

The Greenspan Effect on Equity Markets: An Intraday Examination of US Monetary Policy Announcements[□]

First Draft: March 2004

Current Draft: October 2005

Allan A. Zebedee

*Department of Finance, College of Business Administration,
San Diego State University, 5500 Campanile Drive, San Diego, CA 92182 USA
allan.zebedee@sdsu.edu*

Eric Bentzen

*Department of Management Science
Copenhagen Business School, Solbjerg Plads 3, 2000 Frederiksberg, Denmark
bentzen@cbs.dk*

Peter R. Hansen

*Department of Economics
Stanford University, 579 Serra Mall, Stanford CA, 94305-6072 USA
peter.hansen@stanford.edu*

Asger Lunde

*Department of Marketing, Informatics and Statistics
Aarhus School of Business, Fuglesangs Allé 4, Aarhus DK-8210 V, Denmark
alunde@asb.dk*

[□] The authors wish to thank Cynthia Bansak, Ken French, and James Hamilton, as well as participants at the 2004 NBER Summer Session for valuable comments. All errors are our own responsibility. Zebedee gratefully acknowledges the financial support of San Diego State's Research, Scholarship and Creative Activity program.

The Greenspan Effect on Equity Markets: An Intraday Examination of US Monetary Policy Announcements

Abstract

In this paper, we provide an intraday analysis of the impact of monetary policy on the equity markets. Specifically, we study changes in prices and changes in volatility for the S&P 500 associated with Federal Open Market Committee announcements as well as real-time changes in market expectations about future policy. The analysis shows an economically and statistically significant inverse relationship between equity market returns and changes in the Fed funds rate target. The magnitude of the response is dependent on whether the change was expected or unexpected. An expected change in the Fed funds rate target of 25 basis points results in approximately a 30 basis point decline in the broad equity market, while, an unexpected change of 25 basis points in the Fed funds rate target results in approximately 125 basis point decline in the broad equity market. The speed of these market reactions is rapid with the equity market reaching a new equilibrium within fifteen minutes. In contrast to these results, the analysis also shows a positive relationship exists between equity market returns and changes in expectations about future monetary policy. Taken together, these results regarding price changes (returns) suggest that the price discovery process in the equity markets is dominated by the realization of expectations and not market expectations per se. Meanwhile, the volatility analysis suggests a volatility spike follows both FOMC announcements and real-time changes in expectations, but the duration of these spikes is relatively short-lived and dampens out within one hour.

Keywords: Monetary Policy, Exchange Traded Funds, Realized Variance, High-Frequency Data

JEL Classification Codes: C22, G11, G12

*FOMC will be in a position to either validate or topple the market's economic beliefs*¹

*Nasdaq Jumps 10.5% as Stock Rally is Sparked by Greenspan Remarks*²

*Investors Stay on Sidelines Ahead of FOMC Meeting*³

*A 'Greenspan Rally' Proves Short for Stocks*⁴

*Greenspan Magic Good for 92.74 Point Rally*⁵

1. INTRODUCTION

Monetary policy has an enormous influence on the behavior of financial market participants, as evidenced by the attention that the Federal Reserve Board receives in the financial press. The reason is simple; monetary policy can significantly affect asset prices. By directly influencing short-term interest rates, the actions of policymakers such as Alan Greenspan can change expectations about future cash flows as well as the cost of capital. In 1995, Alan Greenspan was mentioned in 16 Wall Street Journal headlines and in a total of 115 articles, where as in 2002 his name was mentioned in 47 headlines and 436 articles. Over this seven year period, the visibility of Alan Greenspan's name has increased dramatically.⁶ Clearly, this increased following by the financial press suggests a strong link between US monetary policy and the financial markets. In this paper, we study this link by examining the reaction of the equity market in terms of return and volatility in response to changes in US monetary policy and, more specifically, changes in the Federal or Fed funds rate target.

A number of academic studies have also examined the impact of macroeconomic events on the financial markets. Most of the research that has focused on the impact of monetary policy on asset prices has followed Cook and Hahn (1989) whose approach is to regress *daily* changes in returns on changes in the Fed funds rate target. Cook and Hahn examine the reaction of the bond market to changes in the Federal funds rate target and find that increases in the rate target caused large positive movements in short term rates and smaller but still significant movements in long-

¹ WSJ 10/02/00.

² WSJ 12/06/00.

³ WSJ 05/10/01.

⁴ WSJ 02/28/02.

⁵ WSJ 11/07/02.

⁶ In addition to Alan Greenspan becoming more noticeable in the financial press, the phrases the Federal Reserve Board (Fed) and the Federal Open Market Committee (FOMC) have also become more visible in the Wall Street Journal. In 1995, the Federal Reserve Board was mentioned in 71 headlines and 387 articles, while the FOMC was mentioned in one headline and five articles. Seven years later, the Fed was mentioned in 149 headlines and 1,046 articles where as the FOMC was mentioned in zero headlines but in 90 articles.

term rates. In contrast to this traditional approach, we use *intraday* data coupled with the exact time of the announcement⁷ to more accurately characterize the response of the equity markets. Furthermore, we decompose the announced changes in the Fed funds rate into expected and unexpected components using Fed funds futures data. As shown by Krueger and Kuttner (1996), the federal funds futures rate is an unbiased estimator of the federal funds rate target and therefore, can be used as an inference of market expectations.

Our empirical model follows in the spirit of Andersen, Bollerslev, Diebold, and Vega (2003) by modeling intraday returns and their time-varying volatility. While Andersen, Bollerslev, Diebold, and Vega (2003) examined the impact of 41 regularly scheduled macroeconomic events (including FOMC announcements) on the foreign exchange market, we focus solely on FOMC announcements and their impact on the US equity market. Like other papers in this area, our study initially focus on the announcement days, however we then augment the analysis with non-announcement days in order to examine the impact of changes in expectations about future policy. Real-time changes in expectations of US monetary policy are measured by the first difference of the Fed funds futures rate.

Our findings indicate that the Fed funds rate target does indeed impact the equity markets. While changes in the Fed funds rate target do elicit an equity response, the strength of the response is dependent on whether the change was expected or unexpected. An expected change in the Fed funds rate target of 25 basis points results in approximately a 30 basis point decline in the broad equity markets; while an unexpected 25 basis point change in the Fed funds rate target results in approximately 125 basis point decline in the broad equity market. The speed of these market reactions is rapid with the analysis showing the equity market responds within fifteen minutes of the announcement.

In addition, the results also indicate inter-meeting FOMC announcements are special. These announcements nearly always take the market by surprise and they are often followed by dramatic swings in the financial markets. Clearly, inter-meeting announcements should be given special consideration by researchers and policy makers.

Another innovation of the paper is the inclusion of real-time changes in expectations of US

⁷ Prior to February 1994, changes in monetary policy were not directly observable and had to be inferred through a variety of sources including the financial media and survey data. However, since February 1994, the Federal Reserve publicly announces all changes in monetary policy and these announcements are typically made during market hours at approximately 14:15 EST following regularly scheduled FOMC meetings.

monetary policy. Similar to actual announcements, we would expect an inverse relationship between changes in expectations and asset prices. Instead, we find a positive relationship. We interpret this conflicting result to suggest that the price discovery process in the equity markets is dominated by the realization of expectations and not market expectations *per se*.

The volatility analysis shows a volatility spike is associated with FOMC announcements. This volatility spike is also dependent on whether the announcement was expected or unexpected. An expected change in the Fed funds rate target results in a small statistically significant spike that persists for approximately 25 minutes. An unexpected change results in a larger spike but again it is relatively short-lived dampening out within 15 minutes. In contrast, changes in market expectations result in a volatility spike which persists for at least one hour.

The remainder of the paper is organized as follows. The next section briefly describes Fed funds rate target and surveys related literature. Section 3 presents the data used in the paper and provides a descriptive analysis of the data series. Section 4 describes our methodology for modeling the price discovery and volatility processes. The empirical results are presented in Section 5, while Section 6 concludes.

2. FEDERAL FUNDS RATE TARGET

The Federal Open Market Committee (FOMC) is responsible for setting U.S. monetary policy. The committee is comprised of 12 Federal Reserve Bank presidents and the seven members of the Board of Governors. The Chairman of the Board, currently Alan Greenspan, presides over the FOMC. The primary policy tool of the committee is the *Federal or Fed funds rate target*. Unlike the *effective or actual market Fed funds rate*, which is determined in the market, the *Fed funds rate target* is set by the FOMC. Using open market operations, the Fed adjusts the supply of bank reserves with the goal of keeping the *market Fed funds rate* close to the *Fed funds rate target*.

For the most part, changes to the Fed funds rate target are made during the eight regularly scheduled FOMC meetings per year.⁸ FOMC meetings conclude with a press release announcing monetary policy decisions.⁹ This FOMC statement is released immediately as a

⁸ Other FOMC meetings are scheduled as economic and financial conditions warrant.

⁹ Prior to February 1994, changes in monetary policy were not immediately reported and had to be inferred through a variety of sources including the financial media and survey data.

written statement at approximately 14:15 EST following the conclusion of the meeting in an effort to make US monetary policy more transparent.^{10,11} This transparency began as a temporary trial in February 1994 and was later permanently adopted in February 1995. In general, the FOMC statement reports the current Fed funds rate target and whether it has changed as well as a brief synopsis of the committee's view of current economic conditions and what the FOMC's next policy action will likely be. As such, the Federal funds rate target reflects the current state of US monetary policy.

As mentioned above, the study by Cook and Hahn (1989) is the seminal work in the impact of US monetary announcements on asset prices and a number of studies have extended their work to other sample periods as well as various financial assets. For example, Reinhart and Simin (1997) examine the reaction of different financial markets to Fed policy actions from 1989 to 1992. They confirmed the earlier findings of Cook and Hahn that changes in the Federal funds rate target are associated with changes in the short-term rates as well as long-term rates but at diminishing levels. In addition to the bond market, they also examined the foreign exchange markets, commodity markets and equity markets for a reaction to changes in Fed policy. Their results were largely inconclusive but they did report a general tendency of these markets to move following policy changes.

Our interest in this paper is focused on the equity markets' reaction to FOMC announcements. In addition to the research by Reinhart and Simin (1997), other studies have found mixed results particularly when examining the effect of an absolute change in the Federal funds rate target on equity markets. For example, Tarhan (1995) found no evidence that the Fed influences stock prices, where as Thorbecke and Alami (1994) and Thorbecke (1997) found a significant negative effect from changes in the Fed funds rate target.

While expectations of Fed policy are not directly observable, several papers have attempted to disentangle policy announcements into an anticipated and an unanticipated component by using market based proxies. Krueger and Kuttner (1996) show the federal funds future rate is an efficient forecast of the funds rate and therefore an appropriate market based measure of

¹⁰ These announcements are intended to minimize any confusion and uncertainty about the stance of policy. A public announcement ensures that all financial market participants have the same access to information regarding changes in monetary policy

¹¹ The time of the day was discussed on several meetings in 1994. At the May meeting, the time 14:15 was suggested, later discussed at the August meeting and finally approved at the September 1994 meeting. The time of the day was discussed in a special sub-committee.

monetary policy expectations. Kuttner (2001) provide evidence that asset prices respond to unanticipated changes and not to anticipated changes in monetary policy announcements. Bernanke and Kuttner (2005) find that there is a strong and consistent response of the stock market to unexpected monetary policy actions. In another paper, Bomfin (2003) extended the work of Cook and Hahn by also examining volatility and he finds the asset prices are more volatile following surprise announcements. In contrast to this paper, these studies relied on daily data and focused on the periods immediately surrounding the policy announcement.

With the increased availability of high frequency data and the regularity of macroeconomic announcements such as the FOMC announcement during market hours, a number of recent studies have migrated from daily analyses to intraday analyses to examine the intraday impact of policy announcements. For example, Bollerslev, Cai and Song (2000) find that regularly scheduled macroeconomic announcements are an important source of intraday volatility in asset prices. Specifically, they discover two spikes in the intraday volatility at 08:30 and 10:00 EST in the US Treasury bond market corresponding to regularly=scheduled macroeconomic announcements at these times.

Balduzzi, Elton and Green (2001) examined the effect of macroeconomic news announcements on both the price and volatility processes. They find that prices in the bond markets tend to adjust to news within one minute of a regularly scheduled macroeconomic announcement. They also report that volatility increases immediately after the announcements and persist for up to 60 minutes. Andersen, Bollerslev, Diebold, and Vega (2003) also use high frequency data to examine the intraday impact of macroeconomic announcements. They examine the intraday impact on the foreign exchange market of 41 different macroeconomic announcements including the federal funds rate target using the International Money Market Services real-time data on expectation to decompose the surprise component. They find that unanticipated announcements significantly impact the foreign exchange market.

This paper adds to the literature on the impact of monetary policy on the U.S. equity markets by providing an intraday analysis of the equity markets response to FOMC announcements as well as real-time changes in expectation of future FOMC announcements. We characterize this response both in terms of returns and volatility and distinguish between expected and unexpected announcements. Furthermore, we add to the breadth of the analysis by examining the differential impact of regularly scheduled and intra-meeting announcements.

3. DATA

There are three primary data sources used in the analysis: FOMC announcement data, equity data and Fed funds futures data. The analysis covers the period from January 3, 1995 through December 31, 2002. A description of each data source is provided below.

3.1 Announcement Data

Table 1 lists FOMC announcements made over the sample period. The table includes regularly scheduled announcements following FOMC meeting as well as inter-meeting announcements. In total, the sample includes 68 announcements – 64 following regularly scheduled FOMC meeting and four inter-meeting announcements. The timing of these announcements is critical and we are grateful to the Federal Reserve Board for providing the exact time of each of these announcements. In general, announcements following regularly scheduled meetings occur during market hours at approximately 2:15 PM while inter-meeting announcements can occur at any time. With the exception of one announcement, all the announcements however occur during market hours. The exception is the announcement on September 17, 2001. This was the first day US financial markets were open following the 9/11 terrorist attacks. The FOMC made a pre-emptive rate change prior to the opening of the financial markets. Since the announcement was made outside market hours, the observation is not directly incorporated into the analysis. Rather the analysis focuses on the intraday market reaction to the remaining 67 announcements from 1995 to 2002.

Insert Table 1

In total for the 67 announcements, 53 announcements resulted in no change in the Fed funds rate target ($\Delta FFR_t = 0$), while 8 resulted in a positive change ($\Delta FFR_t > 0$) and the remaining 17 resulted in a negative change ($\Delta FFR_t < 0$). The median positive change is 25 basis points although the Fed has on occasion changed the rate by 50 basis points. The median negative change is also 25 basis points.

The time series of Fed funds rate target is presented in Figure 1. The graph presents the full time series with blue bars representing regularly scheduled FOMC announcements. The yellow dotted lines represent annual breaks. From 1995 to late 1998 the Fed funds rate target was in a

fairly narrow range between 5.25 percent and 6 percent. However, after a series of cuts in the target, the rate rapidly moved up in 1999 and 2000 from 4.75 percent to 6.50 percent. In 2001 and 2002, a series of rapid cuts lowered the target to 1.25 percent. The figure clearly shows US monetary policy has gone through an expansion and contraction during our sample period as well as prolonged periods of no movement in the target.

Insert Figure 1

3.2 Equity Data

The US equity market is proxied using Standard and Poor's Depositary Receipts (SPDR). SPDR were created on January 22, 1993, to provide investors with the opportunity to purchase a security which mimics the S&P 500 Index. This financial instrument trades like an individual equity under the ticker symbol SPY which is listed on the AMEX. Previous research by Elton, Gruber, Comer and Li (2002) showed that exchange traded funds trade, like the SPDR, trade close to the net asset value of the underlying assets confirming its value as an intraday proxy for the equity markets. Figure 2 presents a time series of the daily closing prices from January 3, 1995 through December 31, 2002. The sample period includes the bull market of the 1990s as well as the bear market in the early 2000s.

Insert Figure 2

Of course, the focus of this paper is the intraday market reaction to FOMC announcement. Therefore, intraday returns at five minute intervals are constructed for SPY using NYSE's Trades and Quotes (TAQ) database. Specifically, we used quote data to observe the average of the bid and ask prices, or mid-quote, at the beginning of each interval and then using these prices, returns are constructed as the log ratio.

3.3 Federal Funds Futures Data

Krueger and Kuttner (1996) show the Fed funds futures rate derived from the Fed funds

futures contract is an unbiased estimator of the Fed funds rate target. The Fed funds futures contracts began trading on the Chicago Board of Trade in October 1988. The Fed funds futures contract is a market-based forecast of future interest rates or in other words provides a measure of expectations for the Fed funds rate. The contract is cash settled against the average daily federal funds overnight rate for the delivery month. The contract is based on the average monthly Fed funds interest rate and a contract ceases to trade on the last business day of the delivery month. The contract provides an unbiased forecast of the expected interest rate on Fed funds and typically, the next month's contract is the most liquid contract. It is from this contract we extract expectations of US monetary policy on interest rates.¹² The implied Fed funds rate is calculated as 100 minus the contract price. Therefore, a contract priced at 92.75 has an implied Fed funds rate, or an expected annual yield of 7.25 percent. For example, the implied Fed funds rate for November is derived from the December futures contract.

Figure 3 presents a time series of the daily closing implied federal funds rate from January 3, 1995 through December 31, 2002. There are two key items to observe in Figure 3. First, the implied Fed funds rate changes daily and therefore provides a real time measure of the market's expectations. Second, the implied Fed funds rate closely tracks the observed Fed funds rate target. Of particular interest is the ability of the futures market to lead announced FOMC policy decisions.

Insert Figure 3

Intraday trading data were obtained from the Chicago Board of Trade. These data were partitioned into five minute intervals to match the intraday equity data. The implied Fed funds rate is then used to decompose the announced change into an expected and unexpected component. The decomposition relies on the following identity:

$$\Delta FFR_t = \Delta FFR_t^E + \Delta FFR_t^U$$

where ΔFFR_t is the announced change in the Fed funds rate target as presented above, ΔFFR_t^E is the expected change in the Fed funds rate target and ΔFFR_t^U is the unexpected change in the

¹² Kuttner (2001).

Fed funds rate target. The surprise component or the unexpected change in the announced Fed funds target (ΔFFR_t^U) is calculated by taking difference between the announced change and the implied Fed funds rate from the futures market immediately prior to the announcement. The expected component of the rate change is therefore the residual after taking the raw change in the Fed funds rate minus the unexpected change in the rate.

Table 2 presents descriptive statistics for the FOMC announcement dates over the period from January 1995 through December 2002 excluding September 17, 2001. The descriptive statistics are broken into three categories – positive, no change and negative change to reflect the actual announced change in the targeted Fed funds rate. On average, the announcements were anticipated by the market. For example, for the eight positive events in the sample, the mean change in the Fed funds rate target is 28.13 basis points of which the market was expecting on average 30.56 basis points and therefore the surprise or unexpected component is -2.44 basis points.

Insert Table 2

In addition to facilitating the decomposition of the announced rate change, the implied Fed funds rate is used to create a real-time measure of changes in expectations of US monetary policy ($\Delta E_t(FFR_T)$). Specifically, this change in expectations is defined as the first difference of the implied Fed funds rate at five minute intervals to match the equity data.

3. METHODOLOGY

Our empirical model is similar to that of Andersen, Bollerslev, Diebold, and Vega (2003). In their study, they model five minute spot exchange rate returns as a linear function of lagged returns and lags of news on fundamentals, and approximate the return volatility in a similar fashion. In the following section, we describe our adaptation of this empirical model. In doing so, we separate the exposition of the dynamics relating to the price discovery process (the effect on returns) and the volatility process.

3.1 Price Discovery Process

In developing a price discovery model, we estimate four nested intraday models similar to the Cook and Hahn (1989) discussed above. Specifically, in the first model we model five minute returns as a linear function of lagged returns and J lagged values of the change in the federal funds rate target around FOMC announcement dates. The intraday model is:

$$r_t = \beta_0 + \sum_{i=1}^I \beta_i r_{t-i} + \sum_{j=0}^J \eta_{tj} \Delta FFR_t + \varepsilon_t, \quad (1)$$

where r_t is the log ratio of the broad market index and ΔFFR_t is the announced change in the Fed funds rate target.

We then replace the announced changes in the Fed funds rate with its unexpected or surprise component for the following model:

$$r_t = \beta_0 + \sum_{i=1}^I \beta_i r_{t-i} + \sum_{j=0}^J \eta_{tj} \Delta FFR_t^U + \varepsilon_t, \quad (2)$$

We further augment the announcement effect model to include expected or anticipated changes in the Fed funds rate target. This augmented model is:

$$r_t = \beta_0 + \sum_{i=1}^I \beta_i r_{t-i} + \sum_{j=0}^J \eta_{tj} \Delta FFR_{t-j}^U + \sum_{j=0}^J \tau_{tj} \Delta FFR_{t-j}^E + \varepsilon_t, \quad (3)$$

We then investigate the importance of inter-meeting announcements by interacting a dummy variable for inter-meeting announcements with both the expected and unexpected components.

The resulting model is labeled model 4:

$$\begin{aligned} r_t = & \beta_0 + \sum_{i=1}^I \beta_i r_{t-i} + \sum_{j=0}^J \eta_{tj} \Delta FFR_{t-j}^U + \sum_{j=0}^J \theta_{tj} \Delta FFR_{t-j}^U * IM_t \\ & + \sum_{j=0}^J \tau_{tj} \Delta FFR_{t-j}^E + \sum_{j=0}^J \phi_{tj} \Delta FFR_{t-j}^E * IM_t + \varepsilon_t, \end{aligned} \quad (4)$$

where:

$$IM_t = \begin{cases} 1 & \text{if there was an inter-meeting FOMC announcement} \\ 0 & \text{otherwise} \end{cases}$$

In addition to estimating models 1-4 for FOMC announcement days, we also estimate these models for the full sample. The advantages of the full sample are twofold. First, it allows a more complete price discovery model and in particular the inclusion of the change in

expectations of future FOMC announcements ($\Delta E_t(FFR_T)$). Second, it provides a robustness check on both the economic and statistical results. Estimating regression models (1) through (4) using high-frequency data is not a trivial task. Problems such as heteroscedasticity are considerably enlarged by working with 5-minute frequency data, and this in turn, is augmented by a significant diurnal volatility pattern.¹³ The use of the full sample begins to address the robustness of our results. In particular, we are able to report both OLS and HAC standard errors for the coefficient estimates as well as other statistical tests.

We now turn our attention to the stock market volatility and its reaction to FOMC announcements and the markets expectation about the rate target.

4.2 Volatility Process

Following Andersen et al. (2003), the volatility of the disturbance in models 1-4 is approximated using the following model:

$$\begin{aligned}
 |\hat{\varepsilon}_t| = & c + \phi \frac{\hat{\sigma}_{d(t)}}{\sqrt{288}} + \sum_{q=1}^Q \left\{ \delta_q \cos\left(\frac{q2\pi t}{78}\right) + \phi_q \sin\left(\frac{q2\pi t}{78}\right) \right\} \\
 & + \sum_{j=0}^{J'} \eta_{vj} |\Delta FFR_{t-j}^U| + \sum_{j=0}^{J'} \theta_{vj} |\Delta FFR_{t-j}^U| * IM_t \\
 & + \sum_{j=0}^{J'} \tau_{vj} |\Delta FFR_{t-j}^E| + \sum_{j=0}^{J'} \phi_{vj} |\Delta FFR_{t-j}^E| * IM_t \\
 & + \sum_{j=0}^{J'} \omega_{vj} |\Delta E_t(FFR_T)| + u_t
 \end{aligned} \tag{5}$$

where $\hat{\sigma}_{d(t)}$ is the one-day-ahead volatility forecast for day t from a simple Gaussian GARCH(1,1) model using daily close-to-close log-returns. Hence, 5 minute volatility is modeled partly as a function of the volatility of the day in consideration and partly by a diurnal pattern designed to capture deviations from the daily average volatility.

Again, estimating regression model (5) using high-frequency data is difficult due to heteroskedasticity and diurnal patterns. In estimating the volatility process, we tried three specifications for the lag coefficients. The first was to estimate the lag structure without any restrictions and $J' = 12$, the second was to estimate a 3-rd order polynomial distributed lag model with no restrictions, while the third specification was a 3-rd order polynomial distributed lag

¹³ For this reason, an appendix is available with results of several approaches to estimating (1).

model with restricted coefficients (for more details see the appendix).

5. EMPIRICAL RESULTS

In presenting our results, we again distinguish between the price discovery process and the volatility process. The discussion of the price discovery process will first replicate the previous announcement effect studies at the daily interval and then present an intraday analysis while the volatility analysis will focus on the intraday intervals.

5.1 Price Discovery Process

Daily Effects

The purpose of presenting the daily results is twofold. First, the results validate our sample relative to the previous literature. Second, and more importantly, it provides benchmark of the aggregate impact of an FOMC announcement on the broad based market. This aggregate impact is estimated using the traditional Cook and Hahn (1989) approach. Specifically, this methodology regresses the change in the Fed funds rate target on the market return at a daily interval. In other terms, the estimated OLS model is:

$$r_t = \alpha_0 + \alpha_1 \Delta FFR_t + \varepsilon_t$$

where ΔFFR_t is the change in the Fed funds rate target and r_t is the daily return for the S&P 500 the day of the target change.

In total, the model is estimated using 67 observations with September 17, 2001 being excluded from the results. The estimated coefficient α_1 is -0.927 suggesting a one percent change in the Fed funds rate target results in approximately a 0.927 percent drop in the S&P 500 index. However, the t-statistic for this estimated coefficient is 1.250 indicating the result is not statistically significant.

Consistent with the more recent literature, we then decompose the change in the Fed funds rate into two components – the expected, or anticipated component (ΔFFR_t^E) and unexpected component (ΔFFR_t^U). The daily equation is then re-estimated with this decomposition. The results strongly support the previous assertion in the literature the market only responds to unexpected changes in the Fed fund rate target. The estimated equation is

$r_t = 0.23 - 0.78\Delta FFR_t^E - 4.67\Delta FFR_t^U$. The coefficient of the unexpected change in the Fed funds rate target is significant at the 5 percent level. The magnitude of the coefficient indicates a large negative broad market reaction of -4.67 percentage points to an unexpected increase in the Fed funds rate target of one percent. Note, the remaining estimated coefficients are not statistically significant.

While there is a relatively small sample of inter-FOMC announcements (three excluding September 17, 2001), it is worthwhile to note inter-FOMC announcements have a larger and more significant impact on the equity markets. Of course, the distinction of expected and unexpected rate changes is obscured by inter-FOMC announcements further complicating any analysis but by simply distinguishing inter-FOMC announcements in the above model using a zero/one indicator variable it is possible to separate regularly scheduled FOMC announcement results from inter-meeting announcements. The results for this regression are as follows:

$$r_t = 0.190 - 1.275\Delta FFR_t^U - 3.980\Delta FFR_t^U * IM_t + 0.613\Delta FFR_t^E - 12.099\Delta FFR_t^E * IM_t$$

with the exception of the final estimated parameter, none of the estimated parameters are significant at the five percent level. This is the first paper to our knowledge that distinguishes regularly scheduled FOMC announcements from inter-meeting announcements. The results are somewhat surprising at first glance indicating that the market reacts significantly to expected changes in the Fed funds rate when these changes are announced between meetings. However, since these announcements are in fact not part of the eight regularly scheduled annual announcements, these results are consistent with earlier findings that the market reacts to unexpected changes. The results do suggest a special nature of inter-FOMC announcements which should be given special consideration by both policy makers and researchers.

Intraday Effects

For brevity, we present only the cumulative price impact associated with the FOMC announcement estimated from the price discovery model. The full results are available upon request. The basic model is estimated with four lags of the dependent variable while the other time series data, principally announcement data, are estimated with two lags in addition to the contemporaneous period. The lag structure was determined using Akaike Information Criteria and implies the information from the announcements is fully incorporated into the equity market

within 15 minutes of the announcement. The cumulative impacts are calculated by summing the parameter coefficients on the contemporaneous variable as well as the lagged variables.

Table 3 presents the cumulative impact of the estimated parameters and reports p-values in parentheses for the intraday price discovery models presented in Section 3. Panel A displays the results for FOMC announcement days while Panel B displays the results for the full sample. In addition to reporting the OLS p-values, the full sample includes heteroskedastic and autocorrelation consistent (HAC) p-values using the techniques suggested by Newey and West (1987). Note, HAC p-values for the sub-sample of FOMC announcements are not appropriate due to the breaks in the time series between announcements.

Insert Table 3

Looking at the results in panel A, the estimated models clearly suggest that the FOMC announcement has an immediate impact on the equity markets. For example, Model 1 shows a one percent increase in the Fed funds rate target is associated with a statistically significant 1.527 percent reduction in the S&P 500 within 15 minutes of the announcement. When the rate change is decomposed into unexpected and expected components, the effect is even more pronounced. Specifically, Model 2 shows an unexpected change in the Fed funds rate results in -4.054 percent change in the S&P 500. Furthermore, in Model 3 when we include both the unexpected and expected component the cumulative estimate of the impact for the unexpected change in the Fed funds rate is -4.940 which is consistent with the earlier estimate of the daily effect of -4.67. The main difference being in the intraday model the entire effect is realized in 15 minutes rather than the entire trading day.

In addition to finding a significant impact associated with unexpected movements in the Fed funds rate, Model 3 also documents a significant albeit smaller impact associated with expected movements in the Fed funds rate. An expected one percent increase in the Fed funds rate equates to a 1.39 percent reduction in the S&P 500 index. The result suggests the market reacts not only to an unexpected movements but also expected movements significantly. However, the sample of FOMC announcements includes both regularly scheduled and inter-meeting announcements. The inclusion of inter-meeting announcements complicates the analysis because although the

rate changes maybe expected the timing is not expected.

To address this issue, we distinguish inter-meeting announcements in Model 4. These results should be viewed with caution as the number of inter-FOMC announcements in our sample is limited. The results nevertheless do suggest a special nature of inter-FOMC announcements. The equity market impacts estimated above for both expected and unexpected changes in the Fed fund rate appear to be dominated by the inter-meeting announcements. The impact of unexpected changes in the Fed funds rate drops from -4.94 percent to -1.45 percent for regularly scheduled FOMC announcements. The result remains statistically significant. The impact of expected changes in the Fed funds rate is no longer statistically significant for regularly scheduled FOMC announcements. This result is consistent with expectations that anticipated announcements should not affect the market since they are already incorporated in market data.

Overall, the results from panel A of Table 3 support the previous literature indicating that there is a negative association between unanticipated moves in the Fed funds rate target and the equity market reaction. However, unlike the previous studies which used daily price, the use of five minute interval data allows a closer inspection of the speed of the equity market's response. We are able to show the full impact realized in previous studies is realized rapidly, within three five-minute intervals or 15 minutes from the time of the announcement.

Panel B presents the results using the full sample. The results and conclusions from the announcement day analysis in Panel A remain the same. Focusing on the results prior to controlling for inter-meeting announcements, there is a large negative reaction in the S&P 500 index to unexpected changes in the Fed funds rate in addition to a smaller but also negative reaction to expected changes in the Fed funds rate. Both of these reactions are statistically significant using the OLS standard errors. However, when the standard errors are corrected using Newey and West (1987) the significance of the expected change in the Fed funds rate becomes marginal at best. Specifically, the results from model 3 using the full sample indicate a 25 basis point change in the Fed funds rate unexpected by the market results in approximately a 125 basis point decline in the broad equity market. This result is highly significant using both the OLS and HAC p-values. Again this reaction is quick being realized within 15 minutes of the announcement.

The parameters of particular interest for the full sample however are related to the changes in

expectations for US monetary policy. Surprisingly, the impact of these changes is not inversely related to equity market returns rather there is a positive relationship. Models 1 through 4 all indicate that the equity market moves in the same directions as shocks to market expectations. Even though it is a relatively small reaction a 25 basis point change in expectation results in a approximately a 25 basis point change in the equity markets, given the variables continuous nature its economic significance is substantial.

5.2 Volatility Process

In presenting the results for the volatility process, we limit our exposition to the contemporaneous volatility response as well as impact response curves associated with the FOMC announcement. The full results are available upon request. The basic model is estimated to allow volatility shocks to persist for up to 12 intervals or 60 minutes following the shock.

Prior to examining the estimated parameters, we present the summary statistics for the intraday volatility in Table 4. Volatility is estimated by taking the absolute value of the residuals from the price discovery models presented above. Table 4 presents the volatility parameters resulting from model 4 estimated for the full sample. In total there are 121,995 five minute intervals included in the volatility analysis. The volatility over these five minute intervals ranges from a minimum of 0 to a maximum of 3.648 with a mean value of 0.080. The median value for the distribution is 0.055 indicating a number of extreme values on the right-hand side of the distribution. To investigate these extreme values we distinguished announcement days from non-announcement days. While the mean value for announcement days (0.090) is greater than non-announcements days both distributions are skewed to the right.

Insert Table 4

To examine the diurnal effect on volatility we also present in Figure 4 a graphical depiction of the actual and fitted volatility by time of day for Model 4. These results also distinguish between announcement (panel A) and non-announcement (panel B) days. Both panels clearly show a U-shape pattern with a drop off prior to the market close supporting the choice of the volatility model with diurnal controls. Panel A also shows a large volatility spike between 2 PM

and 2:30 PM. This spike coincides with the FOMC announcements and the model results presented below will further investigate this spike.

Insert Figure 4

Table 5 presents the contemporaneous impact on volatility of the FOMC announcements from the various models. The table is organized in two panels. Panel A presents the results using only FOMC announcement days while Panel B presents the results for the full sample. Starting with Panel A, FOMC announcements are associated with contemporaneous volatility shocks. Specifically, Model 1 indicates a 25 basis point change in the Fed funds rate target results in an immediate increase of 28 (1.13) basis points in volatility. Given a mean level of volatility of approximately 9 basis point over the five intervals this is a dramatic spike in volatility. This impact however appears to be contingent on the market expectations. Model 2 indicates an unexpected change of 25 basis point in the Fed funds rate target results in an even larger (1.06 percent) statistically significant immediate increases in volatility. Similarly, Model 3 which shows the impact of an unexpected change in the Fed funds rate is much larger than the impact of an expected change in the Fed funds rate (0.93 versus 0.11 percent). Both results are statistically significant showing announcements whether anticipated or not both result in a volatility spike.

Insert Table 5

Similar to the returns analysis, we also investigate the importance of inter-meeting announcements. Inter-meeting announcements also result in a larger volatility spike. Model 4 indicates unexpected announcements are associated with 0.76 percent volatility spike and inter-meeting announcement result in an additional 0.45 percent. In other words, volatility spikes by an additional 59 percent ($0.45/0.76$) on inter-meeting announcements in comparison to regularly scheduled announcements. In terms of expected announcements, the additional volatility spike is even more pronounced. Inter-meeting announcements result in an additional spike of 0.40 percent on top of the regular scheduled volatility spike of 0.08 percent. All these results are

significant using standard OLS p-values and clearly corroborate the special importance of inter-FOMC announcements. All results are presented assuming a 25 basis points shock.

The analysis of the full sample serves two purposes. First, the results provide an economic and statistical robustness check on the announcement day results. By expanding the sample to the full population of trading days over the study period, we can investigate the sensitivity of the estimated parameters and conduct additional statistical tests. Specifically, with the full sample we are able to estimate HAC based standard errors as suggested by Newey and West (1987). The results presented in Panel B of Table 5 corroborate the results for the announcement days. There are volatility spikes associated with FOMC announcements. These spikes are greater for unexpected announcements than expected announcements and intra-meeting announcements are associated with even greater spikes. However when we examine the statistical significance of the results using the HAC standard errors and p-values in turn the importance of expected and intra-meeting announcements diminishes. For example in Model 4 the HAC p-value for expected changes in the Fed funds target 0.63 indicating the coefficient is clearly not statistically significant. Furthermore the intra-meeting coefficients are not significant when we rely on HAC standard errors. This may however be related to the small number of intra-meeting announcements and this issue warrants further consideration if the Fed increase the number of intra-meeting announcements in the future.

The second purpose of the full sample is to explore the impact of changing expectations and more specifically the expectations of future Fed funds rate changes. By using the full sample we are able to integrate Fed funds futures data as a real-time proxy for market expectations. The contemporaneous volatility response for this real-time measure of expectations are presented in the last row of Panel B in Table 5. The results across the four models are consistent indicating changes in market expectations results in a statistically significant volatility spike. The range of the parameter estimates ranges from 1.62 to 1.81.

In addition to examining the contemporaneous volatility spike associates with FOMC announcements and changes in market expectation we also examine the persistence of the volatility spike by graphing the estimated parameter estimates over the resulting two hour window following an announcement. These impulse responses are available for each model but again for brevity we limit ourselves to model 4 for the full sample (panel B).

The resulting volatility impact responses for model 4 are presented across five panels in Figure 5. Each panel presents the unrestricted coefficients as well as the polynomial and polynomial with end restrictions parameter estimates for the contemporaneous period and 12 lagged periods. The confidence intervals are based on OLS standard errors. The first panel presents the volatility response to a one percent unexpected change in the Fed funds rate. The second panel reading left to right presents the volatility response to a one percent unexpected change in the Fed funds rate for an inter-meeting announcement. The second row of figures presents the results for expected Fed funds rate changes and the third and final row presents the results for real-time changes in market expectations.

Insert Figure 5

Starting with unexpected changes in the Fed funds rate, the contemporaneous volatility spike is evident for both regularly schedule and inter-meeting announcements. The spike however does not persist. In the case of regularly scheduled announcements, volatility returns to normal within three periods or 15 minutes. For inter-meeting announcements the volatility spike persists for two periods or 10 minutes and is then followed by a sustained period of reduced volatility before returning to normal within 12 periods or one hour. Albeit smaller the expected changes in the Fed funds rate target also results in a volatility spike that for regularly scheduled announcements persists for two to four periods depending on the estimation methodology and for inter-meeting announcements persists for up to 30 minutes.

The final panel shows the lingering impact of a change in market expectations intraday volatility for the S&P 500 index. The contemporaneous impact documented in Table 5 is evident however this spike dramatically decreases in the first lagged period and persists at this new lower level for the following hour before returning to normal. Similar to the price discovery analysis, this persistent impact despite being relatively small is of economic significances do the continuous nature of market expectations.

Figure 6 presents the same impulse responses as figure 4 but instead of OLS standard errors the confidence intervals are based on Newey-West standard errors. These more restrictive standard errors clearly affect the statistical significance of the results. In contrast to the OLS

results, expected changes in the Fed funds rate target has no statistically significant impact on volatility. Furthermore, inter-meeting announcements have no statistically differential impact on volatility.

Insert Figure 6

6. CONCLUSION

This paper studies the influence of US monetary policy on asset prices and volatility in the US equity markets on an intraday basis. As monetary policy has become more transparent and a viable futures market in federal funds has developed, we are able to expand on the traditional analysis of macroeconomic policy announcements by incorporating real-time expectations of future monetary policy into an equity price discovery model. By using transaction data on the equity market and the futures market along with the exact time of the announcement, we are better able to characterize the response of the financial markets to policymakers.

Our results are intriguing and challenge some of the traditional results of event studies examining macroeconomic announcements. In particular, we find the equity market does not react to changes in expectations about the federal funds rate as predicted by financial theory but does react to the realization of changes in the federal funds rate target. The equity markets tend to respond quickly and inversely to changes in the federal funds rate target as announced following FOMC policy meetings. This reaction is more pronounced for unexpected announcement in comparison to expected announcements however both are economically and statistically significant. The same reaction is not observed following changes in expectations of the Fed funds rate. In fact, the response albeit small is a positive impact contrary to financial theory. Taken together these results suggest the equity market tends to respond not to expectations but rather the realization of these expectations.

The volatility analysis documents a spike in market volatility immediately surrounding FOMC announcements. The magnitude of these spikes is also dependent on the market's expectations with unexpected announcements being associated with larger volatility spikes. Both of expected and unexpected announcements result in spikes which are short lived dissipating within 15 to 30 minutes of the announcement. Changes in market expectations also

results in a volatility spike however this spike tends to persist for up to an hour.

REFERENCES

- Andersen, T.G., T. Bollerslev, F.X. Diebold, and C. Vega (2003): "Micro Effects of Macro Announcements: Real-Time Price Discovery in Foreign Exchange". *American Economic Review* 93, 38-62."
- Balduzzi, P., E.J. Elton, and T.C. Green (2001): "Economic News and Bond Prices: Evidence from the U.S. Treasury Market". *Journal of Financial and Quantitative Analysis* 36, 523-543.
- Bernanke, B.S. and K.N. Kuttner (2005): "What Explains the Stock Market's Reaction to Federal Reserve Policy?". *Journal of Finance* 60, 1221-1257.
- Bollerslev, T., J. Cai, and F.M. Song (2000): "Intraday periodicity, long memory volatility, and macroeconomic announcement effects in the US Treasury bond market". *Journal of Empirical Finance* 7, 37-55.
- Bomfim, A. (2003): "Pre-announcement effect, news effects, and volatility: Monetary policy and the stock market". *Journal of Banking and Finance* 27, 133-151.
- Cook, T. and T. Hahn (1989): "The effect of changes in the Federal funds rate target on market interest rates in the 1979s". *Journal of Monetary Economics* 24, 331-351.
- Elton, E.J., M.J. Gruber, G. Comer, and K. Li (2001): "Spiders Where are the Bugs". *Journal of Business* 75, 453-472.
- Krueger, J.T. and K.N. Kuttner (1996): "The Fed Funds Futures Rate as a Predictor of Federal Reserve Policy". *Journal of Futures Markets* 16, 865-879.
- Kuttner, K.N. (2001): "Monetary policy surprises and interest rates: Evidence from the Fed funds futures market". *Journal of Monetary Economics* 47, 523-544.
- Newey, W.K. and K.D. West (1987): "A simple, positive semi-definite heteroskedasticity and autocorrelation consistent variance covariance matrix". *Econometrica* 55, 703-708.
- Reinhart, V. and T. Simin (1997): "The Market Reaction to Federal Reserve Policy Action from 1989 to 1992". *Journal of Economics and Business* 49, 149-168.
- Report to the Congress, 1995.
- Tarhan, V. (1995): "Does the Federal Reserve affect asset prices?". *Journal of Economic Dynamics and Control* 19, 1199-1222.

- Thorbecke, W. and T. Alami (1994): "The Effect of Changes in the Federal Funds Rate Target on Stock Prices in the 1970s". *Journal of Economics and Business* 46, 13-20.
- Thorbecke, W. (1997): "On Stock Market Returns and Monetary Policy". *Journal of Finance* 52, 635-654.

APPENDIX

Alternative Lag Specifications

We tried three specifications for the lag coefficients:

1. Estimating η_{vj} and τ_{vj} $j = 1, \dots, 12$ without any restrictions.
2. We reduce the number of parameters to be estimated by using polynomial distributed lags (PDLs) to impose a smoothness condition on the lag coefficients. This requires that the coefficients lie on a polynomial of relatively low degree. A polynomial distributed lag model with order restricts the η_{vj} and τ_{vj} coefficients (respectively for each equation) to lie on a p th order polynomial of the form:

$$\begin{aligned}\eta_{vj} &= \rho_{\eta 1} + \rho_{\eta 2}j + \rho_{\eta 2}j^2 + \dots + \rho_{\eta p+1}j^p, \quad \text{and} \\ \tau_{vj} &= \rho_{\tau 1} + \rho_{\tau 2}j + \rho_{\tau 2}j^2 + \dots + \rho_{\tau p+1}j^p, \quad \text{for } j = 1, \dots, J\end{aligned}$$

Once we estimate from this equation, we can recover the parameters of interest η_{vj} and τ_{vj} . We chose $p = 3$.

3. Finally we impose a far end constraint which restricts the effect to die off beyond the number of specified lags:

$$\eta_{J+1} = \tau_1 + \tau_2(J+1) + \tau_2(J+1)^2 + \dots + \tau_{p+1}^p(J+1) = 0,$$

and likewise for τ_{vj} .

Table 1. *Federal Open Market Committee Announcement Dates and Times (1995-2002).*

Announcement Date	Time	Fed Funds Target Rate	ΔFFR_t	Announcement Date	Time	Fed Funds Target Rate	ΔFFR_t
1-Feb-95	2:15 PM	6.00	0.50	3-Feb-99	2:12pm	4.75	0
28-Mar-95	2:15 PM	6.00	0.00	30-Mar-99	2:12pm	4.75	0
23-May-95	2:15 PM	6.00	0.00	18-May-99	2:11pm	4.75	0
6-Jul-95	2:15 PM	5.75	-0.25	30-Jun-99	2:15pm	5	0.25
22-Aug-95	2:15 PM	5.75	0.00	24-Aug-99	2:15pm	5.25	0.25
26-Sep-95	2:15 PM	5.75	0.00	5-Oct-99	2:12pm	5.25	0
15-Nov-95	2:15 PM	5.75	0.00	16-Nov-99	2:15pm	5.5	0.25
19-Dec-95	2:15 PM	5.50	-0.25	21-Dec-99	2:15pm	5.5	0
31-Jan-96	2:15 PM	5.25	-0.25	2-Feb-00	2:15pm	5.75	0.25
26-Mar-96	11:39 AM	5.25	0.00	21-Mar-00	2:15pm	6	0.25
21-May-96	2:15 PM	5.25	0.00	16-May-00	2:15pm	6.5	0.5
3-Jul-96	2:15 PM	5.25	0.00	28-Jun-00	2:15pm	6.5	0
20-Aug-96	2:15 PM	5.25	0.00	22-Aug-00	2:15pm	6.5	0
24-Sep-96	2:15 PM	5.25	0.00	3-Oct-00	2:12pm	6.5	0
13-Nov-96	2:15 PM	5.25	0.00	15-Nov-00	2:12pm	6.5	0
17-Dec-96	2:15 PM	5.25	0.00	19-Dec-00	2:15pm	6.5	0
5-Feb-97	2:15 PM	5.25	0.00	3-Jan-01	1:13pm	6	-0.5
25-Mar-97	2:15 PM	5.50	0.25	31-Jan-01	2:15pm	5.5	-0.5
20-May-97	2:15 PM	5.50	0.00	20-Mar-01	2:15pm	5	-0.5
2-Jul-97	2:15 PM	5.50	0.00	18-Apr-01	10:54am	4.5	-0.5
19-Aug-97	2:15 PM	5.50	0.00	15-May-01	2:15pm	4	-0.5
30-Sep-97	2:15 PM	5.50	0.00	27-Jun-01	2:12pm	3.75	-0.25
12-Nov-97	2:15 PM	5.50	0.00	21-Aug-01	2:15pm	3.5	-0.25
16-Dec-97	2:15 PM	5.50	0.00	17-Sep-01	8:20am	3	-0.5
4-Feb-98	2:12 PM	5.50	0.00	2-Oct-01	2:15pm	2.5	-0.5
31-Mar-98	2:15 PM	5.50	0.00	6-Nov-01	2:20pm	2	-0.5
19-May-98	2:15 PM	5.50	0.00	11-Dec-01	2:15pm	1.75	-0.25
1-Jul-98	2:15 PM	5.50	0.00	30-Jan-02	2:15pm	1.75	0
18-Aug-98	2:15 PM	5.50	0.00	19-Mar-02	2:15pm	1.75	0
29-Sep-98	2:15 PM	5.25	-0.25	7-May-02	2:15pm	1.75	0
15-Oct-98	3:15 PM	5.00	-0.25	26-Jun-02	2:15pm	1.75	0
17-Nov-98	2:15 PM	4.75	-0.25	13-Aug-02	2:15pm	1.75	0
22-Dec-98	2:15 PM	4.75	0.00	24-Sep-02	2:15pm	1.75	0
				6-Nov-02	2:15pm	1.25	-0.5
				10-Dec-02	2:15pm	1.25	0

Table 2. FOMC Announcement Day Descriptive Statistics. This table reports selective descriptive statistics for the FOMC announcement dates over the period from January 1995 through December 2002 excluding September 17, 2001. The statistics are broken into three categories – positive, no change and negative to reflect the actual announced change in the targeted Federal funds rate. Mean changes in basis points are reported with standard deviations reported in parentheses.

	Total	Positive	No Change	Negative
Number of Events	67	8	53	17
Announced Change	-5.97 (21.36)	28.13 (8.84)	0.00 (0.00)	-36.76 (12.86)
Expected Change	-4.66 (24.23)	30.56 (9.72)	1.90 (4.28)	-38.68 (18.54)
Unexpected Change	-1.31 (5.96)	-2.44 (6.93)	-1.90 (4.28)	1.91 (7.37)

Table 3. *Cumulative Return Response on FOMC Announcement Days for SPY.* The table presents the cumulative return response results estimated for models 1-4 using Ordinary Least Squares. p-values based on OLS standard errors are given in parentheses, and HAC based p-values computed using the method suggested in Newey and West (1987) are given in square brackets. The sample includes 68 FOMC announcement dates over the period from January 1995 through December 2002 excluding September 17, 2001.

Panel A: FOMC Announcements				
	Model 1	Model 2	Model 3	Model 4
ΔFFR_t	-1.527 (<0.0001)			
ΔFFR_t^U		-4.054 (<0.0001)	-4.940 (<0.0001)	-1.445 (0.0052)
$\Delta FFR_t^U * im_t$				-2.979 (0.0027)
ΔFFR_t^E			-1.389 (<0.0001)	-0.190 (0.2282)
$\Delta FFR_t^E * im_t$				-11.599 (<0.0001)
Panel B: Full Sample				
	Model 1	Model 2	Model 3	Model 4
ΔFFR_t	-1.48 (<0.0001) [0.0536]			
ΔFFR_t^U		-4.176 (<0.0001) [0.0140]	-5.102 (<0.0001) [0.0005]	-1.737 (<0.0001) [0.0494]
$\Delta FFR_t^U * im_t$				-3.404 (<0.0001) [0.0504]
ΔFFR_t^E			-1.35 (<0.0001) [0.0516]	-0.239 (0.0608) [0.4397]
$\Delta FFR_t^E * im_t$				-9.882 (<0.0001) [<0.0001]
$\Delta E_t(FFR_T)$	0.851 (<0.0001) [0.0283]	0.993 (<0.0001) [0.0522]	1.196 (<0.0001) [0.0038]	1.168 (<0.0001) [0.0026]

Table 4. *Volatility Summary Statistics.* Volatility is estimated by taking the absolute value of the residuals from the price discovery model. The summary statistics presented in this table are based on the price discovery model presented in Table3, Panel B labeled Model 4. This model is based on the full sample includes explanatory variables for expected and unexpected shocks for regularly scheduled announcements as well as inter-meeting announcements. The price discovery model also includes a real-time measures of changes in expectations of future monetary policy. The summary statistics are presented for all days as well as for announcement and non-announcement days.

	n	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
All Days	121,995	0.000	0.025	0.055	0.080	0.107	3.648
Announcement Days	4,087	0.000	0.022	0.053	0.090	0.110	3.648
Non-announcement Days	117,908	0.000	0.025	0.055	0.079	0.107	1.816

Table 5. *Contemporaneous Volatility Response on FOMC Announcement Days for SPY.* The table presents the contemporaneous volatility response results estimated for models 1-4 using Ordinary Least Squares. p-values based on OLS standard errors are given in parentheses, and HAC based p-values computed using the method suggested in Newey and West (1987) are given in square brackets. The sample includes 68 FOMC announcement dates over the period from January 1995 through December 2002 excluding September 17, 2001.

Panel A: FOMC Announcements				
	Model 1	Model 2	Model 3	Model 4
$ \Delta FFR_t $	1.134 (<0.0001)			
$ \Delta FFR_t^U $		4.221 (<0.0001)	3.720 (<0.0001)	3.047 (<0.0001)
$ \Delta FFR_t^U * im$				1.790 (<0.0001)
$ \Delta FFR_t^E $			0.453 (<0.0001)	0.332 (<0.0001)
$ \Delta FFR_t^E * im$				1.607 (<0.0001)
Panel B: Full Sample				
	Model 1	Model 2	Model 3	Model 4
$ \Delta FFR_t $	0.943 (<0.0001) [0.0129]			
$ \Delta FFR_t^U $		3.678 (<0.0001) [0.0015]	3.443 (<0.0001) [0.0075]	2.629 (<0.0001) [0.0006]
$ \Delta FFR_t^U * im$				2.280 (<0.0001) [0.4890]
$ \Delta FFR_t^E $			0.1644 (<0.0001) [0.6051]	0.107 (<0.0001) [0.6274]
$ \Delta FFR_t^E * im$				1.816 (<0.0001) [0.1546]
$ \Delta E_t(FFR_T) $	1.668 (<0.0001) [0.0013]	1.683 (<0.0001) [0.0058]	1.615 (<0.0001) [0.0001]	1.806 (<0.0001) [<0.0001]

Figure 1. *Federal Funds Rate Target (1995-2002).* The graph presents the full time series with blue bars representing regularly scheduled FOMC announcements and the yellow dotted lines represent annual breaks.

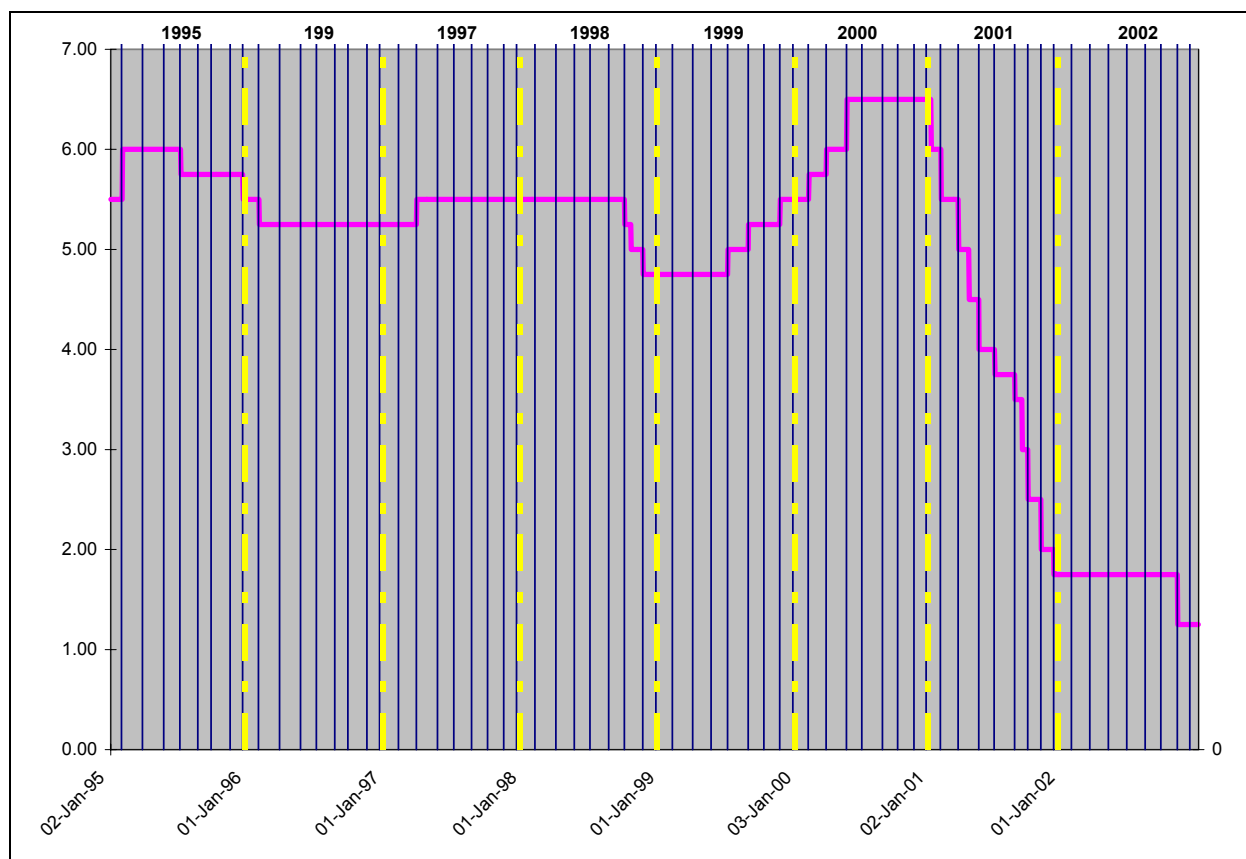


Figure 2. *SPY* (1995-2002).

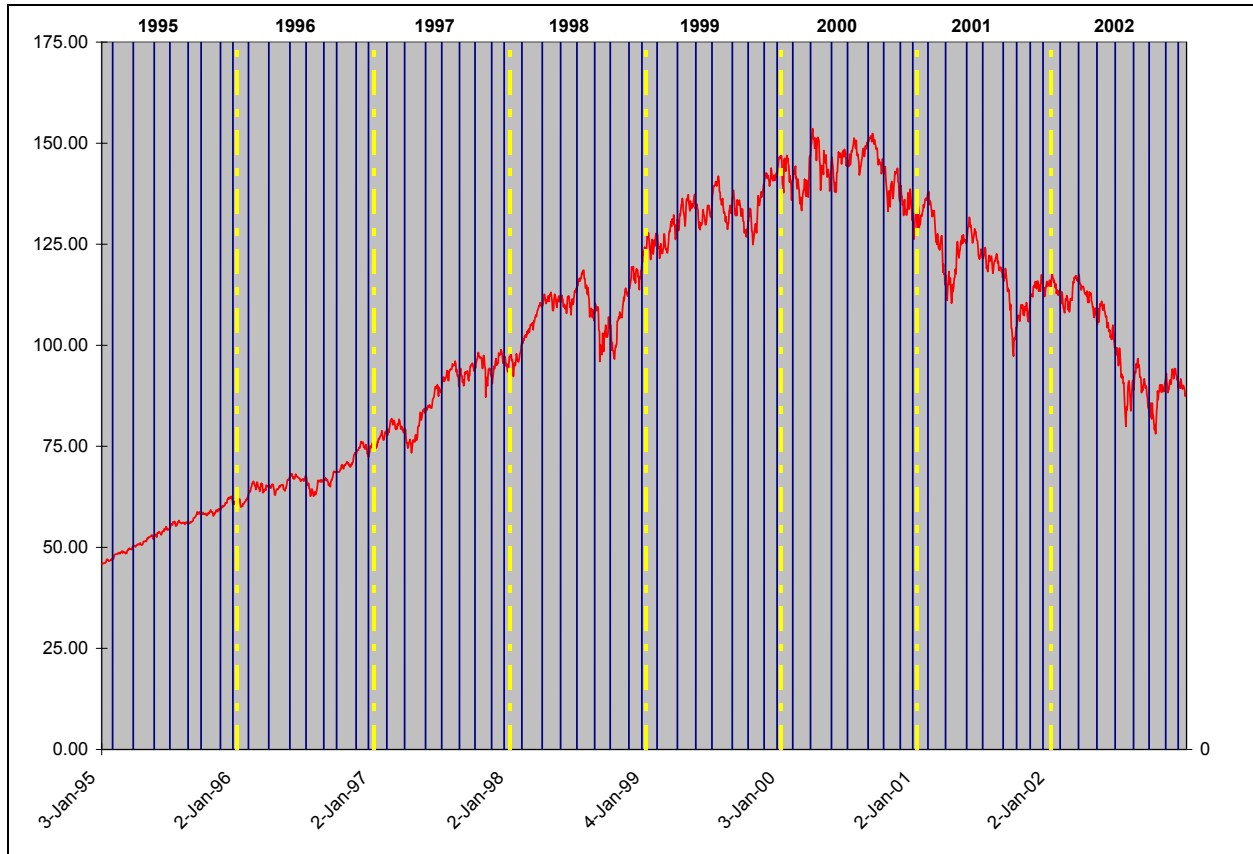


Figure 3. *Implied Federal Funds Rate (1995-2002).*

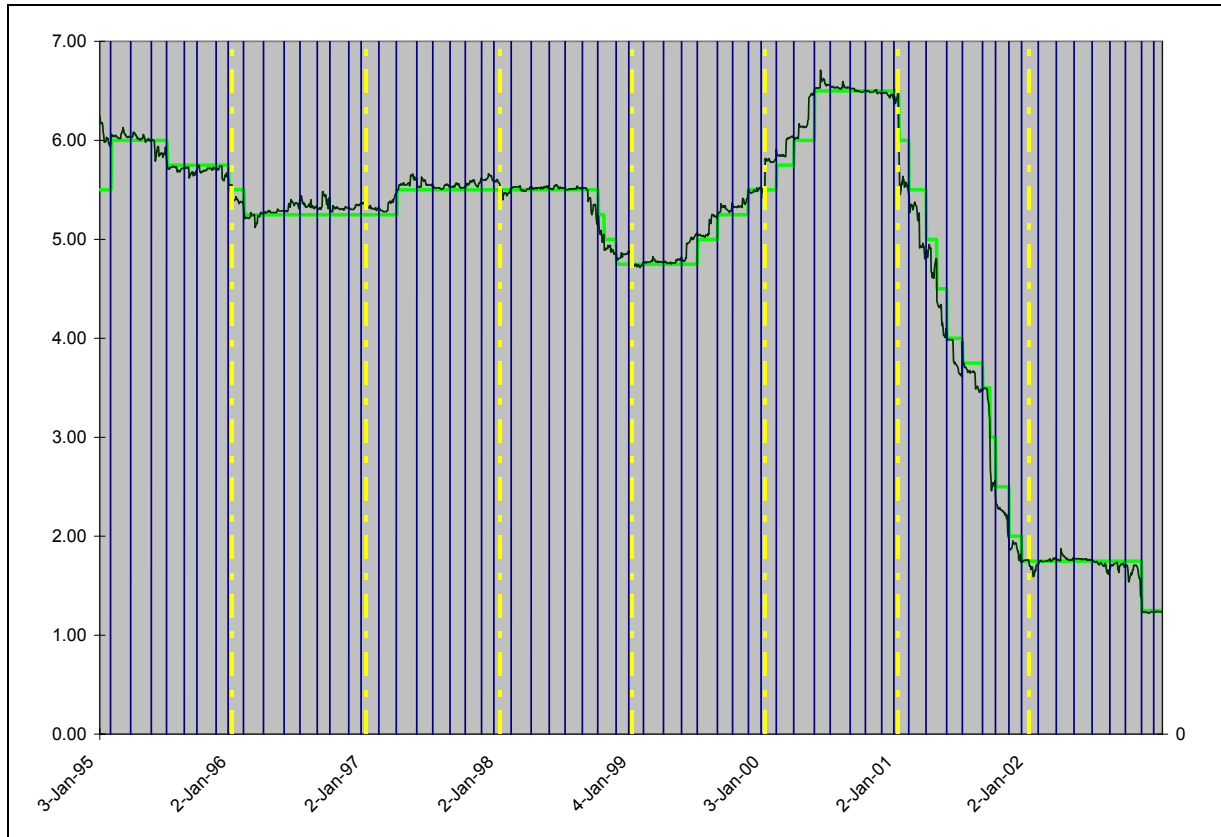
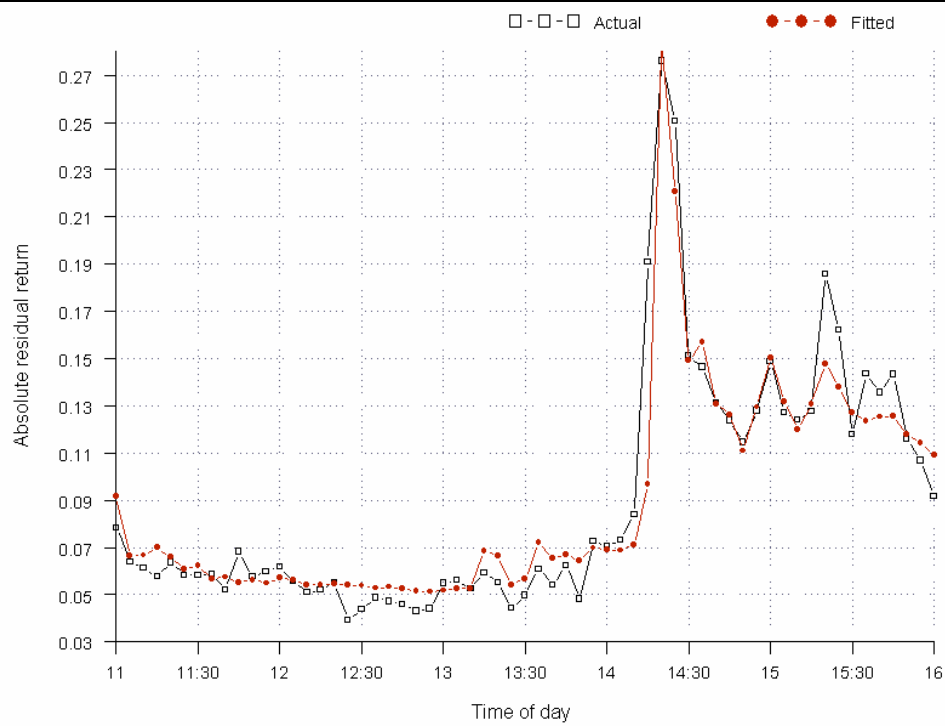


Figure 4. *Actual and Fitted Intraday Volatility Patterns .*

Panel A: Announcement Days



Panel B: Non-announcement Days

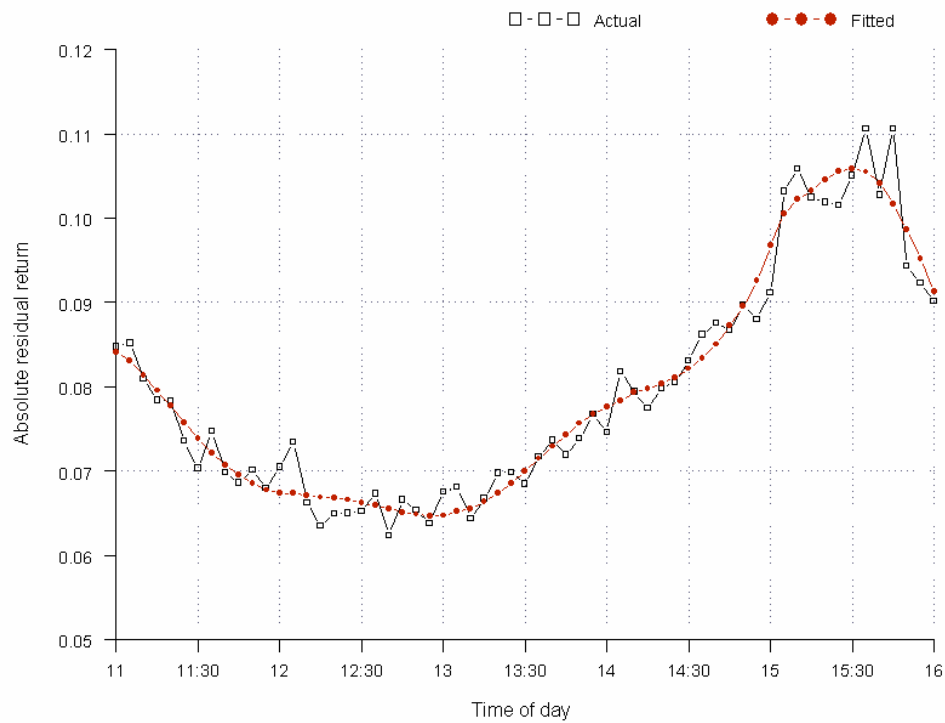


Figure 5. *Volatility Impulse Responses with OLS Standard Errors for Model 4.* Five panels are presented representing unexpected and expected changes in the Fed Funds Rate for regularly scheduled FOMC announcements and inter-meeting announcements as well as real-time changes in expectations regarding future monetary policy. Each panel presents the unrestricted coefficients as well as the polynomial and polynomial with end restrictions parameter estimates for the contemporaneous period and 12 lagged periods. Confidence bands are based on OLS standard errors.

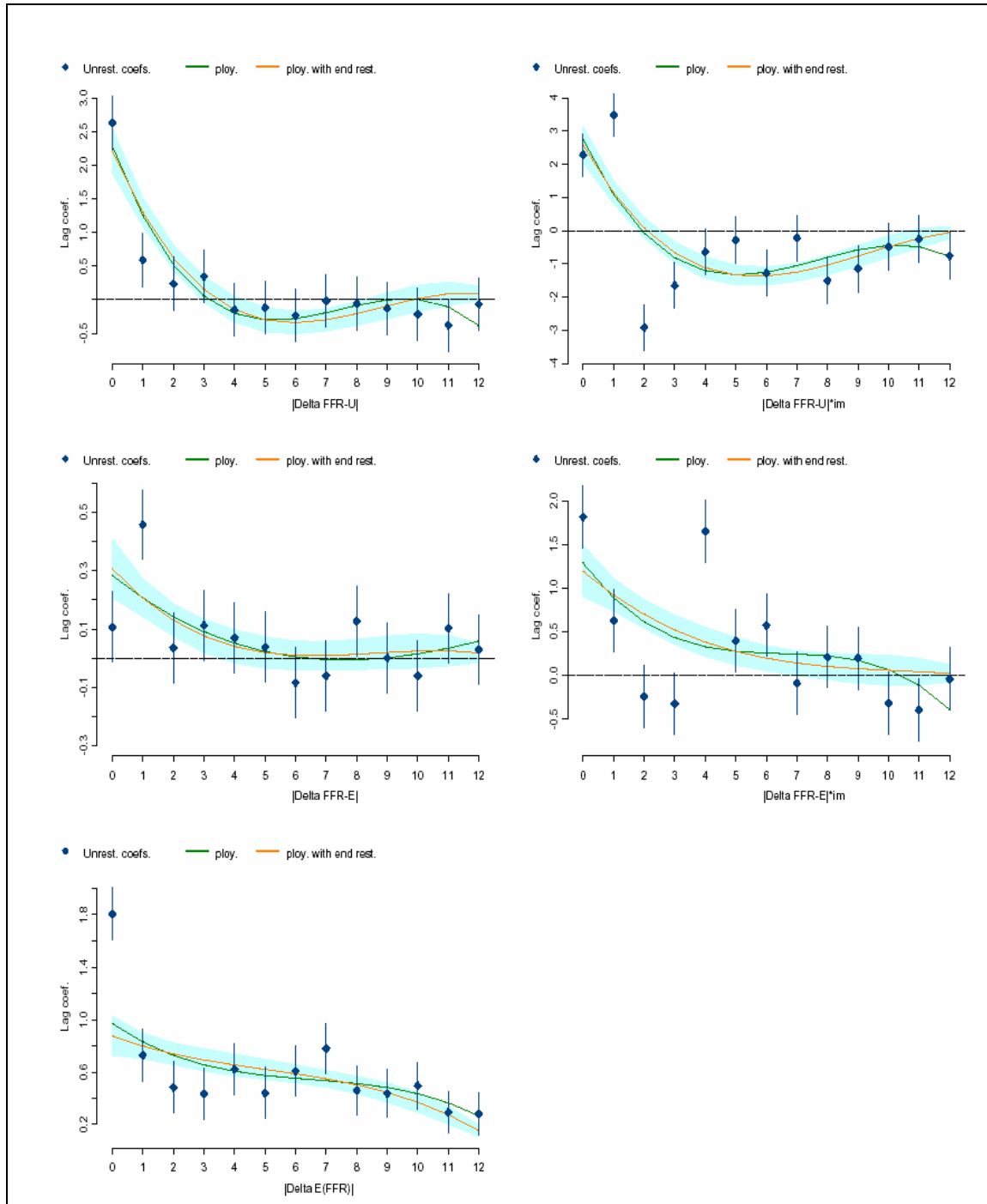


Figure 6. *Volatility Impulse Responses with Newey-West Standard Errors for Model 4.* Five

panels are presented representing unexpected and expected changes in the Fed Funds Rate for regularly scheduled FOMC announcements and inter-meeting announcements as well as real-time changes in expectations regarding future monetary policy. Each panel presents the unrestricted coefficients as well as the polynomial and polynomial with end restrictions parameter estimates for the contemporaneous period and 12 lagged periods. Confidence bands are based on Newey-West standard errors.

