State-Dependent Stock Market Reactions to Monetary Policy*

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This paper presents a test of the response of stock prices to Federal Reserve policy shocks using a Markov-switching framework. The framework endogenously identifies two distinct regimes. The first is a state where the S&P 500 index exhibits a significantly negative response to unexpected changes in the target federal funds rate in the thirty-minute window bracketing FOMC announcements, a result consistent with previous work. However, the model identifies a second regime from September 1998 to September 2002, in which the response of stock prices to policy shocks is insignificant and over ten times more volatile relative to the other regime.

JEL Codes: E44, G12, G14.

1. Introduction

The response of asset prices to Federal Reserve policy is a key component for analyzing the impact of monetary policy on the economy. As Blinder (1998) notes, "Monetary policy has important macroeconomic effects only to the extent that it moves financial market prices that really matter—like long-term interest rates, stock market values, and exchange rates." This paper presents a test of the response of stock prices to Federal Reserve policy shocks using an event-study Markov-switching framework. In the period following

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the Federal Reserve's decision to announce changes in the target federal funds rate in 1994, the Markov-switching model identifies a separate state from September 1998 to September 2002. During this period, the volatility of the stock price response to Federal Reserve actions is more than ten times greater than in the remaining periods in the sample. Further, unexpected changes to the target federal funds rate in this high-volatility state have no statistically significant effect on the level of the S&P 500 index in the thirty-minute window bracketing the policy announcement. In the low-volatility state, the market response to unexpected changes in the target federal funds rate is significantly negative and reflects the recent body of work documenting this effect, including Rigobon and Sack (2004), Bernanke and Kuttner (2005), and Gurkaynak, Sack, and Swanson (2005).

A recent example using the event-study framework to assess the effects of monetary policy on the stock market is Bernanke and Kuttner (2005), who use daily CRSP value-weighted returns and a measure of unexpected changes to the target federal funds rate computed from federal funds futures contract prices the day prior to a change to the target rate. They find that an unexpected 25-basis-point cut in the target federal funds rate is associated with a 1 percent increase in equity prices. A similar approach is used by Gurkaynak, Sack, and Swanson (2005), who use high-frequency data to overcome the potential endogeneity and omitted-variables problems associated with using data covering a broad time window around policy announcements. By focusing on a narrow window around policy changes, they isolate the impact of unexpected moves in the target federal funds rate on equity prices, finding that the S&P 500 increases slightly more than 1 percent in response to a surprise 25-basis-point cut. Related literature measuring the response of equity returns to monetary policy using the event-study framework also includes Patelis (1997), Thorbecke (1997), D'Amico and Farka (2002), Bomfin (2003), Craine and Martin (2003), and Bentzen et al. (2004).[1]

[1] A broad literature exists assessing the reaction of bond prices to monetary policy using the event-study approach, such as Cook and Hahn (1989), Roley and Sellon (1998), Thornton (1998), Bomfin and Reihnart (2000), Kuttner (2001), Cochrane and Piazzesi (2002), and Poole, Rasche, and Thornton (2002).

Rigobon and Sack (2004) develop a heteroskedasticity-based technique for estimating the impact of monetary policy on asset prices and report that an unexpected 25-basis-point decrease in the three-month eurodollar futures rate results in a 1.7 percent increase in the S&P 500 index.

Jensen and Mercer (2002) allow for variation of asset returns across different states. They use three measures of monetary policy shocks—(i) changes in the Federal Reserve discount rate, (ii) changes in the target federal funds rate, and (iii) the Boschen and Mills (1995) monetary policy index—to separate Federal Reserve policy into expansive and restrictive periods. However, the different periods are exogenously specified and do not measure the response to unexpected monetary policy announcements. The framework in this paper endogenously detects different states and estimates the corresponding state-dependent response of stock prices to monetary policy.

The outline of the paper is as follows: Section 2 describes the data, section 3 discusses the Markov-switching framework, and section 4 presents the empirical results. Section 5 reports results from a set of robustness checks, and section 6 concludes.

2. Data

The sample consists of the eighty scheduled announcements associated with Federal Open Market Committee meetings from the beginning of 1994, when the Federal Reserve began to announce its policy decisions, through the end of 2003. Following Kuttner (2001), we use daily thirty-day federal funds rate futures, available from the Chicago Board of Trade, to measure the unexpected component of Federal Reserve policy decisions.[2] Our measure of shocks is identical to the daily monetary policy surprises in Gurkaynak, Sack, and Swanson (2005). Tick data provided the stock market data, which

[2]Krueger and Kuttner (1996) and Rudebusch (1998) confirm that federal funds futures prices are efficient. Söderström (2001) finds that federal funds futures rates have weak predictive power using daily data but are much more successful for predicting the average funds rate and funds rate changes around target changes and meetings of the FOMC. Poole, Rasche, and Thornton (2002) document that the futures market is better able to anticipate policy changes since 1994, when the Federal Reserve began to announce publicly its policy decisions.

consist of high-frequency observations of the S&P 500 index. The stock market returns are log differences of the S&P 500 index at the beginning and end of a thirty-minute window around announcements following FOMC meetings. The thirty-minute window is intended to be long enough to avoid market-microstructure issues but short enough to limit the endogeneity and omitted-variables problems associated with measuring the market response to Federal Reserve actions in daily data.

3. State-Dependent Market Reactions

The general approach follows an event-study framework, with the econometric specification deriving from the Markov-switching approach in Hamilton (1989). This framework allows for, but does not require, the market return to respond differently to unexpected changes in the target federal funds rate across different periods of the sample. The specification is

$$H_t = a + b^u(S_t)\Delta i_t^u + \varepsilon_t, \tag{1}$$

where H_t is the market return, S_t is the unobserved state variable, Δi_t^u is the unexpected change in the target federal funds rate, and $\varepsilon_t \sim N(0, \sigma(S_t)^2)$. This specification allows the variance of the error term to vary with the state, requiring that $b^u(S_t)$ and $\sigma(S_t)$ switch synchronously.

A two-state Markov chain governs the evolution of the unobserved state,

$$\Pi = \begin{bmatrix} p_{00} & 1 - p_{00} \\ 1 - p_{11} & p_{11} \end{bmatrix}, \tag{2}$$

where $p_{ij} = \Pr[S_t = j | S_{t-1} = i]$ for $i = 0, 1$ and $j = 0, 1$. A nonlinear iterative filter formulates probabilistic estimates of the state and constructs the log-likelihood function, where estimation proceeds by maximizing the likelihood function (see Hamilton 1989; Kim and Nelson 1999). The model given by (1) and (2) specifies two states but provides for the possibility that only one state is in place over the sample period.[3] The data determine the properties and timing of each regime.

4. Results

4.1 High- and Low-Volatility States

Table 1 reports parameter estimates for the Markov-switching model using observations corresponding to scheduled FOMC announcements. Estimation endogenously delineates the sample between two regimes, one running from the beginning of the sample in February 1994 until November 1994 and then recurring from September 1998 through September 2002. Two primary factors characterize this regime: (i) the volatility of the market return is eleven times greater than in the other regime and (ii) the response of stock prices to

Table 1. Maximum-Likelihood Estimates

Parameter	**Scheduled FOMC Meetings**	**All Observations Including Intermeeting Moves**
a	$-.083^{**}$	$-.076^{*}$
	(.031)	(.031)
$b^u(0)$: Low Volatility	-1.914^{**}	-1.622^{**}
	(.635)	(.554)
$b^u(1)$: High Volatility	-1.547	-6.881^{**}
	(1.751)	(.675)
$\sigma(0)^2$: Low Volatility	$.028^{**}$	$.030^{**}$
	(.007)	(.008)
$\sigma(1)^2$: High Volatility	$.320^{**}$	$.423^{**}$
	(.066)	(.091)
ln Likelihood	-28.007	-37.5374

Note: * and ** denote significance at the 5 percent and 1 percent level, respectively.

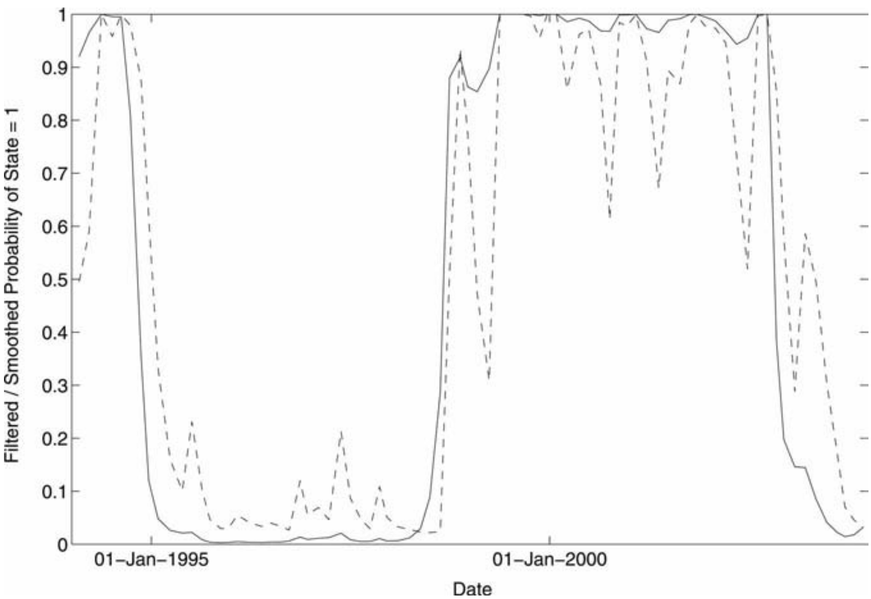
[3]Due to data limitations, we do not consider more than two states as a reasonable description of the data.

an unexpected increase in the target federal funds rate is statistically insignificant. Thus, the direction of the stock price response to changes in Federal Reserve policy is less predictable and more volatile.

The low-volatility state corresponds to December 1994 through August 1998, recurring from 2002 to the end of the sample. Key attributes of this state are (i) low volatility of the market return and (ii) a significantly negative response to unexpected increases in the target federal funds rate. A 25-basis-point unexpected reduction in the target federal funds rate increases the S&P 500 index around 50 basis points, a response approximately half of that estimated by Bernanke and Kuttner (2005) and Gurkaynak, Sack, and Swanson (2005).

Figure 1 gives filtered and smoothed probabilities of being in the high-volatility state. The filtered probability of being in state j

Figure 1. Probability of High-Volatility State



Note: The dashed line denotes filtered probabilities, while the solid line denotes smoothed probabilities.

at t is $\Pr[S_t = j|\Omega_t]$, where Ω_t is the information set that includes all past observations and those at time t. The smoothed probability is $\Pr[S_t = j|\Omega_T]$, where Ω_T includes information over the entire sample.

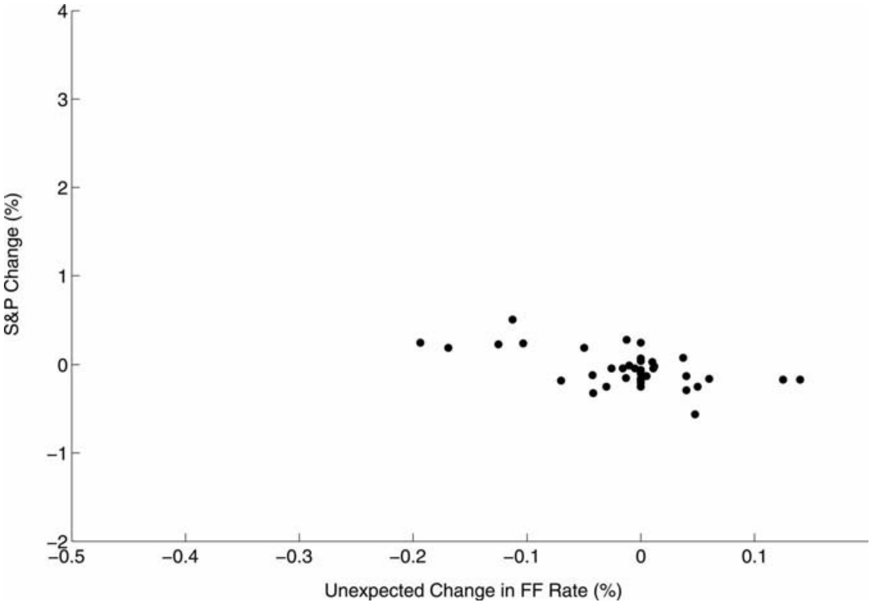
Ambiguity in the press releases for the first three public announcements of changes to the target federal funds rate likely causes four observations from 1994 to be placed in the high-volatility state. The Federal Reserve started officially announcing changes to the target federal funds rate at the beginning of 1994, but it wasn't until May 17, 1994, that it officially announced the exact target federal funds rate and provided a brief statement regarding the views of the FOMC about the state of the economy.[4] Thus, the market had less information regarding target federal funds rate changes prior to May 1994, resulting in a more uncertain and volatile market response. For this reason, the inclusion of these early observations into the high-volatility state appears reasonable.

Figures 2 and 3 are scatter plots of the unexpected component of changes in the target federal funds rate against the market return, broken out by state. Figure 2 is the low-volatility state, illustrating the negative relationship between the unexpected component of changes in the target federal funds rate and the market response, as well as the low variability of the response. Figure 3 is the high-volatility state, where the volatility of the response is more pronounced relative to the low-volatility state. In figure 3, the hollow markers denote intermeeting moves and are discussed in the following section.

Using data from Gurkaynak, Sack, and Swanson (2005) over the same sample period yields the same qualitative results for each regime. The difference in data used in their paper rests with how the unexpected change in the target federal funds rate is computed. They use the thirty-minute window surrounding the policy announcement, whereas our data follow Bernanke and Kuttner (2005), using the previous day's closing price. Both sets of data

[4]For example, the entire press release following the FOMC meeting on April 18, 1994, read as follows: "Chairman Alan Greenspan announced on April 18, 1994, that the Federal Reserve would increase slightly the degree of pressure on reserve positions. This action was expected to be associated with a small increase in short-term money market interest rates."

Figure 2. Low-Volatility State

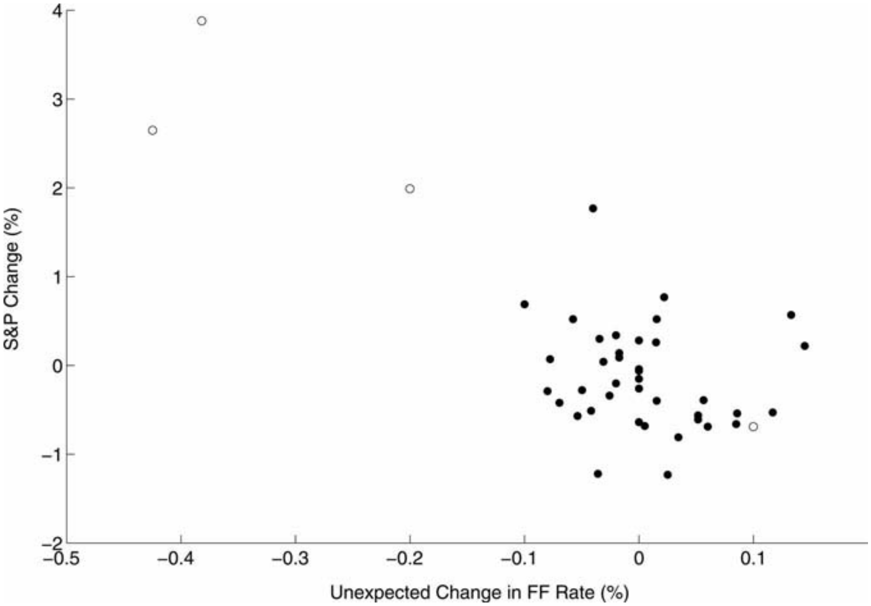


use the change in the S&P 500 index in the thirty-minute window surrounding the policy announcement. The one difference arising from the different data is the timing of the regimes, where the high-volatility regime extends to the end of the sample with data from Gurkaynak, Sack, and Swanson (2005), resulting in fifty-one of the eighty observations falling into this state. However, the probabilistic inference of being in the high-volatility state begins declining in September 2003. Otherwise, the timing of the states is in close agreement.

There are several possible explanations for changes in volatility in the sample. One possibility is that during the mid to late 1990s, traders simply faced increased noise in estimating current asset values. Thus, traders could not sort out the effects of monetary policy as well, causing a less-predictable market response to policy shocks.

A second possibility is that the market interpreted Federal Reserve actions more as a "signal" revealing private information during the high-volatility state, rather than altering underlying

Figure 3. High-Volatility State



Note: Hollow markers denote intermeeting target federal funds rate changes.

fundamentals in financial markets.[5] For example, the market may have been more likely to interpret a rate increase in the high-volatility state as a signal from the Federal Reserve that the economy is stronger than expected. This interpretation suggests that the market simply interpreted information differently across the sample.[6]

[5]Market participants may perceive the Federal Reserve as possessing private information due to data gathering and analysis capabilities. Work addressing this issue includes Peek, Rosengren, and Tootell (1999, 2003), Romer and Romer (2000), and Faust, Swanson, and Wright (2004).

[6]Amato, Morris, and Shin (2002) provide an example of how agents may respond to noisy signals. In their model, agents have incentives to learn about economic fundamentals and coordinate their actions with those of other agents in the economy. Agents receive a private signal and a public signal, both containing information about the state of the economy and noise. The coordination incentive can cause agents to overreact to the public information.

4.2 Specification Testing

To establish the Markov-switching approach as an appropriate framework to address the stock market response to monetary policy, we first test the standard ordinary least squares (OLS) specification against the Markov-switching alternative. This test suffers from the problem in Davies (1977), in which some nuisance parameters are not identified under the null hypothesis. Consequently, the likelihood ratio statistic has a nonstandard distribution. Using the approach in Hansen (1992), the standardized likelihood test statistic is 3.16 with a 1 percent critical value of 2.36 and p-value less than 1e-6, indicating that the standard OLS model with time-invariant parameters is formally rejected in favor of the Markov-switching alternative.[7]

Given the close point estimates and large confidence interval around $b^u(1)$, a reasonable alternative model restricts the response of returns to be equal across regimes but allows the volatility to switch,

$$H_t = a + b^u \Delta i_t^u + \varepsilon_t, \tag{3}$$

where $\varepsilon_t \sim N(0, \sigma(S_t)^2)$. The restriction on (1) yielding (3) is given by

$$H_0 : b^u(0) = b^u(1).$$

We cannot reject this restriction, since the log-likelihood value for the model in (3) is -28.031, a value close to the unrestricted log-likelihood value of -28.007.[8] The estimate of b^u from (3) is -1.87 and significant, a value close to that in the low-volatility regime. Estimates of the variance in each regime in the restricted model are

[7]The critical values are actually bounds arising from simulating the asymptotic distribution and, as Hansen (1992) points out, are conservative estimates, which strengthens the result that the OLS model can be rejected in favor of the Markov-switching alternative.

The result of the test is invariant for $M = 1, 2, 3, 4$, where M is the bandwidth number in the Bartlett kernel used in simulating the covariance function (see Hansen 1996). The critical value reported is for $M = 4$.

[8]Given that not all parameters are restricted to be equal across both states, this approach to specification testing does not suffer from the problem of nuisance parameters not being identified under the null hypothesis (see Davies 1977).

nearly unchanged. This test, as well as the test against OLS, underscores the clear evidence for time variation in the variance of returns but raises questions regarding the response of returns in each regime. It is the case that returns in the unrestricted model do not respond significantly in the high-volatility regime. However, the above test reflects that the insignificant response in the high-volatility regime may be a consequence of increased noise instead of a breakdown in the relation between surprise changes in the target federal funds rate and returns.

Alternatively, we can specify a more-general model than (1) by allowing the intercept term to be state dependent and including the expected change to the target federal funds rate as an additional explanatory variable, also with a state-dependent coefficient. For example,

$$H_t = a(S_t) + b^u(S_t)\Delta i_t^u + b^e(S_t)\Delta i_t^e + \varepsilon_t, \tag{4}$$

where Δi_t^e is the expected change and $\varepsilon_t \sim N(0, \sigma(S_t)^2)$. The total change in the target federal funds rate is $\Delta i_t = \Delta i_t^e + \Delta i_t^u$.

The joint set of restrictions on the more-general model (4) that yield (1) is given by

$$H_0 : b^e(0) = b^e(1) = 0, \quad a(0) = a(1).$$

The null hypothesis tests whether the coefficients on the expected component in both states are zero and whether unconditional returns, governed by the intercept, are independent of the state. Setting the coefficient on Δi_t^e to zero in both states is justified on economic grounds, since the market should not respond to correctly anticipated changes to the target federal funds rate. The above restrictions cannot be rejected at conventional significance levels, supporting the specification given in (1). The statistically insignificant coefficients on expected changes to the target federal funds rate are consistent with estimates in Bernanke and Kuttner (2005) and the specification in Gurkaynak, Sack, and Swanson (2005). Also, the filtered and smoothed probabilistic estimates of the states under specifications (1) and (4) are in close agreement.

Further analysis suggests that the Markov-switching model is capable of quickly detecting a change between the low- and high-volatility states. The framework could have quickly detected the

Table 2. OLS Estimates by Regime

	Low Volatility	High Volatility
Observations	41	39
Intercept	$-.075^{**}$	$-.134$
	(.028)	(.093)
Unexpected Change	-1.821^{**}	-1.761
	(.421)	(1.638)
R^2	.335	.030

Note: ** denotes significance at the 1 percent level.

change in the relationship between unexpected changes in the target rate and stock prices. For example, using a truncated data set with only the first forty-nine observations from the sample, estimation of the model indicates a regime switch at approximately the same time as would occur if using the full sample. Since the data for such analysis are easily available and not subject to revision, the Markov-switching framework could possibly allow the Federal Reserve to learn within the course of only a few meetings if the market had entered a state where policy changes have a significantly more volatile effect on stock prices.

4.3 Comparison to OLS

To compare with other results, such as Bernanke and Kuttner (2005) and Gurkaynak, Sack, and Swanson (2005), table 2 reports OLS estimates for subsamples corresponding to the high- and low-volatility states. The coefficient estimates on the unexpected component for each state are similar to those from the Markov-switching model—significantly negative in the low-volatility state and negative, but not significant, in the high-volatility state. However, of primary interest is the R^2, which is .33 in the low-volatility state and .03 in the high-volatility state. The difference in R^2 is a clear indication of the higher volatility and unpredictability of the market response to monetary policy in the high-volatility state.

In Gurkaynak, Sack, and Swanson (2005), similar conclusions arise using high-frequency data in the thirty-minute window surrounding FOMC announcements. The coefficient on the unexpected component is significantly negative using observations in the low-volatility state and not significantly different than zero in the high-volatility state. The corresponding R^2 is .50 in the low-volatility state and .04 in the high-volatility state. The R^2 using the sample of observations from the beginning of 1994 to the end of 2003 corresponding only to scheduled FOMC meetings yields a significantly negative coefficient on the unexpected component and an R^2 of .07.

Comparing OLS with the Markov-switching estimates underscores that using OLS when regime changes occur yields estimates that are a weighted average of the responses in each regime. OLS estimates using the entire sample indicate that the market responds negatively, on average, to an unexpected increase in the target federal funds rate. However, OLS does not capture the changes in volatility that are apparent when using a Markov-switching framework.

5. Robustness Checks

5.1 Intermeeting Moves

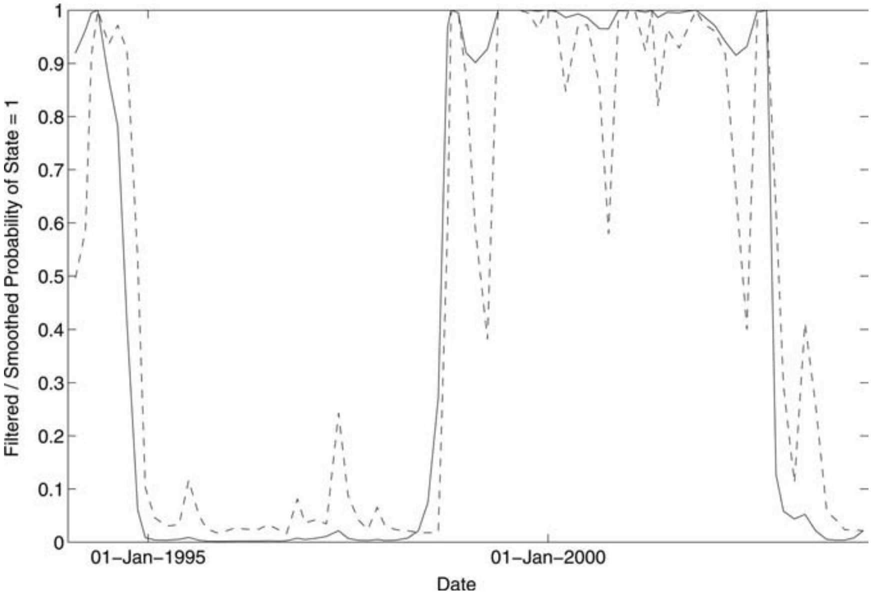
The analysis thus far only considers the effects of changes to the target federal funds rate during scheduled FOMC meetings. Over the sample, there are five intermeeting changes to the target federal funds rate: April 18, 1994; October 15, 1998; January 3, 2001; April 18, 2001; and September 17, 2001.[9] These intermeeting rate changes differ from regularly scheduled FOMC meetings in that the unexpected component of the intermeeting moves is relatively large, since these changes are unexpected by their very nature.

The four intermeeting changes all occur during the high-volatility state and are represented by the hollow circles in figure 3. These observations include the three largest movements in both asset prices and the unexpected component of changes to the target federal funds rate.[10] Inspection reveals that the four observations line up precisely

[9] The move on September 17, 2001, the first day of trading on the New York Stock Exchange after September 11, is considered an anomaly and, following Bernanke and Kuttner (2005) and Gurkaynak, Sack, and Swanson (2005), is excluded from the analysis.

[10] Using influence analysis, Bernanke and Kuttner (2005) exclude these three intermeeting moves from their study.

Figure 4. Probability of High-Volatility State Including Intermeeting Target Changes



Note: The dashed line denotes filtered probabilities, while the solid line denotes smoothed probabilities.

and that including them in the sample strongly influences the coefficient estimate of the market response to the unexpected component in the high-volatility regime.

Table 1 provides estimates using the sample including intermeeting moves, and figure 4 provides the filtered and smoothed probabilistic estimates of the high-volatility state. The timing of the low- and high-volatility states is largely unaffected, as comparison of figures 1 and 4 indicates. The market response in the low-volatility state is −1.622 and significant, similar to the estimate using the sample excluding intermeeting moves. The primary difference arises in the high-volatility regime, where the market response is −6.881 and significant, contrasting to the estimate from the sample excluding intermeeting moves. Thus, unlike shocks that occur following regularly scheduled meetings, wholly unexpected rate changes appear to have a powerful effect on the market during the high-volatility state.[11]

5.2 Asymmetry, Discount Rate Changes, and Policy Reversals

As final robustness checks, we assess whether asymmetry, discount rate changes, or policy reversals have an effect on the results. Asymmetry exists if the market response depends on the sign of the unexpected change to the target federal funds rate. In other words, we test whether surprise increases affect the market differently from surprise decreases. Controlling for discount rate changes and policy reversals may also be important, given that such changes may convey additional information on the state of the economy to the public.

To account for each of these effects, we use the model given by (1) with the addition of a dummy variable,

$$H_t = a + b^u(S_t)\Delta i_t^u + b^d d_t + \varepsilon_t, \tag{5}$$

where d_t is either 0 or 1. Note that b^d is not state dependent. Results are given in table 3 for all the robustness checks. The coefficient on the dummy variable is insignificant and does not affect the timing of the low- and high-volatility states, indicating that asymmetry is not playing a role in the results.

To control for changes to the discount rate, $d_t = 1$ for the twenty observations when a change occurs and 0 otherwise.[12] The coefficient on the dummy is insignificant, and the timing of the states is unaffected. For policy reversals, $d_t = 1$ for the six observations when there was a change to the target federal funds rate in the opposite direction relative to the previous change. Again, the coefficient on the dummy is insignificant, and the timing of the states is unaffected.

[11] An important point to keep in mind, however, is that these results stem from adding only four observations to the sample, constituting a small subsample.

[12] We ignore May 19, 2000, and January 4, 2001, two dates when the discount rate changed, but the target federal funds rate did not.

Table 3. Robustness Checks

Parameter	Asymmetry	Discount Rate Changes	Policy Reversals
a	$-.101^{**}$ (.032)	$-.090^{**}$ (.033)	$-.095^{**}$ (.037)
$b^u(0)$: Low Volatility	-2.304^{**} (.679)	-2.002^{**} (.660)	-2.097^{**} (.711)
$b^u(1)$: High Volatility	-1.838 (1.839)	-1.523 (1.836)	-1.601 (1.694)
d	.139 (.103)	.047 (.082)	.150 (.092)
$\sigma(0)^2$: Low Volatility	$.031^{**}$ (.008)	$.030^{**}$ (.008)	$.026^{**}$ (.008)
$\sigma(1)^2$: High Volatility	$.302^{**}$ (.075)	$.319^{**}$ (.073)	$.312^{**}$ (.072)
ln Likelihood	-27.155	-27.899	-26.985

Note: ** denotes significance at the 1 percent level.

6. Conclusion

Beginning in 1994, when the Federal Reserve began to announce publicly its policy decisions following FOMC meetings, through the end of 2003, there are two distinct regimes characterizing the response of the S&P 500 index to unexpected changes in the target federal funds rate—a high- and low-volatility regime. During the high-volatility regime, from September 1998 through September 2002, the market response to unexpected changes in the target federal funds rate following scheduled FOMC meetings is highly variable and not significantly different from zero. During the low-volatility regime, unexpected changes in the target federal funds rate are much less volatile and negatively related to stock prices. The results are robust when controlling for various factors, such as asymmetric responses, discount rate changes, and policy reversals.

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