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Asymmetric Response to Monetary Policy Surprises at the Long-End of the Yield Curve*

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Abstract

This paper provides a dynamic analysis of the responsiveness of asset markets to monetary policy path revisions. In an era of increased transparency and gradualism in policy making, one might expect an increased response to path revisions in asset markets as the policy actions become more predictable over longer horizons. Using federal funds futures contracts to extract near-term path revisions, we find that the responsiveness of Treasury securities to path revisions is significantly asymmetric, increasing during cycles of tightenings and declining during easings. This is consistent with the earlier literature that documents asymmetric effects of monetary policy on output.

Keywords: Asymmetric monetary policy; yield curve; federal funds futures
JEL Codes: E44, E52

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1. Introduction

Over the last fifteen years, the Federal Reserve took significant steps towards transparency. Combined with its history of gradualism, these steps allowed the Fed to expand its control over interest rates. In 1994, the Federal Reserve started announcing changes in the funds rate target. While interest rates have been the primary operational tool that reflected changes in the policy stance until 1999, policy statements that accompanied interest rate announcements after this date informed the market participants not only about the current policy changes but also about the future path of monetary policy. These developments allowed market participants to better understand the decision making process and form more accurate forecasts of future policy actions, which accelerated the traditional channels of the monetary transmission mechanism.

During his 2004 speech on "Gradualism" then-governor Bernanke noted that:[1]

> "… private-sector expectations play a crucial role in the determination of long-term interest rates and other asset prices and yields. Specifically, by leading market participants to anticipate that changes in the policy rate will be followed by further changes in the same direction, policy gradualism may increase the ability of the Fed to affect long-term rates and thus influence economic behavior."

In this paper, we explore the responsiveness of asset markets and in particular longer term yields to revisions in near-term monetary policy expectations. In an era of increased transparency and improved communication in policy making, one might expect the Federal Reserve's gradualist approach to become more visible to market participants. When market participants get a clearer signal that the changes in the policy rate will be followed by further

[1] At an economics luncheon co-sponsored by the Federal Reserve Bank of San Francisco (Seattle Branch) and the University of Washington, Seattle, Washington
http://www.federalreserve.gov/boarddocs/speeches/2004/200405202/default.htm

changes in the same direction, longer term yields may get more responsive to policy path revisions.

In this paper, we make several contributions to the literature. First, in order to investigate the responsiveness of longer term yields to policy path revisions, we develop a measure for longer term policy expectations. This measure allows us to document a strong asymmetry in the responsiveness of long-term rates to changes in the expected policy path. Furthermore, we illustrate that the decline in the effectiveness of monetary policy along the yield curve is much more muted during tightening cycles. This is a refinement over the earlier findings of a general decline in the effectiveness of monetary policy at longer horizons (see e.g. Cook and Hahn, 1989, Roley and Sellon, 1995, Kuttner, 2001, Demiralp and Jorda, 2004, Gürkaynak et al.,2005). Indeed, these findings tie together the literature on the monetary transmission mechanism over the yield curve to the studies that detect an asymmetry in the effectiveness of monetary policy in influencing output (see e.g. De Long and Summers, 1988, Cover, 1992, Morgan, 1993). Our findings suggest that the Federal Reserve is less influential in dealing with recessions because its ability to influence longer term interest rates weakens during easing cycles. In contrast, the Fed's ability to influence longer term rates during times of expansions suggests that the policy maker has the necessary policy tools to prick asset market bubbles relatively easily.

In a second contribution, we provide a dynamic analysis of the responsiveness of asset markets to monetary policy path revisions. The dynamic analysis underlines the evidence of an asymmetry where the responsiveness of longer term yields follow the policy cycles. However, we do not find any noticeable improvement in the responsiveness of asset markets to monetary policy actions over time.

The rest of the paper is organized as follows: In the next section we provide a brief literature review on the anticipation effect in asset markets and provide a perspective on the issue. Section three presents the empirical results while section four concludes. The appendix explains the methodology of calculating policy path revisions based on federal funds futures contracts.

2. Anticipation Effect in Asset Markets

Under the current interest rate targeting regime, the textbook description of the monetary transmission mechanism starts with a change in overnight interest rates which leads to consequent changes in longer term interest rates through the term structure relationship, and changes in the equity prices through the Gordon equation by changing expected excess returns.

What is missing in this textbook description is the asset markets' response to expected monetary policy actions before the policy decision is announced. Evidence of this type of an "anticipation effect" in Treasury markets has been documented in several studies where market rates are found to respond to monetary policy actions in the period prior to a target change (see e.g. Kuttner, 2001; Lange, Sack, Whitesell, 2003; Gürkaynak, Sack, and Swanson, 2005). Meanwhile, Carpenter and Demiralp (2006a) documented an anticipation effect in the federal funds market in the days prior to a target change, despite the close control by the Trading Desk. Bernanke and Kuttner (2005) documented an anticipation effect in equity markets. The common understanding in all these studies is that asset markets respond to anticipated policy prior to the policy event and they only respond to the unexpected (or the surprise) component following the event.

In this paper, we estimate the anticipation effect in asset markets for a longer time horizon which allows us to detect an asymmetric response to policy actions. Using a near-term measure for policy expectations, we quantify the asset markets' response to anticipated policy actions six months into the future. To that end, we consider a methodology to form market expectations based on federal funds futures contracts. Using this methodology, which is an extension of the technique described by Kuttner (2001), we compute the unanticipated component of target changes that are related to the current policy action and changes (or revisions) in the policy path in the upcoming six months. This measure of policy path revisions allows us to identify a strong asymmetry in the responsiveness of the longer term Treasury securities to policy surprises which cannot be detected if unanticipated policy actions are measured for horizons less than six months.

We find that the asset markets' responsiveness to path revisions are uniformly larger relative to their responses to the current month's policy surprise and the estimated responses are equal to their theoretical values of one for suitable maturities. This should not be interpreted as current policy actions are becoming secondary but that their influence comes earlier when investors build in expectations of those actions.

3. Empirical Analysis

The appendix describes our methodology of calculating policy surprises on the day of an FOMC meeting or an intermeeting change as well as for each month into the future (up to six months). Furthermore, we calculate the revisions in the expected policy path which are constructed as average surprise series over a particular time frame.

Figure 1 plots the 20-month moving averages of the policy surprise series (Figure 1a) as well as the path revisions (Figure 1b). The surprise series for each future month reflects the revisions in the expected target level for that month while the path revisions indicate the average changes in the expected policy path in the upcoming months. The figure highlights several interesting observations. First, easing cycles are generally associated with negative surprises.[2] This may reflect the market's tendency to form conservative forecasts of the future easings during times of recessions. Alternatively, it may be due to the Fed's tendency to surprise the markets by considering target cuts that are larger than anticipated. Given the general trend towards transparency, we believe that the latter is less likely to be the underlying reason. Second, even though the absolute sizes of the surprise series are larger during easings relative to tightenings, we do observe a general decline for easings as well as tightenings over time.[3] While this pattern is clearly consistent with the steps towards transparency, other developments could also contribute to smaller surprises such as fewer and smaller target changes (such as the period between 2002 and 2003).

Moving to the lower panel, we note that path revisions are consistently smaller than the surprise series associated with individual months. This finding is expected because a market surprise is frequently about the timing of an expected policy action which is either postponed or moved earlier due to the current decision. Hence, over a six month horizon, these timing adjustments cancel each other off, resulting in smaller path revisions.

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[2] In fact, when we break down the sample into easing cycles, interim periods, and tightening cycles, we observe that for a total of 34 observations for which the size of the current month's surprise was less than -0.05, 29 of them corresponded to easing cycles. The table below provides this breakdown in more detail:

Policy Cycle	Begins	Ends	Number of Observations	Surprise1 <-0.05	Surprise1 < -0.10	Surprise 1 >0.05	Surprise 1 > 0.10
Easing	6/5/89	9/4/92	38	14	11	1	1
Interim	10/7/92	12/22/93	11	1	0	1	0
Tightening	2/4/94	2/1/95	10	2	1	6	4
Easing	3/28/95	5/18/99	35	5	2	2	0
Tightening	6/30/99	5/16/00	8	1	0	2	0
Interim	6/28/00	12/19/00	5	0	0	1	0
Easing	1/31/01	6/25/03	21	6	3	4	1
Interim	8/12/03	5/4/04	7	0	0	0	0
Tightening	6/30/04	6/29/06	17	0	0	0	0
Interim	8/8/06	8/7/07	9	0	0	0	0
Easing	9/18/07	12/16/08	11	4	3	2	1
Interim	1/28/09	11/14/09	7	1	0	0	0
Total			179	34	20	19	7

[3] This finding is consistent with Carpenter and Demiralp, 2006b, who also documented a similar decline in the unanticipated policy actions for the current month.

In order to investigate the effects of unanticipated policy actions on asset markets, we consider a simple specification shown in equation (1):

$$A_t = \alpha + \beta_1 (Anticipated)_t + \beta_2 (Surprise_i)_t + \varepsilon_t \qquad (1)$$

where A_t is the change in the asset market variable, which is either the daily change in the Treasury yield (from three month bills to thirty year bonds), or the CRSP value weighted return on day *t*. *Anticipated* refers to the expected monetary policy action, and $Surprise_i$ refers to the monetary policy surprise for month *i*, such that *i*=1,2,…,6.[4]

Equation (1) is estimated on the days of FOMC meetings and target changes for the period after May 1989 when the futures market for the federal funds contracts gained sufficient liquidity. We exclude those intermeeting changes that are followed by FOMC meetings within the same month because we need to impose additional restrictive assumptions to calculate expected policy changes on these days, as explained in the appendix.[5] We also exclude the intermeeting change on September 17, 2001 because the markets' reactions on this day may have been driven by the terrorist attacks. The sample period ends on November 4, 2009.[6]

Equation (1) allows us to compare the responsiveness of asset markets to the individual surprise series for each month into the future. If the expectations hypothesis holds, we would expect the market response to anticipated policy actions to be insignificant and the response to unanticipated policy to be significant on the event day.

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[4] We obtained identical results with an alternative specification which omits the anticipated component as in Gürkaynak et al. (2005) or Ehrmann and Fratzscher (2004).

[5] We have a total of ten such intermeeting changes followed by FOMC meetings. The following observations are excluded from the analysis: August 10, 1989, November 6, 1989, December 7, 1990, February 1, 1991, March 8, 1991, August 6, 1991, December 6, 1991, January 3, 2001, January 22, 2008 and October 8, 2008.

[6] The sample period for the equity market equation is somewhat shorter because the CRSP data is only available through June 30, 2008.

The first six bars in Figure 2 plot the coefficient estimates associated with the surprise series for these regressions.[7] The anticipated components (not shown) are significant for the three-month and six-month Treasury yields but are insignificant for longer yields consistent with the expectations hypothesis. The first six panels in Figure 2 display a declining impact of monetary policy on longer term securities. The coefficient estimates associated with surprise 1 are comparable to Kuttner (2001) or Demiralp and Jorda (2004) who conducted similar analyses with respect to the current month's surprise, though the estimates differ from the fact that our sample has approximately seven more years of data.

Figure 2 indicates that for maturities longer than six-months, an increase in the surprise horizon is generally associated with higher responsiveness to policy surprises, which peaks around five months. After ten years, the surprise coefficients for the first two months are no longer significant.[8] These findings are intuitive. Under the gradualist approach that the Federal Reserve follows, unanticipated policy actions beyond the current months are perceived to signal further changes in the policy stance over the duration of the assets. Consequently, as the surprise term covers a horizon further away from the current month, the responsiveness of the longer term maturities increase.

The last panel in Figure 2 shows the estimation results for equity markets. Bernanke and Kuttner (2005) note that equity markets are subject to sizable outliers which may affect the empirical results. We remove these outliers based on the influence statistics similar to Bernanke and Kuttner (2005).[9,10] The coefficient estimates are negative as in Bernanke and

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[7] For the three-month Treasury bill equation, we only look at the response to policy surprises for the first three months.

[8] We obtain this result for the 30-year bond as well as the 20-year bond (not shown). Because the results for the 20-year bond mimic the 30-year bond very closely, we only show the results for the 30-year bond.

[9] In the presence of outliers, none of the surprise series are significant, driven by the sizable outlier on March 18, 2008.

[10] Bernanke and Kuttner (2005) detect the outliers based on an equation where the CRSP value-weighted index is regressed onto anticipated and unanticipated policy actions for the current month. Because our analysis involves the surprise series up to six months, we identify the outliers for each surprise series and path revisions separately. For each equation, we remove those observations whose influence statistics are greater than 0.25. These outliers are listed as a footnote under Figure 2.

Kuttner (2005) and the size of surprise 1 coefficient (i.e. the surprise for the current month) is comparable to their estimate excluding outliers. Meanwhile, the coefficient estimates for surprises 5 and 6 are not statistically significant, suggesting that equity markets are perhaps not as forward looking as the market for Treasury securities.

The estimation results from equation (1) allowed us to observe the effects of the individual surprise series on asset markets. How asset markets respond to average path revisions is more interesting. Averaging allows us to control for policy surprises in opposite directions which would offset each other over a longer horizon. This way, we can differentiate between policy surprises that have short-lasting effects and those that are more persistent. To that end, we estimate equation (2):

$$A_t = \alpha + \beta_1 (Anticipated)_t + \beta_2 (R_i)_t + \varepsilon_t \quad i = 3,6 \qquad (2)$$

where R_i is the policy path revision averaged over *i* months, as described in the appendix.

The results from these regressions are shown by the last bars in Figure 2. The horizon for the policy path revisions is six-months for all assets but two. For the three-month T-Bill, we consider the three-month path revision because this is the horizon that corresponds to the maturity of the security. We also consider the three-month path revision for the CRSP equation because our results for the individual surprises indicated that policy surprises for longer horizons tend to be insignificant for equity markets. Indeed, if we consider the six-month path revision, the coefficient estimate is about two percentage points smaller (but still significant).

Despite their declining influences at longer maturities, path revisions generally generate higher responses in asset markets relative to the individual surprise series. By and large, these findings conform with Gürkaynak et al., 2005, who also investigated the responsiveness of asset markets to target changes and longer term revisions. Different from their findings, however, we find that the stock market's response to path revisions is larger than its response to the current month's target surprise.[11]

So far our analysis reiterated the earlier findings of a diminishing influence of monetary policy over longer term maturities (Kuttner, 2001, Demiralp and Jorda, 2004) and extended this finding for policy surprises beyond the current month. Is this a general result that holds during tightenings as well as easings, or is there an asymmetry in the effectiveness of monetary policy depending on the sign of the policy action? The asymmetric influence of monetary policy on output has been documented earlier. The argument is that monetary policy is less effective during easings due to factors such as a loss of confidence by firms and consumers during recessions, credit constraints that supplement only tight policy, and less downward flexibility of prices. In this section, we investigate the implications of this asymmetry over the yield curve. We believe that the monetary policy's asymmetric influence on output necessitates an asymmetric influence over longer-term yields. By illustrating this claim empirically, we can provide the missing link between the asymmetric monetary policy literature and the term structure literature.

We consider the following specification to check whether monetary policy's influence over the yield curve is asymmetric:

$$A_t = \alpha + \beta_1 (Anticipated)_t + \beta_2 (R_i)_t + \beta_3 (R_i)_t D^{Tight} + \varepsilon_t \quad i = 3,6 \qquad (3)$$

where D^{Tight} is a dummy variable that captures policy tightenings. In this specification β_2 reflects the response of asset markets to target cuts or FOMC meetings with no target change, while $\beta_2 + \beta_3$ reflects the response to rate hikes. If monetary policy is

[11] This could arise from the different methodologies in calculating path revisions or the fact that they investigated intraday changes whereas we look at daily changes in asset markets. Gürkaynak, Sack, and Swanson (2005) decomposed policy surprises into a component that is related to the target change and another component that is related to the future path of policy through factor analysis. Looking at a narrow window around the time of target announcement, they found that the impact of the path factor was generally about 10 to 15 basis points larger than the impact of the target change for the long end of the yield curve. As for the stock market, however, the impact of the path factor was smaller than the effect of changes in the target.

more effective in slowing down aggregate output during expansions, and if this is because monetary policy has better control over longer term yields during tightenings, then β_3 as well as $\beta_2 + \beta_3$ should be significant across the yield curve.

Figure 3 displays the coefficient estimates from equation (3). In order to compare these results to those from equation (2), we label the policy path estimates from equation (2) as "combined" to note the fact that these estimates are obtained for a combined sample with all event dates. The first thing we note in Figure 3 is the strong asymmetry in favor of tightenings along the yield curve. The dummy variables for tightenings (β_3) are statistically significant for all assets but the six-month Treasury bill and the equity market.[12] Even then, $\beta_2 + \beta_3$ is insignificantly different from its theoretical value of one for the six-month T-Bill.[13] Second, although there is an observed decline in the effectiveness of monetary policy along the yield curve, it is much more muted in the case of tightenings. In fact, the gap between the estimates obtained for the combined sample and those for tightenings widens as we move along the yield curve. Meanwhile, no asymmetry is detected for the equity market.[14]

Figure 3 has important implications for policy making. It supports the findings in the earlier literature that tight monetary policy is more effective as a stabilization policy and attributes this finding to the policy's better control over longer term interest rates. It is important to note that the evidence of an asymmetry is only detected with our six-month policy path revisions. Shorter-term policy surprises such as unanticipated policy actions for the current month or even three-month path revisions fail to uncover this asymmetric

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[12] Furthermore, β_2 is significantly different from $\beta_2 + \beta_3$ in all the cases where β_3 is significant.

[13] Note that only for the case of three-month and six-month Treasury bills, the horizon of the path revision is the same as the maturity of the security. Therefore, if the expectations hypothesis holds, we would expect the coefficient estimates associated with path revisions to be equal to one for these securities. There is no theoretical restriction for the other securities, however.

[14] Similar to the earlier estimates, the outliers are excluded for the stock market equation.

response (not shown) likely because longer term rates' response to short-term surprises are too small to allow for any asymmetry.

A Dynamic Perspective

The evidence in the previous section suggests that the Federal Reserve is quite influential in controlling longer term interest rates during times of tightenings. It would be interesting to see if this ability has evolved over time or more generally if the responsiveness of asset markets changed in a dynamic setting. This question is particularly relevant for understanding the current crisis because many people attributed the crisis at least partly to the Federal Reserve's inability to increase the longer-term rates in mid-2004.

Figure 4 plots the federal funds rate target together with the three-month, ten-year, and thirty-year Treasury yields from May 1989 through December 2008. During that period, short term interest rates followed the funds rate target closely as shown by the close correlation between the target and the three-month Treasury bill. Longer-term rates also followed the target closely for the most of the sample except for the Fed's most recent tightening cycle from June 2004 through June 2006 (the shaded area). Despite the fact that the target was increased 425 basis points during this period, longer term rates hardly changed as illustrated by the 30-year bond.[15] It was argued that the Fed's lack of control over longer term rates, in particular the mortgage rates, was responsible for the housing price bubble which triggered the crisis in August 2007.

Was the Federal Reserve as powerless in controlling the longer term rates during the 2004-2006 tightening cycle as suggested? Could the global savings glut be responsible for reducing the Fed's control over longer-term rates during that period? Or could the simple

[15]The 30-year Treasury constant maturity series was discontinued on February 18, 2002, and reintroduced on February 9, 2006. Because of this break, we use the secondary market data in our analysis.

correlations displayed in Figure 4 disguise the true connections between policy expectations and longer term interest rates?

These questions can be investigated in a dynamic framework via rolling regressions. Rolling regressions of equation (2) allow us to spot any changes in the responsiveness of asset markets to Federal Reserve Policy. Figure 5 displays the dynamic response of Treasury securities to six-month path revisions over 20-observation rolling windows. We keep the estimation window relatively short to capture individual policy cycles. However, because the estimation window is rather small, our rolling regression analysis is more sensitive to outliers. In order to make sure that our results are not driven by these outliers, we detect and exclude them for each security based on their influence statistics. In the figure, we only show the results for the six-month Treasury bill, 5-and 10-year Treasury notes, and the 30-year Treasury bond to avoid repetition because the results for closer maturities are very similar. The lists of outliers for each security are provided as an end-note in Figure 5.

The upper left panel in Figure 5 displays the response of the six-month bill.[16] We plot the target series as the solid line to observe how the responsiveness of the security changes along the business cycle. The response of the six-month T-bill is highly significant throughout the analysis, hovering around its theoretical value of one. The coefficient estimates tend to increase during tightenings and decrease during easings but the evidence of an asymmetry is rather negligible.

The upper right panel shows the response of the five-year Treasury note. The evidence of an asymmetry is much more pronounced this time, where the coefficient estimates increase substantially during tightenings and decrease during easings. Furthermore, we observe an overall increase in the responsiveness of this asset, which is particularly

[16] Because we have identified (and excluded) the outliers based on our influence statistics, the small sample results based on each rolling window do not exhibit any large fluctuations. Nevertheless, because the outliers are detected based on the full sample and not based on each sub-sample (we believe such a procedure would be rather ad-hoc) it is natural to observe some fluctuations in the coefficient estimates associated with alternative surprise series.

noticeable for tightenings. This finding is consistent with the implications of gradualism and improved transparency which may suggest an enhancement of the Fed's ability to control longer term rates as suggested by Bernanke (2004).

The lower left panel illustrates the responsiveness of the ten-year note. The evidence of an asymmetry becomes even more observable as the maturity of the security lengthens, consistent with our earlier findings in Figure 3. Indeed, the responsiveness to path revisions during the 2001-2003 easing cycle becomes mostly insignificant for this security.

The last panel in Figure 5 displays the response of the 30-year bond. The evidence of an asymmetry is pronounced. Even though there is an overall decline in the coefficient estimates relative to shorter maturities, their values approach one during the last tightening cycle in 2004-2006. This finding suggests that despite the common perception of a disconnect between the longer-term rates and the target rate during this time period, the responses of longer-term assets were highly consistent with longer-term policy expectations.

Figure 6 displays the dynamic responses of Treasury securities to three-month path revisions. The responsiveness of 5-, 10- and 30-year securities tend to be smaller in magnitude compared to their responses to six-month path revisions. This is expected because the longer the horizon of the path revision, the more we expect it to influence longer-term investment decisions. While the response of the three-month Treasury bill is almost always significant and close to one, the responsiveness of the 5-year note is statistically insignificant in many instances. Similar observations can be made with respect to the dynamic responses of the 10-year note and the 30-year bond.

Figure 7 shows the rolling regression results for equity markets. Our earlier findings in Figure 2 suggested that this market is not as forward looking as the rest of the asset markets. For that reason, we consider the three-month path revision as the proper measure of expectations. Figure 7 reiterates our findings in Figure 3 that there is no observable difference in the responsiveness of the stock market during times of tightenings or easings. Stock market response becomes significant in 1993 remains significant until the middle of the tightening cycle in 1994. It becomes significant again through the end of the easing cycle in 2002 and remains significant until the middle of the tightening cycle in late 2005. Comparing these two clusters of significant coefficient estimates, there seems to be an increase in the responsiveness of the stock market over time, although this trend is not well-pronounced. It is also interesting to note that during the brief tightening cycle of late 1999 and early 2000, as well as the end of the tightening cycle in 2006 the stock market response became positive though not statistically significant.

Conclusions

In this paper we analyzed the responsiveness of asset markets to monetary policy path revisions. Our findings underlined a strong asymmetry in the responsiveness of longer term Treasury yields to path revisions. We found that the monetary policy is more influential in controlling longer-term rates during times of tightenings than easings. This finding provides a smooth transition from the term structure literature to the literature that found asymmetric effects of monetary policy on output.

Our results highlight the importance of gradualism and transparency in improving the central banks' control over longer term interest rates that most affect the economy. A common misperception of monetary policy is to think of the Federal Reserve as setting interest rates in the economy. In fact, Federal Reserve only sets the federal funds rate target. The federal funds rate is not important by itself because only a small fraction of total borrowing is done at that rate. Longer-term interest rates are far more significant than the funds rate, because those are the rates that are relevant for most of the spending and investment decisions.

Although the central banks cannot directly determine long-term interest rates, they can influence those rates through the formation of private-sector expectations about future monetary policy actions. In that respect, the performance of the central bank can be evaluated by its ability to control long term interest rates.   Using a measure for longer-term policy expectations, our results suggested that the Federal Reserve's policy of gradualism and transparency is indeed very successful in aligning longer term interest rates with policy expectations, particularly during periods of tightenings.

Data Appendix

Federal funds futures data are obtained from CME.

CRSP value weighted return (including dividends) for NYSE and Alternext (what used to be AMEX) is obtained through Wharton Research Data Service (WRDS).

The data for the target funds rate before 1994 is also obtained from the Board of Governors and after 1994, is from FOMC transcripts.

The data for Treasury rates are obtained from the Board of Governors, H.15 release. We use the secondary market rates for Treasury bills and constant maturity rates for longer maturities except for the 30-year bond. Because of the break in the 30-year Treasury bond from 2002 to 2006, we use the secondary market rates for this maturity as well.

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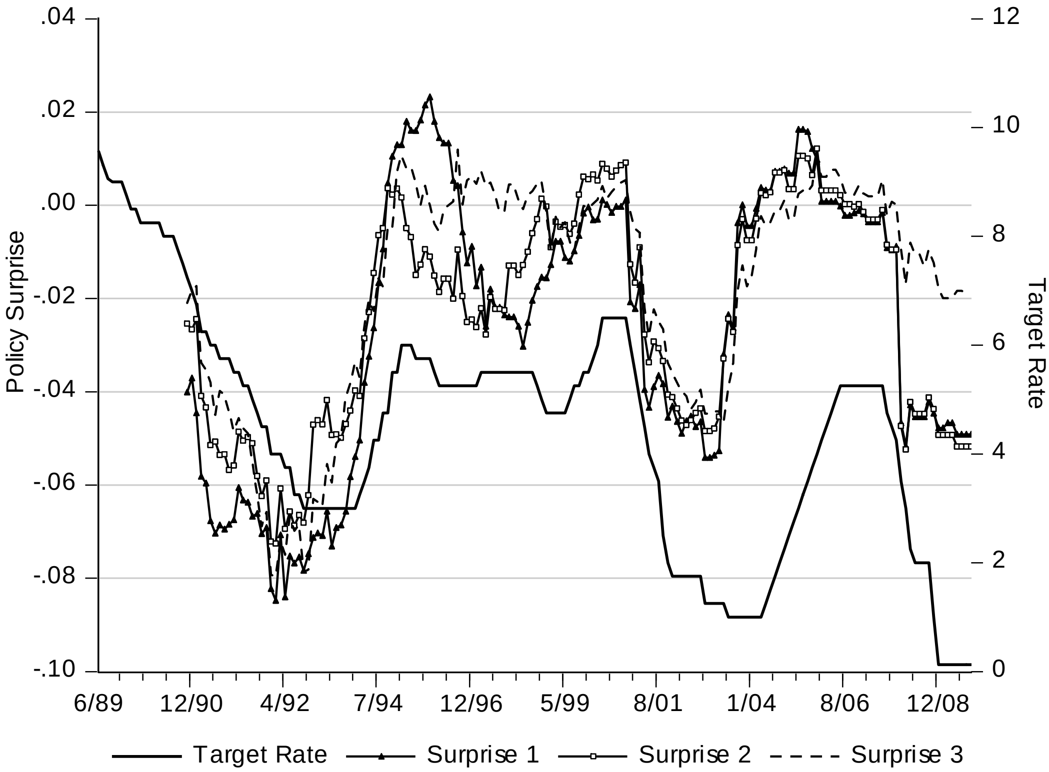

Figure 1a: Monetary Policy Surprises
(20-observation Moving Average, percentage points)

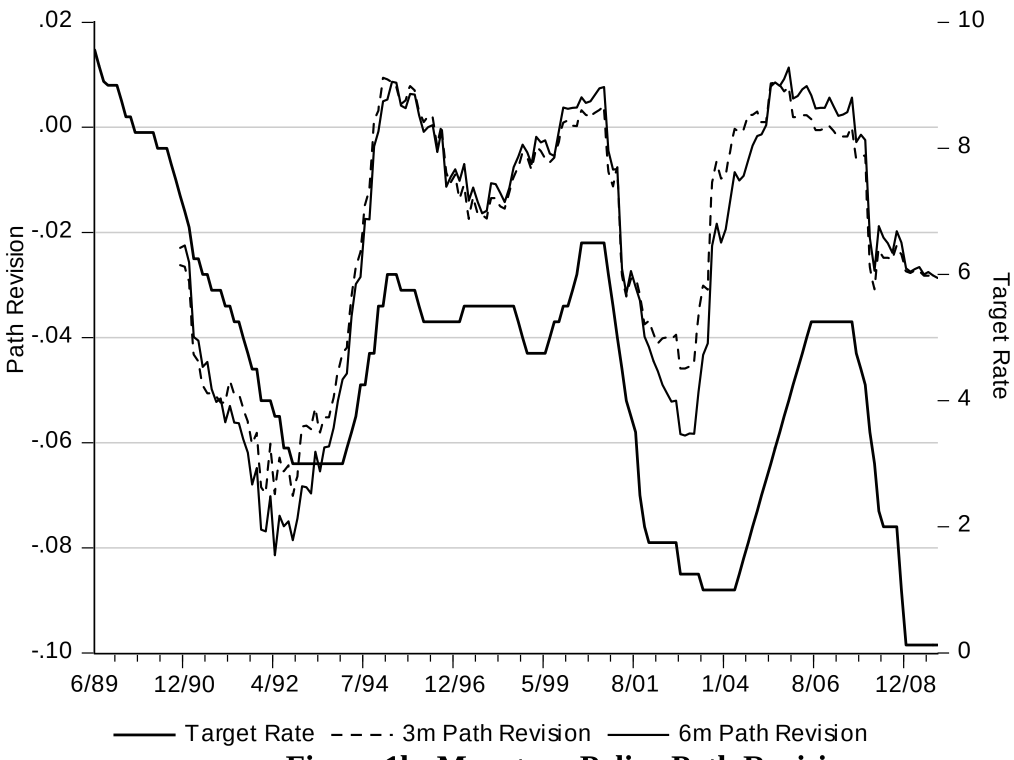

Figure 1b: Monetary Policy Path Revisions
(20-observation Moving Average, percentage points)

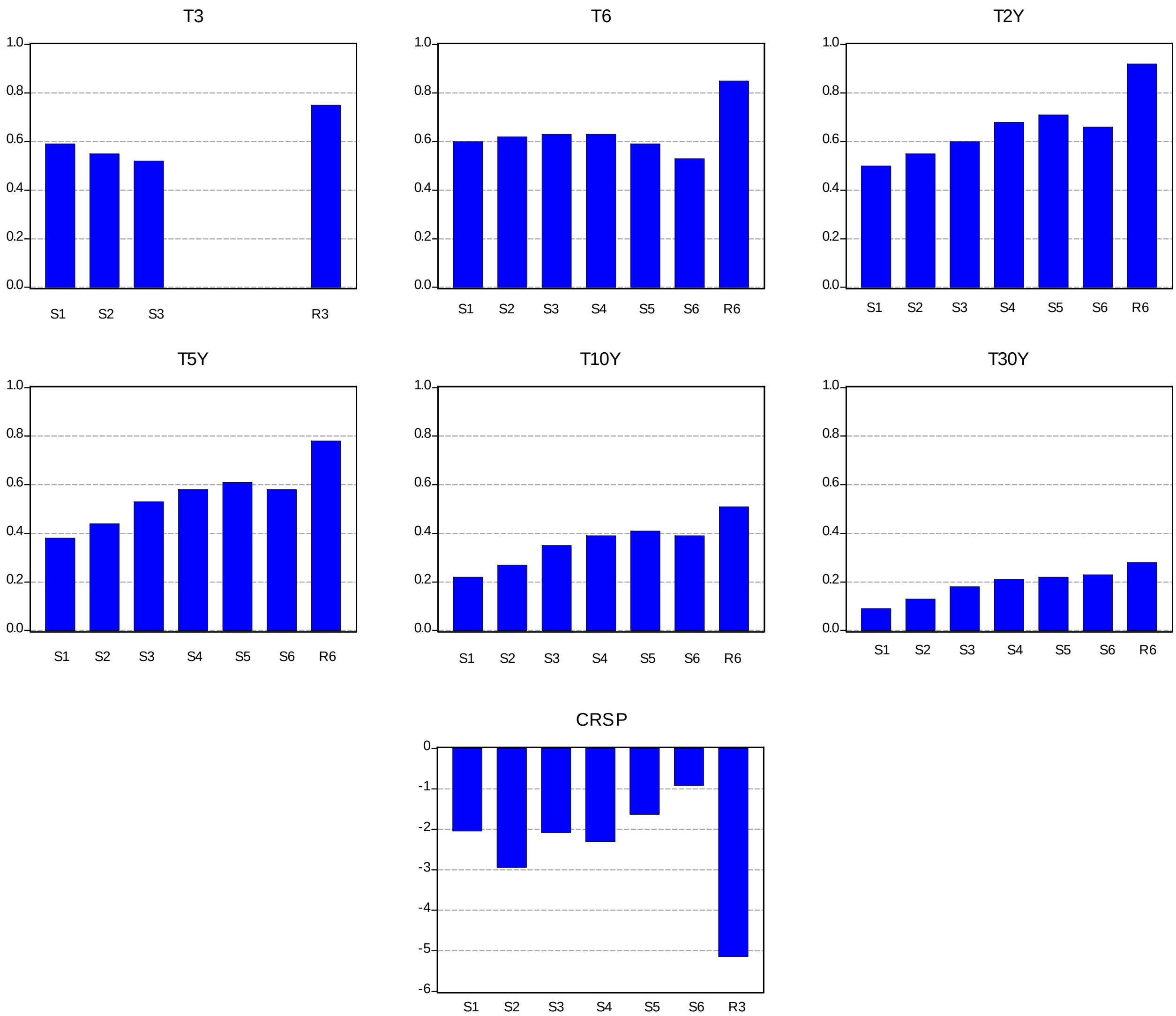

Figure 2: The Response of Asset Markets to Policy Surprises and Path Revisions
(in percentage points)

Notes:
S1: Surprise 1, S2: Surprise 2,S3: Surprise 3, S4: Surprise 4, S5: Surprise 5, S6: Surprise 6, R3: three-month revision, R6: Six-month revision, T3: Three-month Treasury bill, T6: Six-month Treasury bill, T2Y: Two-year Treasury note, T5Y: Five-year Treasury note, T10Y: Ten-year Treasury note, T30Y: Thirty-year Treasury bond.

The coefficient estimates are significant at 95 percent level of confidence. The coefficient estimate for S1 is not significant for the 30-year Bond. The coefficient estimates for S5 and S6 are not significant for equity markets.

The following outliers are excluded from the CRSP regressions:
Surprise 1: 8/21/1991, 7/2/1992, 2/4/1994, 3/20/2001, 4/18/2001, 3/18/2008
Surprise 2: 8/21/1991, 7/2/1992, 10/15/1998, 3/20/2001, 4/18/2001, 3/18/2008, 12/16/2008
Surprise 3:, 9/4/1992, 4/18/2001, 3/18/2008, 12/16/2008
Surprise 4: 7/2/1992, 2/4/1994, 4/18/2001, 9/18/2007, 3/18/2008, 12/16/2008
Surprise 5: 7/2/1992, 2/4/1994, 4/18/2001, 9/18/2007, 3/18/2008, 12/16/2008
Surprise 6: 7/8/1993, 4/18/2001, 9/18/2007, 3/18/2008, 12/16/2008
3-month revision: 7/2/1992, 9/4/1992, 10/15/1998, 4/18/2001, 3/18/2008
6-month revision: 7/2/1992, 10/15/1998, 4/18/2001, 9/18/2007, 3/18/2008, 12/16/2008

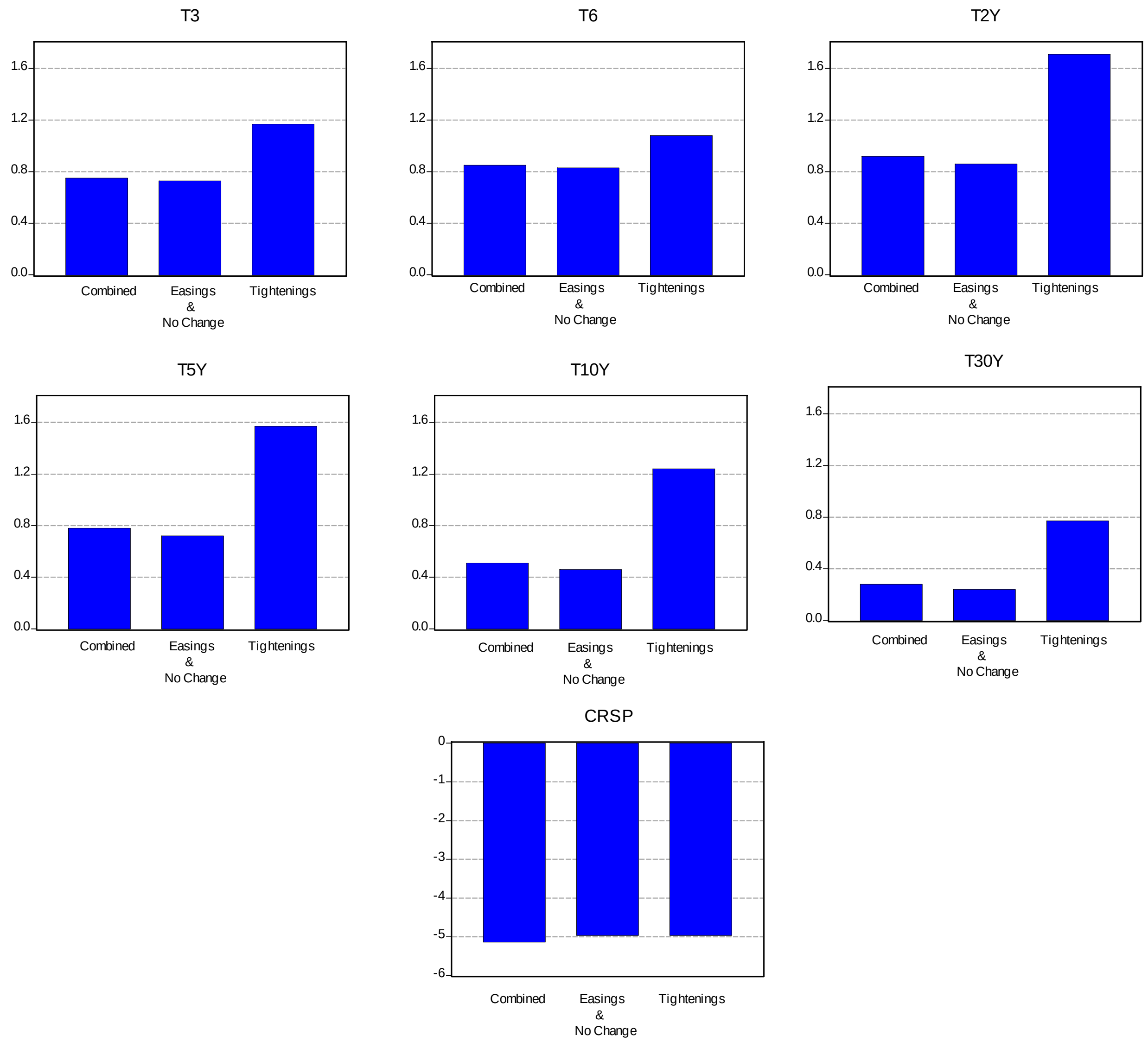

Figure 3: The Asymmetric Response of Asset Markets
(in percentage points)

Notes:
T3: Three-month Treasury bill, T6: Six-month Treasury bill, T2Y: Two-year Treasury note, T5Y: Five-year Treasury note, T10Y: Ten-year Treasury note, T30Y: Thirty-year Treasury bond.

The coefficient estimates are significant at 95 percent level of confidence. The coefficient estimates for tightenings are not significant for T6 and CRSP.

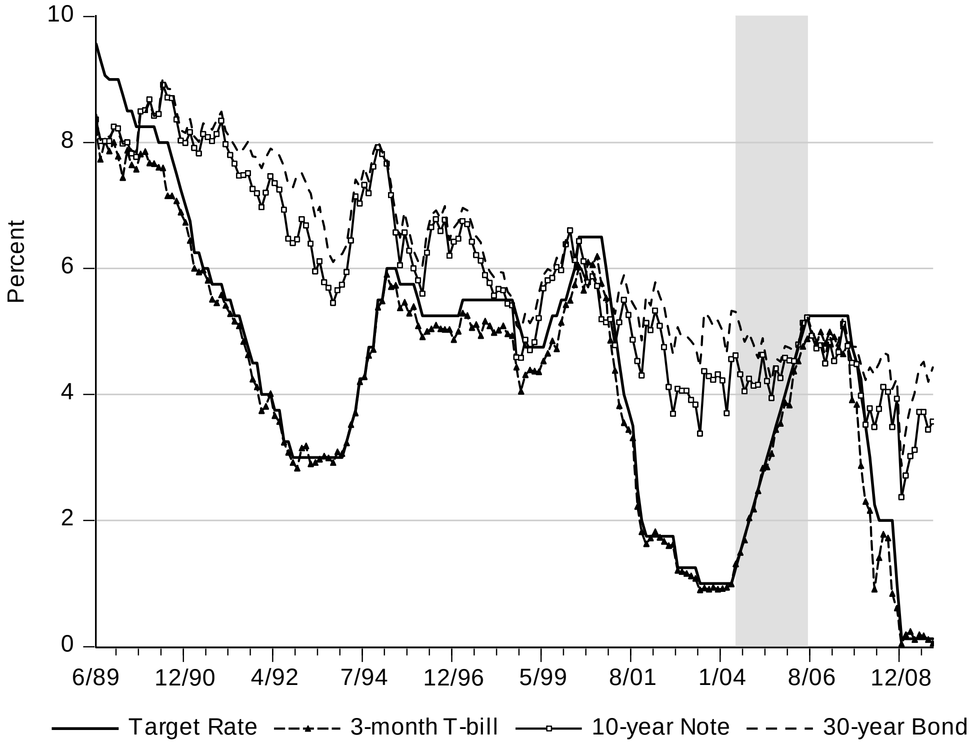

Figure 4: Selected Interest Rates
(monthly frequency)

The shaded area corresponds to the Federal Reserve's tightening cycle from June 30, 2004 through June 29, 2006.

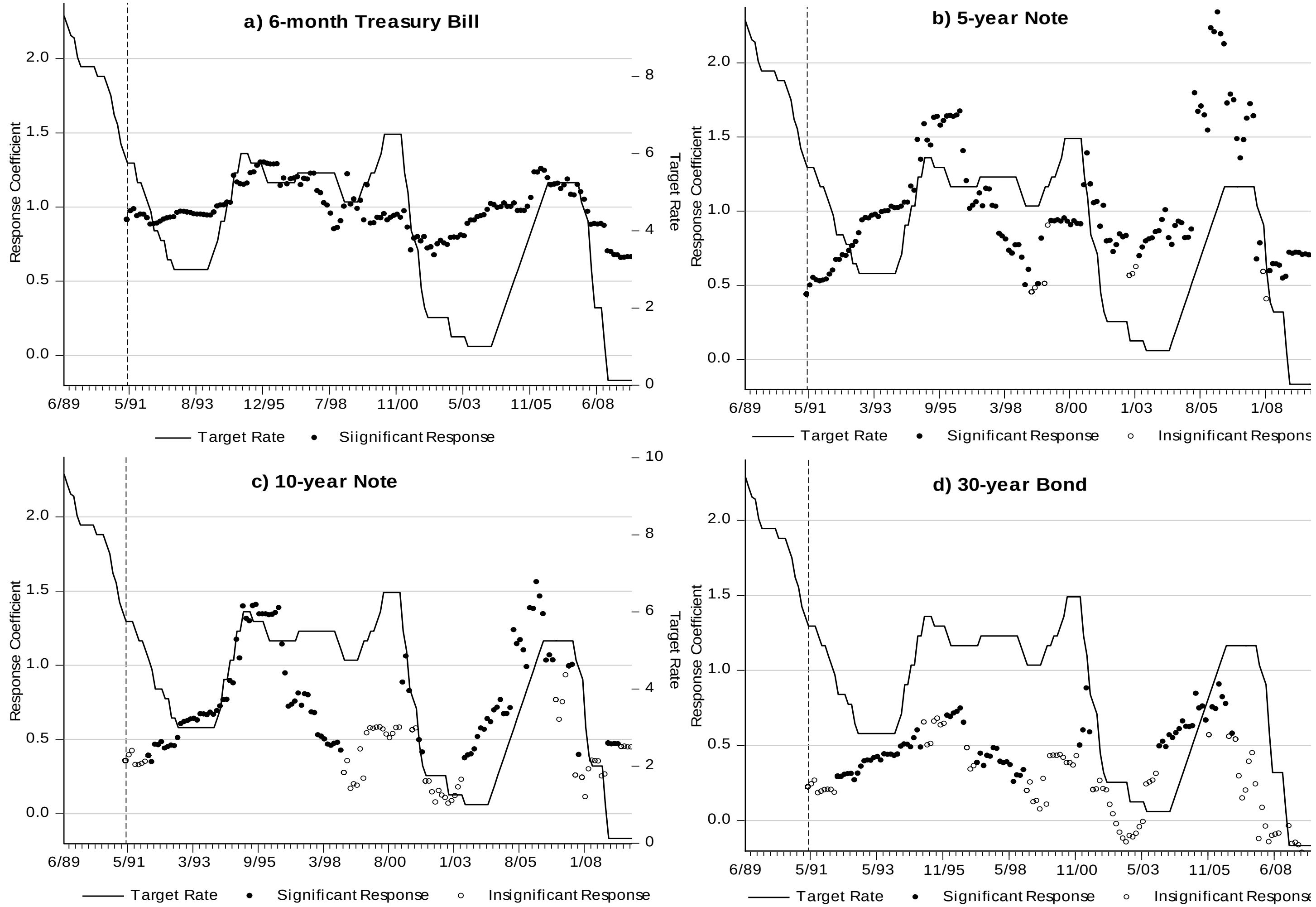

Figure 5: The Dynamic Response of Treasury Securities to Six-Month Path Revisions
(in percentage points)

Notes:
The following outliers are excluded from the response estimates to 6-month path revisions: 6-month T. Bill: 8/21/1991, 12/20/1991, 9/4/1992, 4/18/2001, 3/18/2008, 9/16/2008; 5-year Note: 4/18/1994, 4/18/2001; 10-year Note: 4/18/1994, 4/18/2001; 30-year Note: 7/2/1992, 4/18/1994, 4/18/2001, 3/18/2008.

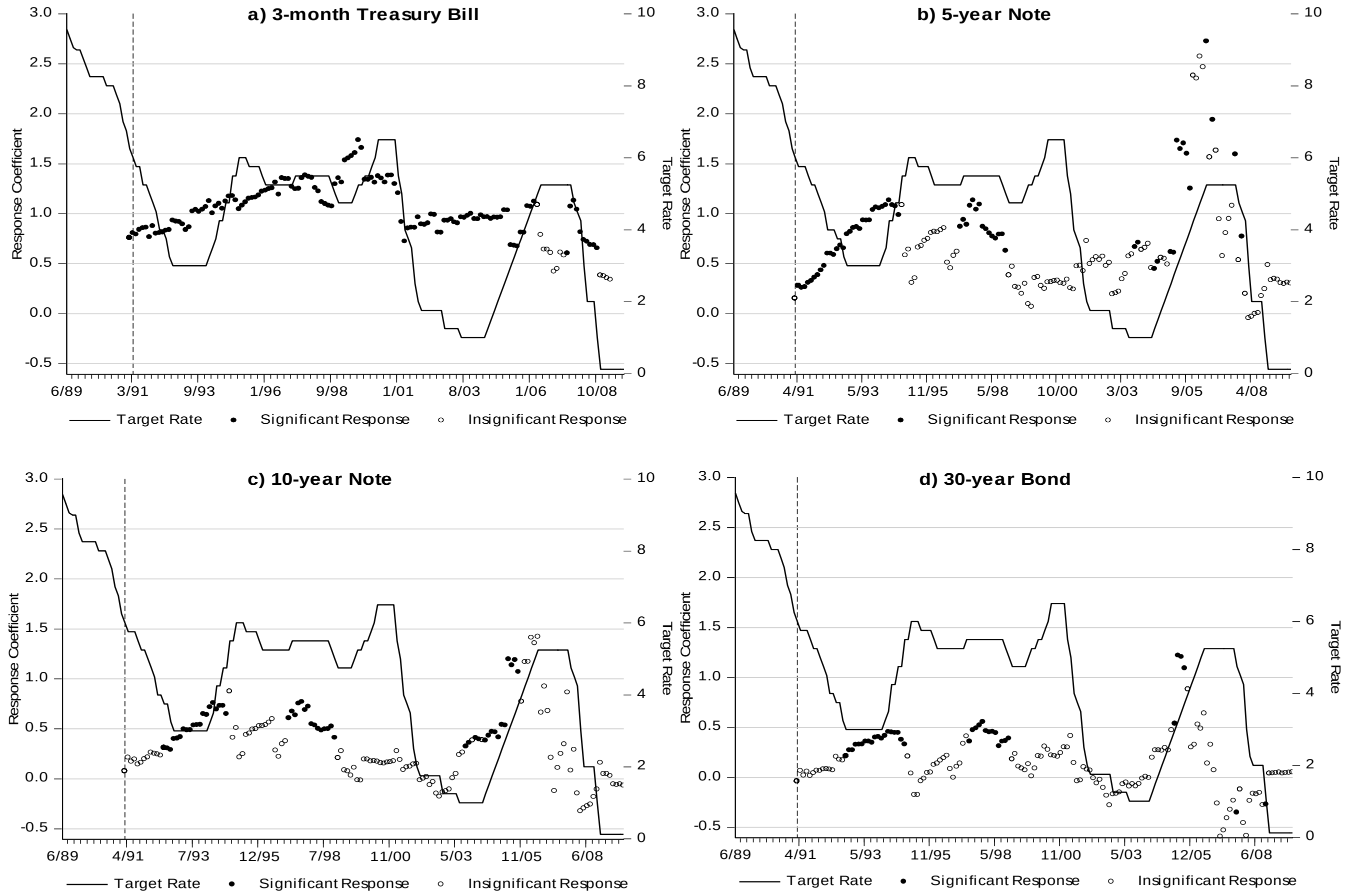

Figure 6: The Dynamic Response of Treasury Securities to Three-Month Path Revisions
(in percentage points)

Notes:
The following outliers are excluded from the response estimates to 3-month path revisions: 3-month T-Bill: 8/21/1991, 12/20/1991, 4/9/1992, 7/2/1992, 9/4/1992, 5/20/1997, 4/18/2001, 3/18/2008, 9/16/2008; 5-year Note: 10/16/1989, 7/2/1992, 9/4/1992, 4/18/1994, 4/18/2001, 3/18/2008; 10-year Note: 10/16/1989, 12/20/1991, 7/2/1992, 9/4/1992, 4/18/1994, 4/18/2001, 3/18/2008; 30-year Note: 10/16/1989, 12/20/1991, 7/2/1992, 4/18/1994, 4/18/2001, 6/25/2003

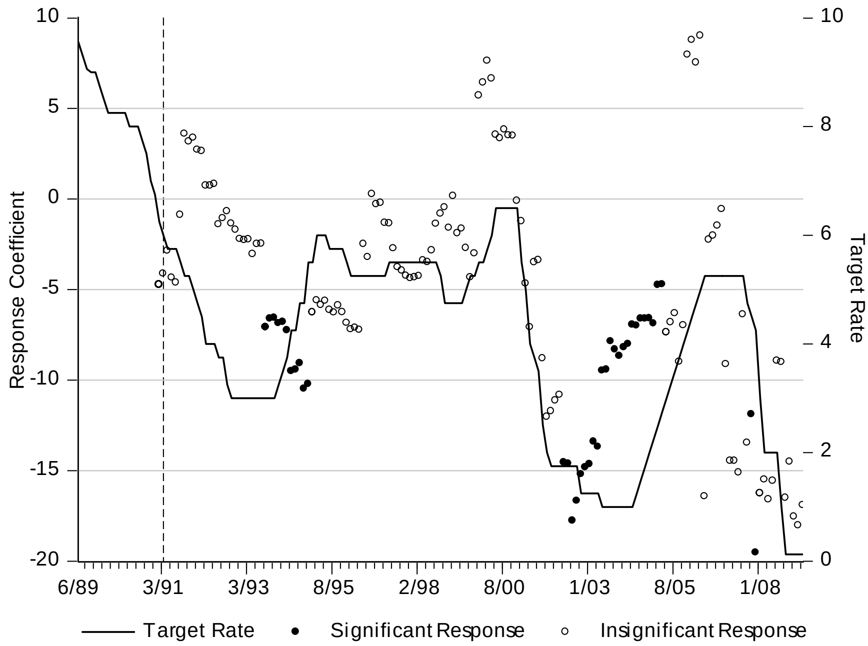

Figure 7: Stock Market Response to 3-month Monetary Policy Path Revisions

Appendix: Measuring Market Expectations

In this section, we describe the methodology that is used to calculate policy expectations. This methodology is an extension of Kuttner (2001), who used a market-based measure to identify unexpected funds rate changes based on the price of federal funds futures contracts. Several researchers considered extensions of this analysis to capture longer-term expectations. For example, Gürkaynak (2005) computed policy expectations for the future FOMC meetings. Demiralp (2008) computed policy expectations for the next three months. The analysis in this paper uses a similar method to gauge the revisions in the policy path in the future months.

In order to estimate revisions in the policy path, we need to understand how the target change on day *t* affects policy expectations in future months. We assume the market expects the average overnight rate for a given month to be equal to the funds rate target as in Kuttner (2001). This assumption is strongly supported by the data for our sample period, as daily deviations from the target are only temporary (see Carpenter and Demiralp, 2006a). Furthermore, we assume that on the day of a target change *t*, future policy changes are only expected on regularly scheduled FOMC days.

Market Expectations in Month 1

As described in Kuttner (2001), the interest rate of the federal funds futures contract on a particular day *t* reflects the expected average funds rate for that month, conditional on the information prevailing up to that date.[17] Based on this fact and knowing that the effective funds rate as a monthly average is very close to the target rate (typically within a few basis points), the current month (or "spot-month") futures rate ($FF1$) on the day before a target change can be expressed as:

[17] Naturally, this measure presumes that market participants are aware of the target and can observe the changes. If the market participants were unaware that the target had changed, expectations would not necessarily reflect the changes in the policy instrument.

$$FF1_{t-1} = \frac{t \times T_0 + (m_1 - t) \times E_{t-1}(T_1)}{m_1} + \mu_{t-1} \quad \text{(A.1)}$$

where T_0 is the funds rate target on day t-1, T_1 is the funds rate target on day *t*, E_{t-1} is the expectations operator based on information as of day *t*-1, and μ_{t-1} is a term that may represent the risk premium or day of month effects in the futures market. In an efficient market with risk-neutral investors, this term would be zero. m_1 is the total number of days in month 1.

Assuming that the target change occurs on day *t*, the spot rate (*FF*1) on day *t* is given by:

$$FF1_t = \frac{t \times T_0 + (m_1 - t) \times T_1}{m_1} + \mu_t \quad \text{(A.2)}$$

The difference between the spot-month rates prior to and after the target change i.e. (A.2)-(A.1), gives us the policy surprise for the current month ($Surprise_1$) as of day *t* assuming that the term premium remains constant:

$$(FF1)_t - (FF1)_{t-1} = \Phi\underbrace{[T_1 - E_{t-1}(T_1)]}_{Surprise_1}, \text{ where } \Phi = \left(\frac{m_1 - t}{m_1}\right) \quad \text{(A.3)}$$

Equation (A.3) is used to compute the policy surprise except for two cases:

1. Kuttner notes that the day-*t* targeting error and the revisions in the expectation of future targeting errors may be non-trivial at the end of the month. Consequently, if a target change occurs in the last five days of the month, the difference in one-month futures rate (FF2) is used to derive the policy surprise since the one-month rate reflects the expected average funds rate for the next month:[18]

[18] To be more precise, Kuttner (2003) considers the “end of month” to be the last three days of the month. We slightly extend this period to include the last five days of the month to eliminate the sensitivity of our results to some target changes that took place in this interval. This is a legitimate generalization because if a target

$$(FF2)_t - (FF2)_{t-1} = \Phi[\underbrace{T_1 - E_{t-1}(T_1)}_{Surprise_1}], \text{ where } \Phi = \left(\frac{m_1}{m_1}\right) = 1 \qquad \text{(A.4)}$$

2. If the target change takes place on the first day of the month, we need to use the one-month futures rate from the *previous* month to assess market's expectations on day 1.

$$(FF1)_t - (FF2)_{t-1} = \Phi[\underbrace{T_1 - E_{t-1}(T_1)}_{Surprise_1}], \text{ where } \Phi = \frac{m_1}{m_1} = 1 \qquad \text{(A.5)}$$

Kuttner sets $\Phi = 1$ for simplicity, assuming that the new target is effective as of the day of the target change. Because the majority of our sample covers the post-1994 period where target change announcements were made in the afternoon (and after the open market operations for that day were already executed), we assume that the new target is effective as of the following day and set $\Phi = \left(\frac{m_1 - 1}{m_1}\right)$

The calculation of the surprises (or path revisions) for future months follow the same general principle and are discussed next.

Market Expectations in Month 2

a) No FOMC Meeting in Month 2

If there is no FOMC meeting in the second month, then, the policy surprise in that month is the same as the market surprise from the first month ($Surprise_1$):

$$Surprise_2 = Surprise_1$$

change takes place within the last five days (or the last three days) of a given month, then no FOMC meeting is scheduled for the next month in both cases, which is the necessary assumption to make this adjustment. Gürkaynak (2005) applied a similar adjustment for target changes that took place within the last week of the month. In a recent paper, Hamilton (2008) points out the elevated end-of-month volatility in the federal funds rate and highlights that the underlying assumption about the funds rate being equal to target may fail towards the end of the month, which supports our month-end adjustment for an extended interval.

b) FOMC meeting on day k of Month 2

If there is an FOMC meeting on day *k* of the next month, then one-month futures contract (*FF*2) as of day *t*-1 (in the current month) is equal to:

$$FF2_{t-1} = \frac{kE_{t-1}(T_1) + (m_2 - k)E_{t-1}(T_2)}{m_2}$$

where T_1 is the funds rate target as of day *t* in month one, T_2 is the funds rate target after day *k* in month two, E is the expectations operator, and m_2 is the number of days in month 2.

Taking the difference between the price of the one-month contract between days *t* and *t*-1:

$$FF2_t - FF2_{t-1} = \frac{k}{m_2}[T_1 - E_{t-1}(T_1)] + \frac{m_2 - k}{m_2}[E_t(T_2) - E_{t-1}(T_2)] \tag{A.6}$$

Solving for the second term on the right hand side:

$$\underbrace{E_t(T_2) - E_{t-1}(T_2)}_{Surprise_2} = \frac{m_2}{m_2 - k}\left[(FF2_t - FF2_{t-1}) - \frac{k}{m_2}\underbrace{[T_1 - E_{t-1}(T_1)]}_{Surprise_1}\right] \tag{A.7}$$

The term on the left hand side in equation (A.7) gives the market surprise for the second month ($Surprise_2$) which is related to the surprise from the first month. The intuition is rather simple: total change in one-month futures rate on day *t* consists of two parts: revisions in expectations for overnight rates that are expected to prevail until day *k* of next month (which is the market surprise for the current target change), and revisions in expectations for overnight rates that are expected to prevail after day *k* next month ($Surprise_2$). Hence, we can identify the remainder of the market surprise for the next month by subtracting current month's surprise from the total revision.

Equation (A.7) is used to obtain the market surprise for most days of the month except for:

i. If an FOMC meeting is scheduled in the last five days of the *next* month (i.e. $m_2 - k < 5)$, the difference in the two-month futures rate is used to derive the policy surprise since it reflects the expected average funds rate for the following month:

$$(FF3)_t - (FF3)_{t-1} = \Phi[\underbrace{T_2 - E_{t-1}(T_2)}_{Surprise_2}], \text{ where } \Phi = 1 \qquad \text{(A.8)}$$

ii. If the target change takes place on the first day of the *current* month (i.e. $t = 1$), we use the two-month futures rate from the *previous* month to assess market's expectations on day 1.

$$\underbrace{E_t(T_2) - E_{t-1}(T_2)}_{Surprise_2} = \frac{m_2}{m_2 - k}\left[(FF2_t - FF3_{t-1}) - \frac{k}{m_2}\underbrace{[T_1 - E_{t-1}(T_1)]}_{Surprise_1}\right] \qquad \text{(A.9)}$$

iii. If the target change takes place on the first day of the *current* month (i.e. $t = 1$) *and* if an FOMC meeting is scheduled in the last five days of the *next* month (i.e. $m_2 - k < 5)$, the difference in the two-month futures rate and the three month futures rate from the previous month is used to derive the policy surprise:

$$(FF3)_t - (FF4)_{t-1} = \Phi[\underbrace{T_2 - E_{t-1}(T_2)}_{Surprise_2}], \text{ where } \Phi = 1 \qquad \text{(A.10)}$$

Market Expectations in Month j

The above methodology can be extended to any month *j* into the future such that:

If there is no FOMC meeting in month *j*, then $Surprise_j = Surprise_{j-1}$

If there is an FOMC meeting on day *k* of month *j*, then

$$\underbrace{E_t(T_j) - E_{t-1}(T_j)}_{Surprise_j} = \frac{m_j}{m_j - k}\left[(FFJ_t - FFJ_{t-1}) - \frac{k}{m_j}(Surprise_{j-1})\right] \tag{A.11}$$

In the special cases the market surprise is calculated as follows:

$Surprise_j = \frac{m_j}{m_j - k}\left[FFJ_t - FF(J+1)_{t-1} - \frac{k}{m_j}(Surprise_{j-1})\right]$, if t=1, and

$Surprise_j = FF(J+1)_t - FF(J+1)_{t-1}$, for the last five days of month *j*.

$Surprise_j = FF(J+1)_t - FF(J+2)_{t-1}$, if the target change takes place on the first day of the current month (i.e. $t = 1$) *and* an FOMC meeting is scheduled on the last days of month *j* (i.e. $m_j - k < 5$).

Intermeeting changes with FOMC meeting later in the month

Using the above methodology, policy revisions for the current month as well as future months can be calculated for each target change except for intermeeting changes followed by an FOMC meeting in the same month. In the latter case, one has to impose additional assumptions which may be questionable. To illustrate this point, suppose there is an intermeeting change on day *t* with an FOMC meeting scheduled later in the month on day *k*, such that *k*> *t*.

The spot-month contract on day *t*-1 reflects the average funds rate expected in that month:

$$FF1_{t-1} = \frac{tT_0 + (k-t)E_{t-1}(T_1) + (m_1 - k)E_{t-1}(T_2)}{m_1} \tag{A.12}$$

where:

T_0 is the target prior to the intermeeting change, T_1 is the target after the intermeeting change until the FOMC day, and T_2 is the target after the FOMC day. If the market does not anticipate an intermeeting change, then $E_{t-1}(T_1) = T_0$. If there are no further changes after the intermeeting change, then $T_1 = T_2$.

On the day of the intermeeting change, the price of the spot month contract is equal to:

$$FF1_t = \frac{tT_0 + (k-t)(T_1) + (m-k)E_t(T_2)}{m} \qquad \text{(A.12)}$$

Taking the difference between the price of the spot-month contract between days *t* and *t*-1:

$$FF1_t - FF1_{t-1} = \frac{(k-t)\left[T_1 - E_{t-1}(T_1)\right] + (m-k)\left[E_t(T_2) - E_{t-1}(T_2)\right]}{m} \qquad \text{(A.14)}$$

In (A.14), the first term in the numerator reflects the unanticipated component of the target after the intermeeting change while the second term reflects the revision in expectations for the target after the FOMC meeting. Therefore, unless $E_t(T_2) = E_{t-1}(T_2)$, the second term is nonzero and one cannot identify the unanticipated component of the target after the intermeeting change. The second term will only be equal to zero if the market does not revise the target level expected after the FOMC meeting. While it may be plausible under certain scenarios, this is a stronger assumption which may not necessarily hold in all such cases, and we check the robustness of our findings by excluding these observations from the sample in our empirical analysis.

Path Revisions

Our methodology of calculating policy surprises for each month *i* into the future allows us to estimate average path revisions over a particular period. Indeed, if financial markets are rational and forward looking, we expect them to respond to average changes in the policy path in the "foreseeable future", consistent with the Federal Reserve's signals about changes in the policy path over that time frame.

In order to illustrate the relevance of path revisions in understanding market response to monetary policy actions, consider the following example. Suppose the target is at 4 ¾ percent and the market expects three 25 basis points easings in the next three meetings. So the expected policy path is -0.25, -0.25, and -0.25 for each consecutive FOMC meeting respectively. Instead, suppose that the FOMC does not change the target in the first month and the market revises its expected path changes as: 0, -0.50, -0.25. That is, the 25 basis points action that was expected in the first month is postponed to the next meeting with no change in the 3-month ahead expectations. Here, focusing on the -25 basis points surprise for the current month would overlook the adjustments to the policy path. In particular, the market's reaction to the current surprise would likely be muted in this scenario, because the market simply postpones an expected policy action by one month. Similarly, only looking at the longer term changes in, say, month 3 would also be insufficient because the three-month futures would suggest no revisions at all and underestimate the market's response. Instead, the market's response to monetary policy should be evaluated as a combined response to its path revision for months one, two, and three (and probably even longer).

Path revisions are estimated in the following manner. Recall that m_j is the number of days in month *j* and let cum_i be the cumulative sum of days in an *i* month period such that $cum_i = \sum_{j=1}^{i} m_j$. Furthermore, let t_1 be the day of a target change in month 1 and t_j be the day of an FOMC meeting in month *j*, $j > 1$. Then,

$$R_2 = \frac{1}{cum_2}\left[(m_1 - t_1 + t_2)\times Surprise_1 + (m_2 - t_2)\times Surprise_2\right] \quad \text{(A.15)}$$

$$R_3 = \frac{1}{cum_3}\begin{bmatrix}(m_1 - t_1 + t_2)\times Surprise_1 + (m_2 - t_2 + t_3)\times Surprise_2 \\ + (m_3 - t_3)\times Surprise_3\end{bmatrix} \quad \text{(A.16)}$$

and more generally for any month *j*:

$$R_j = \frac{1}{cum_j}\begin{bmatrix}(m_1 - t_1 + t_2)\times Surprise_1 + (m_2 - t_2 + t_3)\times Surprise_2 \\ + \ldots + (m_j - t_j)\times Surprise_j\end{bmatrix} \quad \text{(A.16)}$$

where R_i refers to the total path revision in the i -month period into the future.

Overall Evaluation

Two issues are important for the reliability of the generalization discussed in this section. The first one is the constancy of the term premium between the consecutive days of a contract for any maturity. In other words, the monetary policy action should not change the term premium from one day to another. In a recent study, Piazzesi and Swanson (2008) tested this assumption formally and illustrated that the above methodology of looking at the one-day changes in the federal funds rate contracts is not contaminated by the term premium because most of the term premium is “differenced out”. Sack (2004)’s findings also support this assumption by noting that the term premium for federal funds futures contracts is very small. The second issue regarding the reliability of the methodology is the liquidity of futures contracts for longer maturities. As noted by earlier researchers, the liquidity of longer term contracts had been relatively thin in the early part of the sample, which led researchers to express their concerns about using these longer horizon contracts in extracting information on monetary policy expectations (see e.g. Hamilton, 2008, Gürkaynak, 2005, Sack, 2004). For this reason, we stop the analysis at the six month horizon.

The Period After December 2008

The calculation of expectations in the manner described in this appendix depends on the underlying value of the target rate for the current month. This necessitates a decision after December 2008. Following its meeting on December 16, 2008, the FOMC adopted a range for the target rate from 0 to 25 basis points. In our estimations, we calculate three sets of surprise and revision series for possible target values of 0, 12 ½, and 25 basis points after December 16, 2008. Because the results are not sensitive to the underlying choice of the target, we only report the results that uses the mid-value of the range of 12 ½ basis points.