationship between target rate changes and other interest rates. For example, in applying Cook and Hahn's event-study approach to the 1987–1995 period, Roley and Sellon (1995) found that the bond rate rose a statistically insignificant four basis points for each percentage point increase in the target funds rate. (They did, however, find some evidence that policy moves were anticipated in the latter period.) Similarly, weak results for the 1989–1992 period were obtained by Radecki and Reinhart (1994).

More sophisticated econometric procedures have been used to estimate the market's reaction to Federal Reserve policy, focusing on the unanticipated element of the actions. Using a Vector Autoregression (VAR) to model monetary policy, for example, Edelberg and Marshall (1996) found a large, highly significant response of bill rates to policy shocks, but only a small, marginally significant response of bond rates. Other examples of the VAR approach include Evans and Marshall (1998) and Mehra (1996). In an effort to model the discrete nature of target rate changes, Demiralp and Jorda (1999) examined the response of interest rates using an autoregressive conditional hazard model to forecast the timing of changes in the Fed funds target, and an ordered probit to predict the size of the change. These methods can be difficult to implement, however, and there is some debate as to the reliability of VAR-based measures of policy shocks (e.g., Rudebusch, 1998; Brunner, 2000).

3. Interest rates' one-day response to monetary policy

This section first revisits the basic relationship between target rate changes and market interest rates, and confirms its apparent deterioration in the 1990s. It then describes how Fed funds futures rates can be used to distinguish between anticipated and unanticipated changes in the Fed funds target, and documents the much stronger relationship between market rates and unanticipated changes in the funds rate target.

3.1. Cook and Hahn revisited

Table 1 summarizes the relationship between target rate changes and market interest rates over the past 10 years, using an OLS regression identical to that used in the Cook and Hahn (1989) analysis. The sample includes 42 changes in

Table 1
The 1-day response of interest rates to changes in the Fed funds target[a]

Maturity	Intercept	Response	R^2	SE	DW
3 month	− 3.6	26.8	0.42	9.8	2.04
	(2.3)	(5.4)			
6 month	− 5.2	21.9	0.37	9.0	2.04
	(3.6)	(4.6)			
12 month	− 5.1	19.8	0.29	9.5	2.07
	(3.3)	(4.1)			
2 year	− 5.2	18.2	0.26	9.6	2.28
	(3.4)	(3.7)			
5 year	− 4.5	10.4	0.10	9.8	2.40
	(2.9)	(2.1)			
10 year	− 4.0	4.3	0.02	8.5	2.50
	(2.9)	(1.0)			
30 year	− 3.6	0.1	0.00	6.9	2.47
	(3.2)	(0.0)			

[a] *Note*: The change in the target Fed funds rate is expressed in percent, and the interest rate changes are expressed in basis points. The sample contains 42 changes in the target Fed funds rate from 6 June 1989 through 2 February 2000. Parentheses contain t-statistics.

the target rate, with the first on 6 June 1989, and the last on 2 February 2000. The bill rate data are secondary market yields from the Federal Reserve H.15 release. The note and bond data are the yields of on-the-run Treasuries, obtained from Bloomberg.

The coefficients describing interest rates' reaction to target rate changes in the post-1989 period are uniformly smaller and less significant than those for the 1975–1979 sample. The estimated responses of 3- and 6-month bill rates are 27 and 22 basis points, respectively, compared with 55 and 54 basis points in Cook and Hahn. The results are weaker at the long end of the yield curve as well, with essentially no response by the 30-year yield. By contrast, Cook and Hahn reported a statistically significant 10 basis point response for the 20-year bond, the longest-maturity Treasury bond at the time. In a regression pooling the post-1989 and Cook–Hahn data, the hypothesis of equal coefficients in the two subsamples can be rejected at 0.05 level for the 3- and 6-month bills.

One possible explanation for the lack of statistical significance is simply the smaller number of observations—42 target rate changes, compared with 75 in the Cook–Hahn sample. This cannot explain the smaller magnitude of the response, however. Another possibility is that traders were not aware of the policy actions. This is implausible, however, as Fed actions have generally become *more* transparent since the period studied by Cook and Hahn.

A more likely explanation is that target rate changes have been more widely anticipated in recent years. Bond yields set in forward-looking markets should respond very differently to anticipated and unanticipated elements of monetary policy actions; in fact, longer-term rates should react little, if at all, to anticipated target rate changes. Consequently, the regression given by Eq. (1) suffers from an errors-in-variables problem: the surprise target rate change belonging to the regression is contaminated by the expected rate change, and this "noise" leads to an attenuated estimate of interest rates' response to policy surprises. In assessing the market reaction to monetary policy, therefore, it is essential to distinguish between the expected and unexpected elements.

3.2. Using futures rates to gauge policy expectations

Expectations of Fed policy actions are not directly observable, of course, but Fed funds futures prices are a natural, market-based proxy for those expectations. The market was established in 1989 at the Chicago Board of Trade, and contracts based on one- through five-month Fed funds are currently traded, along with a "spot month" contract based on the current month's funds rate. Krueger and Kuttner (1996) found that funds rate forecasts based on the futures price are "efficient", in that the forecast errors are not significantly correlated with other variables known when the contract was priced.

Using futures data as a measure of expected Fed policy has a number of advantages over statistical proxies. First, there is no issue of model selection; second, the vintage of the data used to produce the forecast is not an issue; and third, there are no generated-regressor problems. A disadvantage of using futures data, of course, is that it limits the analysis to the post-1989 period. In addition, there are two technical complications inherent in the use of futures data.

One is that the Fed funds futures contract's settlement price is based on the *average* of the relevant month's effective overnight Fed funds rate, rather than the rate on any specific day.[1] Consequently, the time-averaging must somehow be undone to get a correct measure of the expected funds rate. The second complication is that the futures contracts are based not on the target Fed funds rate, but on the effective market rate. In monthly averages, the two are very close—usually within a few basis points. At a daily frequency, however, the discrepancy between the market rate and the Fed's target is often too large to be ignored.

The question, then, is how best to extract a measure of the unexpected change in the target rate on date $t+1$, relative to the forecast made on date t, or $\tilde{r}_{t+1} - E_t\tilde{r}_{t+1}$, in light of these complications. The spot-month futures rate on

[1] The futures rate is defined as 100 minus the contract's price. An additional twist is that the average is computed over every day in the month, with rates for weekends and holidays carried over from the previous business day.

day t of month s, $f^0_{s,t}$, can be interpreted as the conditional expectation of the average funds rate in month s, plus a term representing the premium accruing to investors long in the spot-month futures contract:

$$f^0_{s,t} = E_t \frac{1}{m} \sum_{i \in s} r_i + \mu^0_{s,t}, \tag{2}$$

where r_i is the overnight funds rate on day i, and m is the number of days in the month.[2] The $\mu^0_{s,t}$ term may represent a risk premium, or capture month or day-of-month effects in the futures market; in an efficient market with risk-neutral investors, this term would be zero. The premium is not modeled explicitly in this paper; it is introduced merely to illustrate how its presence affects the calculation of surprise policy actions from Fed funds futures rates.

Suppose that on date t, futures market participants expected the Fed to change the Fed funds target rate on date $t+1$, and that no further changes were expected within the month. The futures rate on date t would embody the average of realized funds rates through that date, and expectations about the rates prevailing after that date:

$$f^0_{s,t} = \frac{t}{m}\bar{r}_{i \leqslant t} + \frac{m-t}{m} E_t \bar{r}_{i>t} + \mu^0_{s,t}. \tag{3}$$

Expressing the realized funds rate r_i as $\tilde{r}_i + \eta_i$, the sum of the target rate plus an error associated with unanticipated movements in reserve supply or demand, yields:

$$f^0_{s,t} = \frac{t}{m}[\tilde{r}_t + \bar{\eta}_{i \leqslant t}] + \frac{m-t}{m}[E_t(\tilde{r}_t + \bar{\eta}_{i>t})] + \mu^0_{s,t}, \tag{4}$$

where $\bar{\eta}$ is the average targeting error over the relevant portion of the month.

An obvious way to reconstruct the surprise target rate change on date $t+1$ is to look at the difference between the month-s average funds rate and the spot month rate on the day prior to the change, scaled up to reflect the number of days affected by the change:

$$\frac{m}{m-t}(\bar{r}_s - f^0_{s,t}), \tag{5}$$

where $\bar{r}$ is simply the effective funds rate averaged over the entire month. Substituting from above yields:

$$(\tilde{r}_{t+1} - E_t \tilde{r}_{t+1}) + (\bar{\eta}_{i>t} - E_t \bar{\eta}_{i>t}) - \frac{m}{m-t}\mu^0_{s,t}. \tag{6}$$

The surprise computed in this way, therefore, is equal to the ''true'' surprise, plus the average of targeting errors made later in the month, minus the scaled-up premium. The first of these may introduce some noise (especially if an

[2] As it varies from month to month, the number of days in the month should really be denoted as m_s; but for the sake of notational simplicity, the subscript s is suppressed.

unusually volatile settlement period occurs late in the month), but its magnitude is likely to be no more than a few basis points.

The term involving $\mu^0_{s,t}$ is a more serious problem, however, as the scaling magnifies it and introduces time variation. The problem is especially severe towards the end of the month. With 2 days remaining in the month, for example, a one basis point premium would become a 15 basis point error; with 1 day left, the error would be 30 basis points. The problem could be solved by subtracting the premium from the futures rate, but this would only work if $\mu^0_{s,t}$ were a known constant. Replacing the average realized funds rate with a weighted average of past realized funds rates and future target rates eliminates the average future targeting error, but the scaled-up premium remains.

How serious is this problem? As shown in the top panel of Fig. 1, the spot-month future rate does tend to converge to the average funds rate as the month progresses. But the expected next-day change in the Fed funds target from the procedure described above, shown in the bottom panel, becomes much more volatile towards the end of the month. (Much, but not all, of the volatility comes in December, apparently associated with year-end effects in the funds market.) If $\mu^0_{s,t}$ were a constant or a deterministic function of the day of the month, one would see a systematic bias in the predicted change; the predictions' *volatility* increases suggest that it contains a random, time-varying element.

A policy surprise measure less susceptible to this problem can be computed from the 1-day change in the spot-month future rate.[3] The key insight is that the day-t futures rate embodies the expected change on (or after) date $t+1$; if the change occurs as expected, then the spot rate will remain unchanged. Any deviation from the expected rate will result in a change in the futures rate, by an amount proportional to the number of days affected by the change. The 1-day surprise for date t computed in this way would be:

$$\Delta \tilde{r}^u_t = \frac{m}{m-t}(f^0_{s,t} - f^0_{s,t-1}) \tag{7}$$

for all but the first day of the month, on which the 1-month futures rate from the last day of the previous month, $f^1_{s-1,m}$ would be used instead of $f^0_{s,t-1}$.

Under the assumption that no further changes are expected within the month, this method delivers a nearly pure measure of the 1-day surprise target change.[4] As it involves only differences in the futures rate, the μ^0 premium disappears, provided it does not change from one day to the next. The only contamination is the day-t targeting error, and the revision in the expectation of future targeting errors. These errors are occasionally non-trivial, so the

[3] Evans and Kuttner (1998) used a similar procedure to gauge the size of monetary shocks.

[4] This assumption is not entirely justified, as, since 1989, 3 months have had two target rate changes.

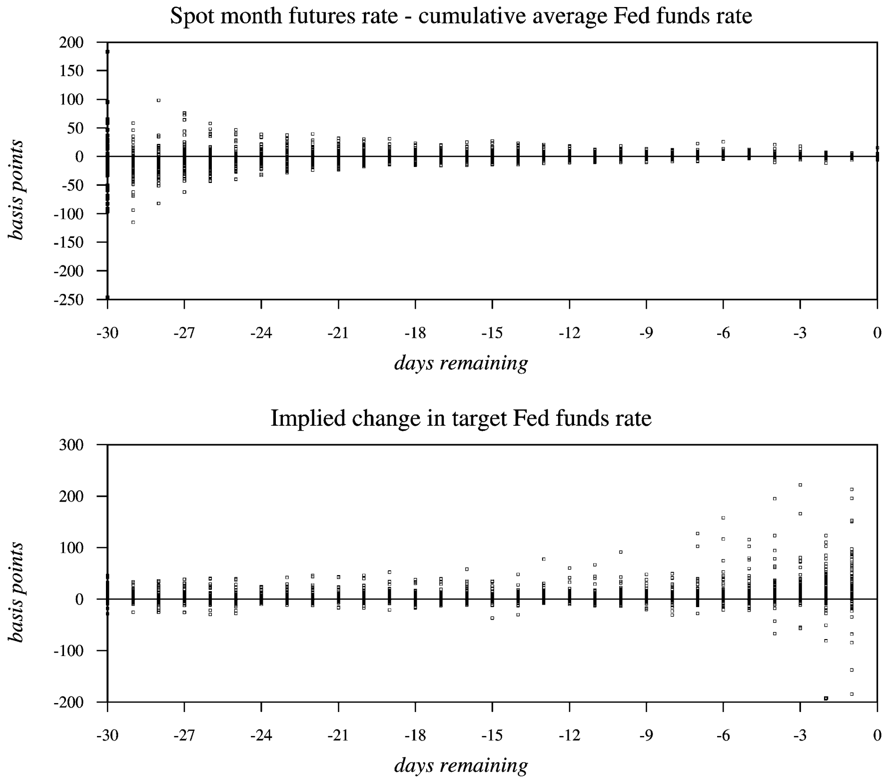

Fig. 1. End-of-month behavior of the futures rate and implied target rate changes.
Note: The top panel plots the difference between the spot-month futures rate on day t and the average through day t of the effective Fed funds rate: $f^0_{s,t} - (1/t)\sum_{i=1}^{t} r_i$. The bottom panel plots the measure of the expected target rate change, if that change were to take place on day $t+1$, based on the scaled-up futures rate and the average funds rate through day t: $[m/(m-t)]\,f^0_{s,t} - \{[t/(m-t)](1/t)\sum_{i=1}^{t} r_i\} - \tilde{r}_t$.

change in the 1-month futures rate is used instead when the target rate change occurs within 3 days of the end of the month. The expected component of the change is then calculated as the actual minus the unexpected, $\Delta\tilde{r}^e_t = \Delta\tilde{r}_t - \Delta r^u_t$.

A final issue concerns the timing of the data. The target rate changes are dated according to the day on which they became known. Until 1994, this corresponded to the day *after* the decision to change rates, when the new target rate became effective. In February 1994, the Federal Reserve began announcing its intention to change the funds rate target on the day of its decision. After the adoption of this procedure, target changes are assigned to the dates of the announcements, which usually come at 2:15 p.m. Eastern time.

Since trading in Fed funds futures ends at 3:00 Eastern time (2:00 Central), the closing futures price used in the analysis usually would have incorporated the news of the Fed's decision.

The sample contains two important deviations from this chronology, however. The first occurred on 18 December 1990, when the Federal Reserve took the unusual step of announcing a 50 basis point cut in the discount rate immediately following the Federal Open Market Committee (FOMC) meeting. The action, which was made public at 3:30 p.m., after the close of the futures market, was correctly interpreted as signaling that the Fed had also cut the funds rate 25 basis points.[5] Stock and bond markets, which were still open when the announcement was made, reacted euphorically to the news, even though the change would not affect the Fed funds spot and futures markets until the following day. To deal with this timing mismatch, the difference between the closing futures rate on the 18th and the opening rate on the 19th is used to measure the surprise element of the action. In addition, because Fed's interest rate data are collected at 3:15 p.m., the change from the 18th to the 19th is used to compute the change in the bill rates; the Bloomberg data come from later in the day, so the change from the preceding day is used in computing the change in bond and note rates.

A similar episode occurred on 15 October 1998, when the Fed surprised the markets by changing its Fed funds target between FOMC meetings—something it had not done since April 1994. The move was announced at 3:15 p.m. Eastern time, after the futures market in Chicago had closed. Consequently, although the announced change in the target Fed funds rate took place on the 15th, the futures market did not register the change until the following day. In this case, a better measure of the policy surprise would involve the difference between the closing futures rate on the 15th and the opening rate on the 16th. Again, the Bloomberg data for the 15th reflects this change, while Fed's does not, and the interest rate changes are aligned accordingly.

Table 2 lists the 42 target rate changes contained in the sample, 22 of which are associated with FOMC meetings (indicated with a check mark in the table).[6] Also, reported is the futures-based decomposition into expected and unexpected components. The decomposition reveals some interesting patterns. Most of the rate cuts in 1989 appear to have been largely anticipated, for example, as was much of the runup of rates in 1994–1995. By contrast, many of the final round of rate cuts in late 1991 and 1992 seem to have taken the market

[5] In its reporting on the move, the Wall Street Journal stated: "The committee is believed to have authorized an immediate reduction of one quarter percentage point in the key federal funds rate," Wessel (1990).

[6] The target rate changes correspond to those in Rudebusch (1995), except for the six-basis point adjustment on 10 August 1989, which is omitted from the analysis, and the 50 basis point rate cut on 19 December 1990, which is assigned to the 18th instead.

Table 2
Actual, expected and unexpected changes in the Fed funds target

Date		FOMC	Actual	Expected	Unexpected
1989	6/6		− 25	− 24	− 1
	7/7	√	− 25	− 22	− 3
	7/27		− 25	− 25	0
	10/18		− 25	− 25	0
	11/6		− 25	− 29	+4
	12/20	√	− 25	− 8	− 17
1990	7/13		− 25	− 11	− 14
	10/29		− 25	+6	− 31
	11/14	√	− 25	− 29	+4
	12/7		− 25	+2	− 27
	12/18	√	− 25	− 4	− 21
1991	1/8		− 25	− 7	− 18
	2/1		− 50	− 25	− 25
	3/8		− 25	− 9	− 16
	4/30		− 25	− 8	− 17
	8/6		− 25	− 10	− 15
	9/13		− 25	− 20	− 5
	10/31		− 25	− 20	− 5
	11/6	√	− 25	− 13	− 12
	12/6		− 25	− 16	− 9
	12/20		− 50	− 22	− 28
1992	4/9		− 25	− 1	− 24
	7/2	√	− 50	− 14	− 36
	9/4		− 25	− 3	− 22
1994	2/4	√	+25	+13	+12
	3/22	√	+25	+28	− 3
	4/18		+25	+15	+10
	5/17	√	+50	+37	+13
	8/16	√	+50	+36	+14
	11/15	√	+75	+61	+14
1995	2/1	√	+50	+45	+5
	7/6	√	− 25	− 24	− 1
	12/19	√	− 25	− 15	− 10
1996	1/31	√	− 25	− 18	− 7
1997	3/25	√	+25	+22	+3
1998	9/29	√	− 25	− 25	0
	10/15		− 25	+1	− 26
	11/17	√	− 25	− 19	− 6
1999	6/30	√	+25	+29	− 4
	8/24	√	+25	+23	+2
	11/16	√	+25	+16	+9
2000	2/2	√	+25	+30	− 5

by surprise. More recently, the 15 October 1998 rate cut is the only action since 1996 to have contained a large element of surprise.

3.3. Results

Having used the futures rates to distinguish between anticipated and unanticipated changes in the funds rate target, the natural question to ask is whether the responses of bill and bond rates to the two components differ—or indeed whether rates respond at all to predictable actions. This can be done within the Cook and Hahn-style analysis by regressing the change in the interest rate on the two components of the target rate change,

$$\Delta R_t = \alpha + \beta_1 \Delta \tilde{r}_t^e + \beta_2 \Delta \tilde{r}_t^u + \varepsilon_t, \tag{8}$$

where R again represents in turn the yields on 3- 6- and 12-month bills, 2- 5- and 10-year notes, and 30-year bonds.

The regression results appear in Table 3. As expected, the coefficients on the expected and surprise components are very different: the response to the unanticipated piece is large and highly significant, while the response to the anticipated piece is small, and statistically insignificant. For each maturity, a Wald test of the $\beta_1 = \beta_2$ restriction rejects the hypothesis of equal responses at the 0.05 level or better.

Table 3
The 1-day response of interest rates to the Fed funds surprises[a]

		Response to target change				
Maturity	Intercept	Anticipated	Unanticipated	R^2	SE	DW
3 month	− 0.7	4.4	79.1	0.70	7.1	1.82
	(0.5)	(0.8)	(8.4)			
6 month	− 2.5	0.6	71.6	0.69	6.3	2.06
	(2.2)	(0.1)	(8.5)			
12 month	− 2.2	− 2.3	71.6	0.64	6.9	2.10
	(1.8)	(0.5)	(7.8)			
2 year	− 2.8	− 0.4	61.4	0.52	7.8	2.25
	(2.0)	(0.1)	(6.0)			
5 year	− 2.4	− 5.8	48.1	0.33	8.6	2.37
	(1.6)	(0.9)	(4.3)			
10 year	− 2.4	− 7.4	31.5	0.19	7.8	2.37
	(1.8)	(1.3)	(3.1)			
30 year	− 2.5	− 8.2	19.4	0.13	6.5	2.46
	(2.2)	(1.7)	(2.3)			

[a] *Note*: Anticipated and unanticipated changes in the Fed funds target are computed from the Fed funds futures rates, as described in the text. Parentheses contain t-statistics. See also notes to Table 1.

Comparing these results to those in Table 1 shows that the response of market rates to surprise changes in the target is considerably larger than the reaction to "raw" changes, exactly as expected; the earlier regression clearly suffered from a major errors-in-variables problem. The response of the 3-month bill yield to the surprise element of the rate change is more than twice as large as it is to the raw change: 79 basis points (for a one percentage point change in the target), compared with 27. At the short end of the yield curve, the coefficients are somewhat larger than those reported by Cook and Hahn, and well in excess of the contemporaneous effects in the impulse response functions estimated by Edelberg and Marshall (1996).

Distinguishing between expected and surprise target rate changes makes an even bigger difference for longer-term interest rates. For 5-year notes, the response is a highly significant 48 basis points, compared with an insignificant 10 basis points. Even the 30-year bond now shows a statistically significant 19 basis point reaction. All are considerably larger than those reported by Cook and Hahn. The results are also much stronger than those of Roley and Sellon (1999), perhaps owing to the different procedure used for calculating the surprise component of the rate change.

The scatterplots in Fig. 2 confirm these results: the raw target rate changes (left-hand panel) and the expected target rate changes (center panel) bear little, if any, relation to changes in the 5-year rate. By contrast, changes in the 5-year rate line up quite nicely with the surprise target rate changes—all except for two observations deep in the southeast quadrant, where unexpected rate increases were associated with bond market rallies.

A closer examination of these two outliers is revealing. Both correspond to larger-than-expected 50 basis point increases in the target Fed funds rate in 1994: the first on 17 May, and the second on 16 August. Why did these rate increases incite bond market rallies? It turns out that both actions were

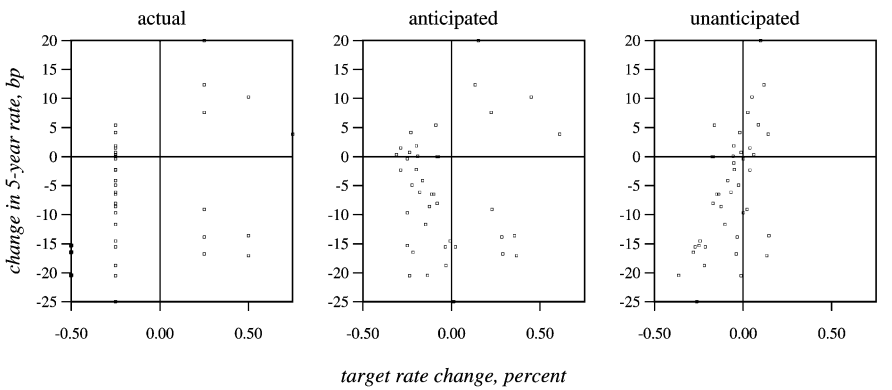

Fig. 2. Target rate changes and the 5-year rate.

accompanied by statements suggesting that further rate increases were not imminent.[7] Therefore, although the policy actions boosted short-term interest rates, expected *future* rates fell, leading to the decline in long rates. It is interesting to note that Fed's policy of announcing the rationale for its actions, adopted in February 1994, seems to have played a key role in the bond market's unusual reactions.[8]

While interest rates' response to surprise rate changes is broadly consistent with the contemporaneous reaction documented by Cook and Hahn, there is an important difference in the response to *lagged* rate changes. Specifically, Cook and Hahn found a significant response of bill rates to the previous day's target rate change, a phenomenon attributed to uncertainty about Fed policy. During the 1974–1979 period they studied, the Fed did not announce changes in the target rate, and market participants were often not completely sure that a change had occurred until the day after its implementation.

Detecting Fed actions has become much easier in recent years. Since 1994, no guesswork whatsoever has been required, as target rate changes have been announced immediately following FOMC meetings. But since the late 1980s, the target (or "intended") rate was generally apparent to market participants, even before the Fed began routinely announcing its actions (Meulendyke, 1998, p. 141). This suggests that there should be little, if any, response to lagged target rate changes in the post-1989 sample.

Table 4 reports the results from regressing the bill rate changes on the previous day's target rate change, and on the surprise element of that change. As expected, lagged actions have essentially no effect on bill rates, and the regression R^2s are 0.04 or less. The results confirm the view that the implementation of Fed policy has become more "transparent" since the 1970s, in the sense that policy actions are now more clearly communicated to market participants.

4. Two robustness checks

The results reported above give the response of interest rates to policy surprises, conditional on a rate change. To guard against the possibility that

[7] The 17 May announcement included the statement that "These actions … substantially remove the degree of monetary accommodation which prevailed throughout 1993". The 16 August announcement stated that "these actions are expected to be sufficient, at least for a time, to meet the objective of sustained, noninflationary growth". Both were widely interpreted as reducing the likelihood of subsequent rate increases; see Wessel (1994), Thomas (1994) and Vogel (1994).

[8] Bomfim and Reinhart (1999) take a more systematic look at disclosure policy's impact on financial markets' reaction, but find little discernible effect. There might also have been some reaction to the FOMC's announced "bias", which was made public for a brief period from May through December 1999. But with only six FOMC meetings during this period, any effect would be hard to quantify.

Table 4
The 1-day response of interest rates to the lagged Fed funds rate[a]

	Lagged target change		Lagged surprise change	
Maturity	Response	R^2	Response	R^2
3 month	− 2.2	0.01	− 6.0	0.02
	(0.7)		(0.8)	
6 month	− 0.9	0.00	− 7.1	0.03
	(0.3)		(1.1)	
12 month	0.5	0.00	− 7.2	0.04
	(0.2)		(1.3)	

[a] *Note*: Parentheses contain *t*-statistics. See also notes to Table 3.

the results are somehow dependent on sample selection, a useful check would be to ensure that similar results are obtained when the sample is not restricted to those days when a change actually took place. This section presents the results of two such checks: one in which the sample consists of daily rate changes on days associated with FOMC meetings, and the second analyzing rate changes at monthly intervals. Both exercises yield similar results, confirming the robustness of the basic findings in Section 3.

4.1. Results for FOMC meeting dates

An ideal sample would be one consisting of those days on which market participants thought there *might* be a target rate change, regardless of whether a change actually occurred. It is impossible to know all such dates, of course, but an interesting subset consists of FOMC meetings, 86 of which occurred between June 1989 and February 2000. Twenty-two of the 42 target rate changes in the sample were associated with meetings, with the rest occurring in the interval between meetings, often on the heels of a key data release. Most of these "intermeeting" changes occurred before 1994; since then, only the 18 April 1994 and the 15 October 1998 actions have come between meetings.

As shown in Table 5, estimating Eq. (8) on FOMC meeting dates rather than on rate-change dates leaves the results qualitatively unchanged. The coefficients are somewhat smaller, but all the responses (except that of the 30-year bond) remain statistically significant. The decreased precision and lower R^2s in these regressions are likely due to the smaller number of target rate changes in the sample, and from dropping the intermeeting changes from early in the period, many of which contained a large surprise element.

Table 5
The response of interest rates to Fed funds surprises on FOMC dates[a]

		Response to target change				
Maturity	Intercept	Anticipated	Unanticipated	R^2	SE	DW
3 month	− 0.3	9.0	62.8	0.56	4.6	2.00
	(0.6)	(2.5)	(9.4)			
6 month	− 0.6	2.4	55.4	0.47	4.7	2.36
	(1.2)	(0.7)	(8.2)			
12 month	− 0.5	− 0.2	56.0	0.45	4.8	2.19
	(0.9)	(0.1)	(8.2)			
2 year	− 0.7	0.6	53.5	0.28	6.6	2.07
	(1.0)	(0.1)	(5.6)			
5 year	− 0.9	− 3.2	36.3	0.13	7.0	2.24
	(1.1)	(0.6)	(3.6)			
10 year	− 1.0	− 5.5	22.0	0.07	6.2	2.16
	(1.4)	(1.2)	(2.4)			
30 year	− 1.0	− 6.2	11.5	0.04	5.3	2.04
	(1.6)	(1.5)	(1.5)			

[a] *Note*: Anticipated and unanticipated changes in the Fed funds target are computed from the Fed funds futures rates, as described in the text. Parentheses contain t-statistics. The sample consists of the 86 FOMC meeting dates between 6 June 1989 and 2 February 2000.

4.2. Results using a monthly unit of observation

Another alternative to Cook and Hahn's event-study approach is to consider surprises defined on monthly intervals. Like the regressions involving FOMC meeting dates, this allows inaction as well as action to create policy surprises. But unlike the FOMC-date regressions, this approach assumes that target rate changes may come in any month—not just at FOMC meetings—so the intermeeting changes will remain in the sample. This approach also shifts the focus away from the precise timing of policy actions, giving it more of the flavor associated with the VAR literature on monetary policy shocks.[9]

To avoid distorting the timing and magnitude of interest rate changes with time-averaging, one would ideally want to define interest rate changes in terms of point-in-time data: e.g., the change in the target rate from the last day of month $s-1$ to the last day of month s. The problem, as discussed above, is that the Fed funds futures contracts' settlement price is determined by the monthly average funds rate, rather than the rate prevailing on a certain day. This averaging means that the difference between the average funds rate in

[9] To the extent that policy responds to information received within the month, these month-ahead surprises do not correspond exactly to the orthogonalized "policy shocks" from VARs, however.

month s and the 1-month futures rate on the last day of month $s-1$ understates the "true" surprise, measured in terms of month-end rates.[10] As with the daily data, rescaling this difference according to the number of days affected by the change would exaggerate any premium associated with the futures rate, and introduce noise into the measure.

The shift to a monthly frequency means it is no longer possible to use successive days' futures rates to measure the surprise. So rather than correct the observed Fed funds surprises, it is easier simply to introduce the same distortion into the changes in market interest rates. As in Rudebusch (1998), the unexpected change in the funds rate is defined as the average rate in month s, minus the 1-month futures rate on the last day of month $s-1$,

$$\bar{\Delta}\tilde{r}_s^u \equiv \frac{1}{m}\sum_{i\in s}\tilde{r}_i - f_{s-1,m}^1 \tag{9}$$

and the expected change in the funds rate target is defined analogously as

$$\bar{\Delta}\tilde{r}_s^e \equiv f_{s-1,m}^1 - \tilde{r}_{s-1,m}, \tag{10}$$

i.e., spread between the futures rate and the Fed funds target on the last day of month $s-1$, $\tilde{r}_{s-1,m}$. The sum of the two is just the month-s average funds rate target minus the target on the last day of month $s-1$, denoted as $\bar{\Delta}\tilde{r}_s$. (The non-standard $\bar{\Delta}$ notation is used to refer to the change from the last day of month $s-1$ to the average of month s.) The $\bar{\Delta}$ filter is also applied to market interest rates,

$$\bar{\Delta}R_s \equiv \frac{1}{m}\sum_{i\in s}R_i - R_{s-1,m}. \tag{11}$$

By calculating the change in this way, the effects of time-averaging on Fed funds surprises are duplicated in the changes in market interest rates, thereby preserving the scale of the relationship between the two.[11]

Table 6 reports the estimates of the regression,

$$\bar{\Delta}R_s = \alpha + \beta_1\bar{\Delta}\tilde{r}_s^e + \beta_2\bar{\Delta}\tilde{r}_s^u + \varepsilon_s, \tag{12}$$

where futures rates are used to compute the surprise target rate changes, as described above. The yield on 3-month bills rises by 74 basis points in response to an unexpected one percent increase in the target, and the 6- and 12-month yields rise by 84 basis points: somewhat larger than the 1-day response to unanticipated rate increases, and not statistically different from 100. The estimated responses of note and bond rates are also stronger than those

[10] These time aggregation issues are discussed in greater detail in Evans and Kuttner (1998).

[11] To remain comparable to the futures rate calculation, the average is taken over every calendar day of the month. The measured funds rate surprise may be contaminated by a forward premium, but if the premium is constant, it will be absorbed into the constant terms in the regressions that follow.

Table 6
The 1-month response of interest rates to Fed funds surprises[a]

		Response to target change				
Maturity	Intercept	Anticipated	Unanticipated	R^2	SE	DW
3 month	0.2	58.0	74.3	0.41	10.1	2.00
	(0.0)	(3.3)	(9.8)			
6 month	1.6	48.1	83.6	0.41	11.1	1.92
	(1.6)	(2.3)	(8.0)			
12 month	1.5	39.2	84.6	0.33	13.0	1.58
	(1.0)	(1.7)	(6.5)			
2 year	2.7	28.5	93.6	0.27	16.6	1.55
	(1.4)	(1.2)	(6.2)			
5 year	3.3	12.7	81.1	0.22	16.6	1.47
	(1.7)	(0.6)	(5.3)			
10 year	3.1	5.8	63.3	0.18	15.1	1.58
	(1.7)	(0.4)	(5.4)			
30 year	2.6	− 1.6	51.9	0.17	13.2	1.61
	(1.7)	(0.1)	(6.6)			

[a] *Note*: The change in the target Fed funds rate is expressed in percent, and the interest rate changes are expressed in basis points. The sample runs from June 1989 through January 2000. Parentheses contain t-statistics.

observed at a 1-day horizon, with the 30-year bond yield rising by over 50 basis points. Overall, these results provide further confirmation of the earlier results' robustness.

5. Implications for the term structure of interest rates

The goal thus far has been merely to describe the response of interest rates to policy actions, and to show that distinguishing between expected and unexpected actions is essential to correctly estimate that response. Given the impact of Fed policy on the yield curve, it is natural to ask whether the estimated responses are consistent with the expectations hypothesis of the term structure, and what the dynamics of Fed policy imply for empirical tests of the expectations hypothesis. The results, it turns out, are quite consistent with the expectations hypothesis; but the uniformity of futures rates' response to surprise target rate changes helps to explain the lack of empirical support for the expectations hypothesis at the short end of the yield curve.

5.1. Are the results consistent with the expectations hypothesis?

This section highlights three aspects of the results in Sections 3 and 4, and takes up the question of whether these findings are consistent with the expectations hypothesis: first, the smaller response of long-term interest rates; second, the less than one-for-one response of bill rates; and third, the significant coefficient on *expected* target rate changes in the monthly bill rate regressions.[12]

Insight into these findings can be gained by using the expectations hypothesis to express the d-day rate (denoted R^d) as the average of current and expected future overnight rates (denoted R^1). The one-day change in the rate on a d-day bill (which becomes a $d-1$-day bill after one day) can then be written as:

$$R_t^{d-1} - R_{t-1}^d = \frac{1}{d-1}(R_t^1 - E_{t-1}R_t^1) + \frac{d-2}{d-1}(E_t R_{t+1}^{d-2} - E_{t-1}R_{t+1}^{d-2}) + \frac{1}{d}(E_{t-1}R_t^{d-1} - R_{t-1}^1), \tag{13}$$

i.e., in terms of the surprise change in the overnight rate, the revision in the expectation of the next day's $(d-2)$-day rate (itself an average of expected future overnight rates), and the difference between the expected $(d-1)$-day rate and the day-$(t-1)$ overnight rate.

This expression shows that under the expectations hypothesis, the direct effect of a surprise change in the Fed funds rate on the d-day rate is proportional to $1/(d-1)$—quite small even for 3-month (91-day) T-bills. Clearly, changes in the overnight rate affect longer-term rates only to the extent that they lead to revisions in expectations of future overnight rates; the more persistent are the changes, the larger the effect on expectations. As noted by Cook and Hahn, mean reversion in the Fed funds rate therefore implies smaller responses for bonds farther out the yield curve.

This observation, together with the hypothesis that many one-day policy surprises have more to do with the *timing* of actions than with their ultimate size, can also explain the less-than one-for-one response of bill rates. The mere advancement or postponement of anticipated rate changes will have a smaller effect than actions that affect expectations of future rates. As an illustration, suppose an anticipated 25 basis point rate increase came 45 days earlier than expected—at the February FOMC meeting, say, instead of at the March meeting. This rate change would have only a limited effect on the 3-month bill rate, as expectations of higher overnight rates 45 days hence would already have been incorporated into the bill rate. In this example, the earlier-than-expected rate hike would result in only a 12 basis point increase in the 3-month bill rate—half the magnitude of the response to an action that was expected to affect the overall *level* of rates.

[12] As an ideal test of consistency with the expectations hypothesis, one might want to compare the responses of the Fed funds futures rates with those of the forward rates in the term structure. But since the longest futures contract is for only 5 months, this could only be done for the very short end of the yield curve.

The timing story is confirmed by analyzing the response of the Fed funds futures rates themselves to surprise policy actions. Since changes in the futures rate can be interpreted as revisions in market expectations, they can be used to gauge the effect of surprise policy actions on target rate expectations. In a regression analogous to Eq. (8), changes in the 1-through 5-month futures rates are regressed on the expected and unexpected change in the target, for those days when the target rate was changed. The results appear in Table 7. The estimated coefficients on the funds rate surprises are all near 0.6, and significantly less than one. Unanticipated actions' less-than one-for-one effect on expectations of future target rates confirms the view that day-ahead surprises have as much to do with the *timing* of FOMC actions, as with the actions themselves.[13]

The third observation highlighted above concerns the response of interest rates to *expected* policy changes. No such relationship was uncovered using the daily data (Table 3), but in the monthly regressions (Table 6), bill rates display a large, and in the case of the 3- and 6-month bills, highly significant response to expected target rate changes.

At first glance, this might appear to contradict the efficient markets proposition that asset prices should respond only to new information. It turns out that monthly changes in bill rates *should* reflect anticipated policy changes, however. Under the expectations hypothesis, the 1-month change in successive k-month bond yields can be written as:

$$\Delta R_s^k = \frac{1}{k}[(R_s^1 - E_{s-1}R_s^1) + (k-2)(E_s R_{s+1}^{k-2} - E_{s-1}R_{s+1}^{k-2}) + (E_{s-1}R_{s+k-1}^1 - R_{s-1}^1)], \tag{14}$$

an expression involving the unexpected change in the 1-month rate, R^1; the revision in expectations of next month's $(k-2)$-month rate, R^{k-2}; and the expected k-month change in the 1-month rate.

The expected 1-month change in the funds rate therefore belongs to the regression as a proxy for the expected k-month change in the 1-month rate. If this were equal to the expected 1-month change, the coefficient on the expected 1-month funds rate change would equal $1/k$; if it were larger, the coefficient would exceed $1/k$. It turns out that the estimated coefficients on the anticipated target rate changes in Table 6 are somewhat larger than $1/k$, plausibly suggesting that anticipated rate changes are associated with expectations of further actions in subsequent months.

[13] Interestingly, running analogous regressions on monthly data yields coefficients which, while significantly less than one, are larger—close to 0.8. This suggests that policy actions which are unanticipated at a 1-month horizon have a larger effect on the level of rates, perhaps because they incorporate Fed's response to any news that may have arrived during the course of the month. This is also consistent with the larger observed response of interest rates estimated on monthly data.

Table 7
The response of funds rate expectations to target rate surprises[a]

Horizon	Intercept	Response to target change: Anticipated	Response to target change: Unanticipated	R^2	SE	DW
1 month	− 0.00	0.03	0.64	0.74	0.053	1.50
	(0.4)	(0.8)	(9.3)			
2 months	− 0.01	0.00	0.62	0.65	0.061	1.66
	(1.0)	(0.1)	(7.7)			
3 months	− 0.02	0.03	0.55	0.57	0.066	1.52
	(1.7)	(0.6)	(6.4)			
4 months	− 0.02	0.01	0.61	0.56	0.074	1.51
	(1.6)	(0.3)	(6.3)			
5 months	− 0.02	0.02	0.57	0.47	0.087	1.44
	(1.3)	(0.3)	(4.7)			

[a] *Note*: Anticipated and unanticipated changes in the Fed funds target are computed from the Fed funds futures rates, as described in the text. Parentheses contain *t*-statistics. See also notes to Table 1.

5.2. Policy persistence and the information in the yield curve

The segment of the yield curve between 3 and 12 months has always presented a puzzle for research on the term structure: contrary to the implications of the expectations hypothesis, the slope of the yield curve over this range seems to have very little predictive power for subsequent changes in short-term interest rates.[14]

Cook and Hahn (1989) argued that the persistence of funds rate changes is to blame for the failure. If changes in the target rate tend to persist for months at a time, the argument goes, then the slope of the yield curve will contain little information about the expected path of policy. Since the Fed policy is presumably the major factor driving the short end of the yield curve, this means changes in the term spread will be dominated by fluctuations in the term premium. To support their argument, Cook and Hahn cited the uniform 50–55 basis point response of 3- 6- and 12-month bill rates to one percent changes in the target rate, and noted that other policy-related actions such as discount rate changes and money announcements also generated similar responses across maturities. In the results presented above in Table 3, surprise actions produced a similarly uniform 71–79 basis point response of bill rates, corroborating the Cook–Hahn conclusion.

[14] It should be noted that this puzzle is less evident in the more recent sample than in earlier periods. The regression of the 3-month change in the 3-month bill rate on the forward-spot spread yields an estimated slope coefficient of 0.54, with a *t*-statistic of 3.4.

Cook and Hahn's evidence on this question was only circumstantial, as it did not explicitly examine the persistence of the funds rate. The persistence question was addressed more directly by Rudebusch (1995) who, using a high-frequency duration model, found that a change in the funds rate had no implications for further changes beyond a horizon of about 5 weeks, further corroborating Cook and Hahn's argument.

The response of the Fed funds futures rates reported in Table 7 provides an alternative way to document the uniform response of policy expectations to target rate changes, and confirms the perceived persistence of those changes. The coefficients for the 1- through 5-month contracts range from 0.55 to 0.64—less than one, again to the extent that the surprises alter only the expected timing of Fed actions, but very comparable in magnitude. In a Wald test, the hypothesis that the responses are equal across horizons cannot be rejected at the 0.05 level.[15] A surprise rate increase therefore implies a higher *level* of rates in coming months, but says nothing about expectations of future rate changes. These results, therefore, provide further evidence supporting the Cook–Hahn and Rudebusch explanation of the failure of the expectations hypothesis at the 3- to 12-month horizon.

6. Conclusions

The aim of this paper has been to estimate the effect of changes in Federal Reserve policy on a spectrum of market interest rates, using Fed funds futures data to distinguish anticipated from unanticipated changes in the funds rate target. Its main finding is that of a strong relationship between surprise policy actions and market interest rates; the response to anticipated actions is small. The results are robust for estimating on FOMC meeting dates, and to defining rate changes at monthly intervals. Interest rates' response to target rate is generally consistent with the expectations hypothesis, although the less-than one-for-one response to surprise actions at the short end of the yield curve suggests that many of these surprises have more to do with timing of rate changes than with the ultimate level of rates. Finally, surprise target rate changes have virtually no effects on expectations of future Fed actions, which helps to explain the failure of the expectations hypothesis on the short end of the yield curve.

More generally, this paper has discussed the use of Fed funds futures contracts in extracting measures of expected policy actions, highlighting possible pitfalls introduced by the contracts' unique time-averaged structure. An interesting line of future research would be to use the methods developed

[15] Analogous results using monthly data show exactly the same pattern: the coefficients are similar in size, and not statistically distinct from one another.

here to analyze the effects of monetary policy on other financial markets, such as those for equity and foreign exchange.

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