Exchange Rates and FOMC Days

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ABSTRACT

FOMC meeting days provide a natural laboratory for exploring the effects of policy uncertainty and learning on exchange rate determination. Intradaily mark/dollar exchange rates are employed for 10 FOMC meetings. The meetings examined are the first 10 following the February 1994 change in policy where the meeting outcome is announced after meetings end. A reasonable hypothesis is that the meeting outcomes are price-relevant public information associated with a switch to an "informed-trading state."

A markov-switching model is used to estimate the time of informed trading. The data suggest that on most days, there is a switch to the informed-trading state during the time of the meeting, well before the end of the meeting. An extensive search of public news indicates that the informed trading cannot be explained as the response to public information.

Bid-ask spreads are jointly estimated with the exchange rate returns. The estimation results indicate that the greater the probability of being in the informed trading state, the wider spreads. This is consistent with dealers protecting against adverse selection in quoting.

The evidence indicates that traders are adjusting positions on more than just public news during FOMC meetings. An interesting question is why such positioning does not occur earlier in the morning prior to the meeting or on a prior day. A remaining puzzle is what causes the switch to the informed–trading state during meeting time.

I. INTRODUCTION

In 1994, the FOMC began announcing changes in the target for the federal funds rate immediately following meetings. Prior to this time, one had to infer policy changes from open market operations and interest rate changes. During the period of February 1994 to March 1995, the federal funds rate target was changed seven times, with six of the changes occurring at regularly scheduled meetings.[1] Prior to each meeting, survey evidence indicates that market participants believed that the federal funds rate would rise, if changed. These days provide a natural laboratory for the study of policy uncertainty and learning on exchange rate dynamics.

The particular focus of our study is on examining the behavior of exchange rates on days when a major policy meeting is known to occur and a major policy target, considered to be a fundamental determinant of exchange rates, may be changed. Economists have traditionally thought of models with homogeneous agents where the meeting outcome provides public information (news) that is shared equally by all agents. In this framework, exchange rates shift when the news is received at the meeting end. Microstructure models of financial markets suggest that on such days we may find exchange rates experiencing shifts due to information-based trading of both the public and private type and such shifts may occur prior to the meeting end and the news of the outcome. Specifically, the literature suggests the exploration of the following hypotheses: a) Strategic behavior by informed traders results in the revelation of their information to the market prior to the meeting end so that exchange rate volatility increases and b) Bid-ask spreads change in response to the probability of adverse selection associated with quoting to the informed. We shall see that the evidence supports both of these hypotheses for the FOMC days considered in our study.

[1] On April 18, 1994 the federal funds target was increased outside a regularly scheduled meeting.

The study is divided into three sections. Section II presents the motivation and modeling strategy employed. Section III examines the evidence on intradaily exchange rate changes via a switching-regime model to infer the time when informed position-taking occurs. The model estimated allows us to identify the time of day when the exchange rate moves from a regime of small, random changes and narrow spreads consistent with liquidity trading toward a regime of large, volatile changes and wider spreads consistent with the presence of informed traders taking positions in anticipation of the FOMC meeting outcome. Ignoring brief switches of only a few minutes, estimates of the time of position taking average 3 hours and 5 minutes prior to meeting end across the sample meeting days. A careful review of public news on these days indicates that few of the switches to the informed-trading state can be explained by public news. This leaves position-taking based on private information as the likely cause of the switch to the informed trading state. The fourth section of the paper provides a more detailed analysis of the determinants of the spread and the probability of being in the informed trading state. The evidence indicates that the probability of the high-volatility, wide-spread state increases during the time of the FOMC meetings as well as after the news is released at meetings' end. So while there is a role for public information associated with the meeting outcome in pricing currency, there is also market positioning going on during the meeting that tends to move prices to the high volatility state. Section V offers a summary and conclusions.

II. MOTIVATION AND MODELING STRATEGY

Monetary policy effects on exchange rates have a long history in the empirical international finance literature. Traditionally, such analyses have emphasized macro-oriented models like the monetary model of the exchange rate and utilized low frequency data. There have also been important studies using an event methodology to infer the effects of monetary policy actions on exchange rates. For instance, recently Bonser-Neal, Roley, and Sellon (1998) estimated models of the effect of FOMC federal funds rate target changes on spot and forward exchange rates. Their analysis focused on the change in exchange rates from the day before to the day after FOMC meetings. Exchange rates were seen to respond significantly to changes in federal funds rate targets. The common interpretation of such results is that the FOMC meeting outcomes provide news to the market that is price-relevant and reflected in the consequent change in exchange rates.

Our analysis takes more of a microscopic look at this issue to examine whether the meeting end is, in fact, providing news to the market that results in exchange rates changing at that time. Why might we expect any other dynamic for exchange rates? If we think of the foreign exchange market as a market with asymmetrically-informed traders in the spirit of Kyle (1985), then we may expect informed traders to take positions during the meeting in anticipation of the policy outcome.[2] Such behavior does not require any information leaks from official sources or unethical behavior, but reflects the informed opinion of the likely action occurring at meeting's end. Such opinions might be formed on the basis of activities taking place at the Board of Governors during the meeting, inventory position changes inferred from counterparties occurring during the meeting, or some other source of relevant information that stimulates changes in quoted prices on currencies. We will let the data

[2] Recently, a model intended for the foreign exchange market has been advanced in Lyons (2001) and Evans and Lyons (2002).

reveal whether we should view the meeting outcomes as news or whether there is an earlier adjustment of the market prior to the end of FOMC meetings.

In order to estimate the time when informed traders take positions on FOMC days, we will estimate a version of a modeling strategy proposed by Hamilton (1989). The analysis is motivated by the belief that the market is populated by heterogeneously informed traders.[3] Specifically, we assume that there are two kinds of traders: informed traders, who anticipate the final value of the foreign currency and profit from speculative positions, and uninformed liquidity traders who trade randomly due to financing needs associated with buying and selling goods and financial assets internationally. In addition, there are market makers who absorb the order flow while earning zero expected profits.

Liquidity traders make up the proportion $(1-\lambda)$ of total market participants. They receive a random signal to either buy or sell foreign currency. The informed traders make up the proportion λ of the market and receive a signal at time $t-1$ regarding the fundamental value of the exchange rate at time t, s_t. The fundamental value is assumed to evolve as a martingale process:

$$s_t = s_{t-1} + \varepsilon_t \tag{1}$$

where $E_{t-1}(\varepsilon_t) = 0$ and $E_{t-1}(\varepsilon_t^2) \equiv \sigma_t^2$.

The foreign exchange market is a market where price precedes quantity. Market makers are obliged to quote bid (B) and ask (A) prices not knowing whether the counterparty will be a buyer or seller. The bid-ask spread is assumed to be symmetrically priced around the fundamental price prevailing at the time of quoting, so that $A_t = s_{t-1} + sp_{t,t-1}$ and $B_t = s_{t-1} - sp_{t,t-1}$. The spread, $SP_t = 2sp_{t,t-1}$, is quoted at time $t-1$ for trading at time t and only depends upon information at $t-1$.

[3] See Bollerslev and Melvin (1994) for a foreign exchange application of a model of heterogeneous agents related to exchange rate volatility via quote-setting market makers.

Market makers know that if they trade with an informed counterparty they will earn losses as the informed have early knowledge of ε_t. Assuming that market maker quotes are good for one unit of currency, then the loss arising from informed trading is

$$L_t = min\left[s_t - B_t, 0, A_t - s_t\right]. \tag{2}$$

The profit expected from trade with the uninformed liquidity traders is

$$E_{t-1}P_t = E_{t-1}\left[\frac{1}{2}\left(A_t - s_t\right) + \frac{1}{2}\left(s_t - B_t\right)\right] = sp_{t,t-1} > 0 \tag{3}$$

Combining equations (2) and (3) and assuming that the standardized innovations, $Z_t \equiv \varepsilon_t \sigma_t^{-1}$, are independent and symmetrically distributed through time, the expected profit for the market maker conditioned on time $t-1$ information is

$$E_{t-1}\left(L_t + P_t\right) = 2\lambda\left[sp_{t,t-1} - \sigma_t E_{t-1}\left(Z_t \mid sp_{t,t-1}\sigma_t^{-1} < Z_t\right)\right]\left[1 - p\left(Z_t < sp_{t,t-1}\sigma_t^{-1}\right)\right] + \left(1-\lambda\right)sp_{t,t-1} \tag{4}$$

where p denotes probability. In equilibrium, competition among market makers will drive this expected profit to zero. Since all expectations are dependent upon time $t-1$ information, in equilibrium the spread must change in proportion to the conditional standard deviation of the fundamental value of s so that equation (4) may be rewritten in terms of the spread as:

$$SP_{t,t-1} = \Gamma\sigma_t \tag{5}$$

where $\Gamma = \dfrac{2\lambda E_{t-1}\left[Z_t \mid sp_{t,t-1}\sigma_t^{-1} < Z_t\right]\left[1 - p\left(Z_t < sp_{t,t-1}\sigma_t^{-1}\right)\right]}{1 + \lambda - 2\lambda p\left(Z_t < sp_{t,t-1}\sigma_t^{-1}\right)}$.

The quoted spread widens with increases in volatility due to the adverse selection problem associated with informed trading. In order to protect against a surprising move in the exchange rate, market makers widen their spreads as the probability of quoting to an informed trader increases.

The model suggests the interpretation of the exchange rate process following two states. State 1 is the usual state of liquidity-motivated trades where the exchange rate moves randomly with a relatively small variance. State 2 is the state containing the informed trades where the exchange rate change may be characterized by relatively large swings and variance is higher. We assume that there exists an unobserved state variable $state_t$ that takes on the value one or two when the observed change in the exchange rate is drawn from a $N(\mu_1, \sigma_1^2)$ distribution or a $N(\mu_2, \sigma_2^2)$ distribution, respectively. Following Hamilton, we postulate that the unobserved state variable evolves as a Markov chain:

$$\begin{aligned} p(s_t = 1 \mid s_{t-1} = 1) &= p_{11} \\ p(s_t = 2 \mid s_{t-1} = 1) &= 1 - p_{11} \\ p(s_t = 1 \mid s_{t-1} = 2) &= 1 - p_{22} \\ p(s_t = 2 \mid s_{t-1} = 2) &= p_{22} \end{aligned} \qquad (4)$$

With regard to the means, it is generally expected that exchange rate returns have a zero mean, so that μ_1 and μ_2 are expected to equal zero. However, it is known that exchange rates may follow runs or swings over time, so that on any given day, the values of μ_1 and μ_2 may well be non-zero.

Before proceeding to the estimation of the spread equation, the approach to modeling regime switching is discussed. An excellent resource regarding the estimation of switching-regime models, is provided in Hamilton (1994). Here we briefly sketch the procedure employed. We want to estimate the exchange rate returns as switching between a high and low volatility state on FOMC days. Associated with such switches, quoted exchange rate bid-ask spreads are expected to rise and fall as market participants change the probabilities of being in one or the other state. A bivariate regime-switching model for the exchange rate and the spread is estimated. Fourteen population parameters are sufficient to describe the distribution of s_t given $state_t$, the distribution of $state_t$ given $state_{t-1}$, and the unconditional distribution of the state of the first observation. The fourteen parameters are contained in:

$\theta = (\mu_1, \mu_2, \sigma_1, \sigma_2, p_{11,} p_{22})'$.

The elements of θ include 2x1 μ vectors of means for the exchange rate return and spread; 2x2 σ variance-covariance matrices; and scalar values for p_{11} and p_{22}. Given estimates of the θ parameters, one can calculate the probability that the process was in a particular state

$state_t$ at time t on the basis of the information through t. Our goal is to apply this procedure to identify shifts in regime that are consistent with the higher volatility associated with informed trading on FOMC meeting days and relate such switches to changes in bid-ask spreads.

Estimation of the θ vector is via the EM algorithm described in Hamilton (1990). Given the desire to relate the states and probabilities to the spread, the probabilities are computed using filtering based upon current and past observations rather than smoothing using any future observations. Standard errors are computed from the inverse of the Hessian matrix of second derivatives. Additional details related to estimation will be discussed below.

III. EMPIRICAL ANALYSIS

III.A. Data to be Analyzed

Model estimation requires data on exchange rate quotes and dates and meeting times for the FOMC. The exchange rate data are derived from the tick-by-tick indicative quotes on the German mark price of the U.S. dollar (DEM/USD) from Reuters.[4] We use the midpoint of the bid and ask prices that are time-stamped to the second they appeared on the Reuters screen. The last quote of each five-minute interval is used to create a data set of five-minute periodicity. Spreads are computed as averages over each 5-minute interval and are measured in basis points. Since the Reuters data employed in this study are indicative quotes displayed to the market at large, they will bracket the firm quotes made in bilateral trading. Since there are no historical data of firm quotes available at the frequency we require for our

[4] The data were obtained from Olsen & Associates in Zurich.

sample period, we utilize the indicative quotes and believe they are reflective of the general conditions in the market.[5]

Switching-regime models are useful for representing data that display characteristics such as asymmetry, leptokurtosis, and conditional heteroskedasticity. Table 1 presents descriptive statistics for the sample of exchange rate returns considered. Returns are measured as 10,000 times the change in the log of the mark/dollar exchange rate. The scaling by 10,000 reflects the small magnitude of high-frequency exchange rate changes and the need to have well-conditioned data for the computation of the Hessian matrix associated with model estimation. The table shows the usual features of high-frequency exchange rate data. In particular, one sees that the distributions tend to be characterized by fat tails and non-normality. The Jarque-Bera statistic, used to test the null hypothesis of normality, provides support for the rejection of the hypothesis for all days.

Table 2 lists the FOMC meeting days studied along with the start and end times, the expected interest rate change and the actual change. We choose a period where there is a clear expectation of FOMC rate increases. Each meeting was approached with the expectation that the outcome would be either a rise in the federal funds rate or else no change. There was a zero probability of a rate decrease.

Information on meeting times was taken from Reuters' Money Market Headline News. The "headline news" screen reports activity of interest to traders and reflects the time that traders would see reports of the meeting times on their monitors. In addition, we also list the official ending times as reported in the FOMC meeting minutes. While one might expect that the news service announcements of a meeting end should follow the official ending times, Table 2 indicates that on three meeting days, the news service reports lead the

[5] A few studies have used firm quotes from electronic broking systems to demonstrate that such quotes have narrower spreads. While we should expect firm quotes in bilateral dealing to be narrower than indicative quotes, a problem with comparing spreads from the electronic brokerage system with the direct dealing network is that the broker screen reveals the "inside" spread or the best bid and offer available across all quoting dealers at any point in time, while the indicative quotes are postings of individual dealers.

official meeting time ending. We have no explanation for the differences between official meeting times and the Reuters reports except for the fact that the Fed spokesperson making the announcement of the meeting end typically appears before the press well after the official end. Since we believe that the Reuters reports will coincide more closely with information available to market participants, we focus on these times rather than the official ending times in our empirical work below.

The fifth column of Table 2 gives the magnitude of the expected change in the interest rate (as reported in the *Wall Street Journal*) while the sixth column reports the actual change. For eight of the ten meeting days, the *Wall Street Journal* reports that the general outlook in the market was an expectation of a Fed interest rate hike.[6]

III.B. Model Estimation: Timing of Regime Switches

The model discussed in section II is estimated with two related goals in mind. First, identifying points in time when the exchange rate regime switches from state 1 to state 2. Second, estimating the effect of shifts between the high and low volatility regime on the bid-ask spread. Estimation is carried out separately for each individual meeting day and estimation time runs from 8:00-21:00 GMT.[7]

First we focus on the estimation of the bivariate model and associated θ vector. Table 3 reports the estimation results. With respect to the exchange rate returns, the means of both states are generally not significantly different from zero but the associated variance of state 2, when informed trading is presumed to have occurred, is generally estimated to be substantially higher than that of state 1. The one day that differs is December 20, 1994.

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[6] For an economic model of federal funds rate target expectations see Jorda and Hamilton (2002). They provide a model of the federal funds target as a marked point process where they predict both the "points" at which the target rate is changed and the "marks" or size of change.

[7] Estimation was carried out by modifying GAUSS files generously provided on James Hamilton's web site that use numerical optimization to maximize the likelihood function. Specifically, the programs EMEST and SMOOTH3 were adapted for use by modifying the

However, as will become apparent shortly, this pre-Christmas day when no Fed policy actions occurred is unlike the others in that the exchange rate traded in a narrow range all day and the data are essentially consistent with only 1 state.

With regard to the bid-ask spread, Table 3 shows that the spreads widen significantly in state 2 relative to state 1. This is consistent with what theory predicts; bid-ask spreads on currencies widen with greater volatility of exchange rates. We will explore the spread determinants in greater detail later.

The estimated Markov-switching models allow inference regarding the timing of informed trading activity. In particular, it is useful to know the estimates of being in the high-exchange-rate-volatility state 2 at each time period. If the outcomes of FOMC meetings provide a public information signal shared by all, we might expect to see exchange rate shifts at the meeting end and no other obvious patterns in informed trading activity during the day. Shifts to the informed trading state during meeting times may indicate that informed trading is occurring prior to meeting end. There is much evidence of regime shifts consistent with informed trading prior to meeting end. Let us characterize the regime-switching patterns and major public news for each day:

February 4,1994: There are several sharp spikes to state 2 during the pre-meeting time of European trading and then a sustained shift to state 2 for about an hour prior to the meeting start. During the time of the meeting, there are repeated shifts to state 2 that persist for 10-15 minutes. At the meeting end, there is another shift to state 2 that is sustained for most of the rest of the day consistent with the outcome being news to the market. The shift to state 2 in the U.S. morning is associated with the employment report that was released at 13:30 GMT that day. The slower-than-expected job growth report led some Fed watchers to conclude that the FOMC would leave rates unchanged. In fact, following the employment data release Merrill-Lynch issued a bulletin stating that "Weather-distorted jobs report

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bivariate versions of these programs to incorporate the spread as well as the exchange rate returns.

delays Fed tightening." Of course, that forecast turned out to be wrong as the FOMC raised rates later that morning. The persistence of state 2 following the meeting end suggests that the rate increase was a surprise. Summarizing the percentage of observations in each sub-period estimated as state 2 (defined as a greater than 50 percent probability of state 2): pre-meeting, 31%; meeting, 59%, post-meeting, 95%.

March 22,1994: A switch to regime 2 occurs twice during the meeting followed by a return to state 1 prior to meeting end and then at meeting end, there is another brief switch to regime 2. A review of Bloomberg and Reuters reports reveals no significant news prior to the meeting end. Summarizing the percentage of observations in each sub-period estimated as state 2: pre-meeting, 0%; meeting, 29%, post-meeting, 53%.

May 17,1994: There is a switch to regime 2 in the middle of the meeting for about two hours. Then at the meeting end there is another return to regime 2. A review of Bloomberg and Reuters reports reveals no significant news prior to the meeting end. Summarizing the percentage of observations in each sub-period estimated as state 2: pre-meeting, 0%; meeting, 35%, post-meeting, 25%.

July 6,1994: This day is unlike the rest in that there are many brief switches to state 2 in the London morning. The European morning regime shifts are likely associated with the German unemployment news release and a Bundesbank repo rate decrease. There are several sharp spikes to state 2 during the meeting and then during the last two hours of the meeting, regime 2 persists. After a brief return to regime 1 before the meeting end, there is a shift to state 2 for more than an hour when the meeting ends. A review of Bloomberg and Reuters reports reveals no significant news that day other than the European morning events. Summarizing the percentage of observations in each sub-period estimated as state 2: pre-meeting, 34%; meeting, 72%, post-meeting, 52%.

August 16,1994: There is a switch to regime 2 about 1.5 hours prior to the meeting end and this regime persists for the rest of the day. A review of Bloomberg and Reuters reports reveals no significant news prior to the meeting end. Summarizing the percentage of observations in each sub-period estimated as state 2: pre-meeting, 0%; meeting, 30%, post-meeting, 100%.

September 27,1994: There is a shift to regime 2 about 2 hours after the meeting start. Another shift to state 2 occurs about an hour later. Then at the meeting end there is another shift to state 2 that lasts less than an hour. The early shift to state 2 after the meeting start may be associated with the release of news that consumer confidence fell for the third month in a row. Summarizing the percentage of observations in each sub-period estimated as state 2: pre-meeting, 0%; meeting, 29%, post-meeting, 33%.

November 15,1994: There is a switch to state 2 early in the London morning and then again right after the meeting starts. There are repeated shifts to state 2 during the meeting and then a state 2 shift at meeting end that lasts about an hour. While retail sales news was released at 13:30 and industrial production news was released at 14:15, it appears that there was no significant market reaction. In fact, the next day *The Wall Street Journal* reported that "A smorgasbord of economic statistics came and went in the morning, but traders largely shrugged off the news." Summarizing the percentage of observations in each sub-period estimated as state 2: pre-meeting, 3%; meeting, 42%, post-meeting, 78%.

December 20,1994: On this day when no action was taken the data are relatively uninformative regarding differences in states. The exchange rate trades within a narrow range with relatively small variance all day. The estimated state oscillates back and forth between states all day. In a sense, the evidence is more consistent with one state prevailing over the day. The next day, *The Wall Street Journal* confirmed this view by reporting that "The dollar was mixed in sleepy pre-holiday dealings yesterday, unmoved by news.....The Fed stayed with no rate increase ...Everybody just breathed a sigh of relief and went back to sleep." Summarizing the percentage of observations in each sub-period estimated as state 2: pre-meeting, 69%; meeting, 48%, post-meeting, 63%.

February 1,1995: There is a switch to regime 2 right before the end of the meeting that persists through most of the rest of the day. There was no relevant public news that day.

Summarizing the percentage of observations in each sub-period estimated as state 2: pre-meeting, 0%; meeting, 6%, post-meeting, 68%.

March 28, 1995: There is a brief switch to state 2 during the early London morning. During the meeting, there are repeated brief shifts to state 2. After the meeting, there are two brief shifts to state 2. Consumer confidence news was released at 14:00 and there were no other significant news announcements during the day. Summarizing the percentage of observations in each sub-period estimated as state 2: pre-meeting, 3%; meeting, 26%, post-meeting, 25%.

This research began with the expectation of finding results consistent with the meeting outcome being news to the market. A shift to the informed trading state was expected on the basis of the news of the FOMC policy decision. However, the data suggest that traders are adjusting positions on more than just public news on meeting days. The evidence is consistent with position taking during the meeting along with some later trading associated with the news content at the meeting end. Our results indicate that FOMC meetings are, indeed, associated with shifts in regime beyond that just coming from the meeting outcome or other public news. While we can rule out other kinds of public information being associated with such meeting-time shifts, exactly what is causing the shifts is, of course, unknown. Furthermore, it is puzzling that such shifts occur during the meetings rather than earlier in the morning prior to meetings or even on prior days. The estimation results would be consistent with intra-meeting information leaks from the FOMC, rumors circulating in the market, and/or traders reading information content into the goings-on around the Fed during meetings. It is known that there was a period when Fed-watchers thought the size of Alan Greenspan's briefcase on meeting days was informative in that a thin briefcase signaled no action and a thick briefcase signaled action. Given the lengths to which the market may go to distill information in noisy signals coming from briefcase size, coffee or restroom breaks, or other seemingly silly signals, one cannot rule out that market participants are treating some seemingly innocuous activity as informative.

III.C. Evidence from a Control Sample

In order to see if the exchange rate dynamics just reviewed are, indeed, due to FOMC meetings on those days, a control sample is examined. If the exchange rate dynamics on non-FOMC days are much like those observed on FOMC days, then we would question the foregoing interpretation of private-information-based trading occurring during the meeting as suggested by the results reviewed so far. Specifically, we match each FOMC day with the same day of the week in the week following each meeting. The control sample, then, will control for any day-of-the-week effects and will allow an examination of the exchange rate evidence for non-FOMC days compared to meeting days. The focus should be on what happens relative to the usual time of FOMC meetings.

Bivariate Markov-switching models were estimated for each of the control days. Of particular interest is whether there is evidence of a switch to state 2 after 14:00 (13:00 for days on daylight saving time) that cannot be explained by public news arrival. If so, then we would have to conclude that the exchange rate dynamics for FOMC days are really no different than any other days. However, if the control day switches to state 2 are explained by public news arrival and/or switch times occur outside the usual FOMC meeting times, then the evidence for FOMC days may be considered as consistent with private-information-based trading related to the meeting.

February 11, 1994: There is a switch to state 2 at 12:15 for which no news is apparent. However, this switch lags German retail sales news. There is another switch to state 2 at 13:30 associated with the U.S. PPI and retail sales releases. Following this news, state 2 persists for over an hour. There is an additional switch to state 2 at about 16:00 for which no news is apparent. This control day most closely resembles the pattern expected on FOMC days.

March 29, 1994: This day is best described as ongoing oscillation between state 1 and state 2. This is reflected in the estimated probabilities p_{11} and p_{22} equaling 0.57 and 0.47 respectively. Important public news on this day is U.S. consumer confidence news at 15:30. However, there is no obvious response to this news that differs from the rest of the day. Additional important news occurs at 18:05, when Bloomberg reports Fed Governor Lawrence Lindsey is giving a speech where he states that the Fed should not have to raise interest rates as much in the future as it has in previous inflation-fighting episodes because of the swift action taken by the Fed nowadays. Again, there is no different pattern of switching between states around the time of this news.

May 24, 1994: This day of low volatility is also characterized by frequent oscillation between states and there are no different patterns during the time period when the FOMC would typically meet. Bloomberg reports one major piece of relevant news at 15:50 associated with a speech by U.S. Trade Representative Kantor where he states that the U.S. and Japan have ended a three-month impasse in trade negotiations. Earlier, Bloomberg had reported that some traders were awaiting Kantor's press conference before trading dollars. However, there is no different pattern of regime switching associated with this news.

July 13, 1994: This day is unique in that state 1 persists for the entire day except for 3 sharp spikes to state 2. One of these spikes occurs at 12:40 following the German wholesale price release. At 13:30 the U.S. CPI news and by retail sales news are released but there is no switch in regime. There is a sharp spike to state 2 at 15:35 for which no news occurs. Finally, at 19:40 another switch occurs that lasts for about 15 minutes. This appears to be due to the announcement that U.S. currency would be redesigned to thwart counterfeiting (interestingly, the dollar briefly depreciated upon this news).

August 23, 1994: A switch to state 2 occurs at 12:50 and lasts for over an hour. There is no news but both Reuters and Bloomberg report that this is due to U.S.-opening covering of positions following heavy Bank of Japan intervention. At 15:40, another hour-long switch occurs for which there is no public news.   Finally, at 18:50, a 25 minute switch is associated with news of a strike at a General Motors plant.

October 4, 1994: The data oscillate regularly between states over the entire period on this day of very low volatility.

November 22, 1994: Again, there is no informative pattern as the data oscillate regularly between states over the entire period on this day of very low volatility. Potentially relevant news on this day is at 12:50 as Bundesbank President Tietmeyer gives a speech that continues generating Reuters headlines for over an hour. The speech includes comments on a strong mark being in Germany's interest along with comments on M3 targets and appropriate interest rate policy. Later in the day, the U.S. stock market suffered its largest drop in 9 months and Bloomberg reports that the last hour of trading was a "ferocious selling frenzy." Yet, the foreign exchange market did not reflect any persistent pattern of volatility associated with these events as the regime switches back and forth regularly over the day.

December 27, 1994: There is essentially 1 state on this day of very low volatility.

February 8, 1995: There is an ongoing pattern of oscillation between states over the entire day on this day of low volatility.

April 4, 1995: Most of this day, from early morning to evening, is spent in state 2 with but sharp spikes to state 1 closely followed by a return to state 2. Important news exists at the morning start of sample following major BOJ intervention and lasts until 10:00. The BOJ had intervened earlier that day and that followed heavy U.S. intervention on the prior day. So there was an expectation in the market of further intervention. Then at 18:45 additional potentially important news is Kantor's speech announcing no progress in talks with Japan to open the Japanese auto market. News reports stated that traders believed U.S. policy was aimed at talking down the dollar to pressure Japan in the trade talks.

II.E. A Comparison of FOMC and Control Days

In this section, a summary of the differences between the exchange rate dynamics on FOMC days and control days is provided. FOMC meetings always start at 14:00 GMT (13:00 DST). The ending time varies, but over the sample used in this study, the mean ending time was 18:49 for meetings during standard time and 18:11 for DST meetings. On two FOMC days, July 6, 1994 and December 20, 1994, there is much oscillation between states all day. Although, July 6 has a persistent run of state 2 for over an hour late during the meeting time that continues well past the meeting end. Eight of the ten FOMC days may be characterized as switching from a morning where state 1 dominates to state 2 during the meeting and/or at the meeting end. Six of these days have a dramatic difference between the estimated regimes when morning and meeting times are compared. These are days with a switch to the informed trading state during the meeting time. On one day, the switch occurs prior to the meeting start due to news (Feb. 4, 1994) and on another day, the switch occurs at meeting end (Feb. 1, 1995). Of the six days with dramatic intrameeting time state switches, five have no public news associated. If we count meeting time as the period 14:00 to 18:40 (13:00 to 18:11 DST), then two of the control days have switches to the informed trading state during normal meeting time that differs from the pattern over the rest of the day. Only one of these days has no public news associated with the switch. So the evidence is consistent with FOMC days having a greater tendency for the informed-trading state to emerge during the meeting time and emerge independent of public news.

Control days tend to have less volatility. The state 2 exchange rate variance estimated for FOMC days has a mean of 97.8 and a median of 85.5. For control days, the mean is 46.9 and median is 26.5. Low volatility days are consistent with liquidity-motivated trading so that the exchange rate moves randomly in a narrow band.

An alternative to the private information-based story told so far is that the switches to state 2 could be related to liquidity and inventory control completely apart from any information-based motives. Suppose that in the hours prior to the end of an FOMC meeting market depth falls as traders are reluctant to take positions given the uncertainty of the meeting outcome. In this case, we could observe more volatile exchange rates based only on liquidity-motivated trades as dealers must be induced to take a position in a thin market. Without actual trade data (which are proprietary information in FX trading), one must exercise caution in discussing liquidity in this market. A few studies have obtained a snapshot of a portion of the market from Reuters electronic trading via the direct-dealing or electronic brokerage networks. A necessary limitation of such an analysis, is that only a fraction of the actual market trade activity is recorded and only for a short period of time. A particularly useful study is that of Danielsson and Payne (2002), who study the indicative quotes from Reuters along with the electronic brokerage data for one week. Of note for the present analysis is that the indicative quote frequency closely matches the aggregate liquidity demand on the electronic brokerage. One may have some confidence that quote frequency is a reasonable proxy for intradaily market depth. With this in mind, a comparison of quote frequency on FOMC days and control days is constructed. Table 4 contains the average number of quotes per minute during FOMC meeting times for meeting days and control days. The meeting times are as given in Table 2 using the Reuters announced ending times. The control days use the mean ending times of 18:49 GMT for standard-time meetings and 18:11 for DST meetings. Table 4 shows quite clearly that quote frequency during FOMC meetings gives no support to the hypothesis that low liquidity is behind the greater volatility during FOMC meetings. The average number of quotes during FOMC meetings is quite similar to that of control days—sometimes there is a bit higher quote frequency during the FOMC meeting than the control day and sometimes there is a bit less. So low liquidity and inventory-based trading seem unlikely to be the source of the exchange rate dynamics observed during FOMC meetings.

Taken as a whole, it seems fair to say that FOMC days are different from other days in terms of volatility dynamics and provide a useful laboratory for studying the issues under investigation here; namely private-information-motivated trading. We next turn to a more in-depth analysis of the evidence related to the intradaily spreads on FOMC days.

IV. Bid-Ask Spreads and FOMC Days

The bivariate Markov-switching model estimated in Section III indicated that bid-ask spreads are significantly higher in the high-volatility informed-trading state 2 than in the low volatility state 1. This is as expected. If informed traders are taking positions based on expectations of FOMC policy changes, we should expect dealers' spreads to reflect the increased probability of quoting to an informed trader. During periods in the day when we expect the market to be relatively rich in informed trading, we would expect to see spreads reflect the potential for adverse selection. Of course, the spreads will also reflect inventory control along with the cost of providing dealer services.

We now turn to a more in-depth exploration of the spread dynamics on FOMC days. In Section II, the spread was derived as a positive function of exchange rate volatility as stated in equation (5). The Markov-switching methodology suggests a parameterization of volatility as a determinant of the spread as

$$SP_{t,t-1} = \Gamma\sigma_t = \Gamma\left\langle \left\{ \left[p_{11}\sigma_1 + \left(1 - p_{11}\right)\sigma_2 \right] \mid state_{t-1} = 1 \right\} + \left\{ \left[p_{22}\sigma_2 + (1 - p_{22})\sigma_1 \right] \mid state_{t-1} = 2 \right\} \right\rangle . \quad (6)$$

Given the estimates from the bivariate model of regime switching of σ_1, σ_2, p_{11}, and p_{22}, along with the identification of the state at $t-1$ one can then use the probabilities and the variance of the exchange rate in each state to derive the expression for the expected exchange rate volatility at time t, as given in equation (6), to use in estimating a model of the spread as a function of the expected state. The probabilities and variances are passed to a maximum likelihood procedure appended to the bivariate EM procedure of Hamilton to estimate the spread equation.

We denote the probability-weighted variance of equation (6) as σ^*. In addition, we expect spreads to have persistence over time so the lagged spread, $SP_{t-1,t-2}$, is included to guard against the state variable (which depends on past information) just proxying for the persistence in the spread. Our empirical estimates will indicate if σ^* accounts for the spread movements based upon adverse-selection potential and whether there is an independent role for σ^* beyond the effect of including the lagged spread. Finally, a dummy variable, *dumend*, that switches from zero to one at the announcement of the meeting end is interacted with the σ^* variable to test whether the relationship between the spread and state is dominated by meeting-end news or whether this effect exists prior to the meeting end. The model is estimated over the same daily period as earlier, 8:00-21:00 GMT.

Estimates of the spread equation are presented in Table 5. Three different specifications are included to explore the robustness of the results to alternative specifications. The first coefficient estimates reported for each meeting day has the σ^* variable interacted with the dummy for meeting end, *dumend*. This provides a test of whether the effect of volatility differs at the meeting end from the rest of the day. The next set of results has *dumend* enter by itself. This provides inference on whether there is a shift in the constant term or the average level of the spread once the meeting has concluded. The third set of results reported for each meeting day replaces the volatility variable with the probability of being in state 2, *pstate2*. This provides inference on the spread effect of changes in the probability of being in the high-volatility informed trading state.

The results of the alternative specifications differ somewhat across FOMC meeting days. The lagged spread is only statistically significant for two days and with a negative sign. So, conditioning on expected volatility and meeting end, the spreads tend to exhibit a lack of persistence. Of particular interest is the coefficient estimated for σ^*, the state-weighted expected volatility variable. Focusing on the first set of results reported for each day, it is seen that the volatility coefficients are positive as expected and statistically significant for all but two days. For the two days where the first specification has an insignificant effect for volatility, February 4, 1994 and November 15, 1994, volatility is seen to be significantly positive once the meeting ends. This is seen by the statistically significant effect of the dummy for meeting end that is interacted with the volatility variable.

The second set of results reported for each day, show volatility having a statistically significant positive effect for all but November 15, 1994. The dummy variable for meeting end is significantly positive for six days. The general inference drawn from these results is that spreads increase with increases in volatility and there is often an additional increase following the end of the FOMC meeting.

The third set of results reported for each day in Table 5 replaces the volatility variable σ^* with a variable measuring the probability of being in the informed trading state, *pstate2*. It is seen that the *pstate2* variable is significantly positive for all days except for November 15, 1994. On this one day, the evidence is consistent with the market widening spreads significantly only at the news of the meeting end. For all other days, the higher the probability of being in the informed trading state, the wider the spread. On four of these days, there is an additional increase in the spread associated with the end of the meeting. The positive signs for the *pstate2* variable are consistent with informed traders having worthwhile information regarding dollar movements in state 2, the informed state, which leads dealers to protect against adverse selection by raising the spread.

To test the hypothesis that the probability of being in the informed state 2 is greater during FOMC meetings than at other times of day, an additional equation with *pstate2* as the dependent variable is added to the model. This equation models the probability of being in the informed trading state as a linear function of a dummy variable for the times of the FOMC meeting, *dummeet*, along with *dumend* and a constant. The equation is estimated jointly with the spread equation using maximum likelihood. Since *dumend* appears as a determinant of the probability of being in the informed trading state in the *pstate2* equation, it is now omitted from the spread equation. Estimation results are reported in Table 6.

The last column of Table 6 contains the coefficients estimated for the *dummeet* variable. The evidence is generally consistent with a significantly higher probability of being in the informed trading state 2 during the time of the FOMC meeting. The two exceptions are July 6, 1994 and December 20, 1994. In the case of July 6, 1994 there is a switch to state

2 for the last two hour of the meeting that persists well past the meeting end. If *dumend* is omitted from this model, then the coefficient estimated for *dummeet* is 0.0114 with a p-value of 0.09. For December 20, 1994, the data are relatively uninformative about the regime as this day of pre-holiday trading had the lowest volatility of all days and the estimated state swings back and forth between states all day. With these two exceptions, the evidence supports a greater likelihood of observing the informed trading state during the time of the FOMC meeting.

Regarding the other results reported in Table 6, the estimates of the b_1 coefficient on *dumend* are consistent with the news of the meeting outcome being price relevant. Note that for four meeting days, this variable was omitted. In these cases, the correlation matrix of the parameters indicated correlations between *dumend* and *dummeet* of -.99. The log-likelihood values of the models were identical with or without *dumend*. Of course, had *dummeet* been omitted instead, then the coefficient estimated for *dumend* would have been statistically significant except in the case of December 20, 1994. In the spread equation, the lagged spread coefficient is negative in the two cases where it is significant and the coefficient on *pstate2* is positive and significant with the exceptions of September 27, 1994 and December 20, 1994.

Taken as a whole, the empirical results support a view of bid-ask spreads on currency rising with a greater probability of being in the informed trading state. In turn, the probability of being in the informed trading state rises with the time of the FOMC meeting and the meeting end. This suggests that FOMC meeting outcomes represent news that is priced and associated with higher exchange rate volatility and wider spreads. In addition, the data support a view of market participants taking positions during the meeting that generates greater exchange rate volatility and wider bid-ask spreads prior to any public news release.

V. SUMMARY

FOMC meeting days, when there may be a change in interest rates, provide a natural laboratory for studying exchange rate dynamics when there is an ongoing policy meeting that may change a fundamental determinant of exchange rates. We analyze the exchange rate evidence for ten FOMC meeting days following the change in FOMC policy in early 1994 where federal funds rate target changes are announced to the market at the meeting conclusion. Our analysis focuses on the time of day when informed position taking occurs in the mark/dollar foreign exchange market via an analysis of the mean and variance of exchange rate returns and bid-ask spreads.

To estimate the time of informed trader position taking, we estimate a switching-regime model of microstructure-motivated exchange rate determination using five-minute observations on the mark/dollar exchange rate for each FOMC meeting day over the period from February 1994 to March 1995. Our prior belief was that FOMC days would be characterized by the exchange rate trading in a narrow range or low-volatility regime with narrow spreads prior to the end of the meeting when a shift to a high-volatility regime and wider spreads would occur as the meeting outcome results in trading motivated by the news release. In general, the evidence is consistent with the meeting outcome being price-relevant news not fully anticipated by the market. However, a more provocative finding is that there are switches to the informed-trading regime well before the meeting end. The switch to state 2 occurred from 20 minutes to 4 hours and 45 minutes prior to the meeting end with a mean switching time of about 3 hours prior to meeting end. A careful review of the news on each day suggests that these results cannot be explained as the response to public information shared equally by all. This is consistent with a market where informed traders are taking positions in advance of the meeting end based upon their expectations of the outcome. A comparison with a control sample suggests that these results do not represent the everyday behavior of the market. FOMC days are special.

If dealers believe that informed traders are active, they will tend to widen spreads to protect against adverse selection in quoting. We examine the evidence of such behavior on FOMC days by jointly estimating the spread mean and variance with the exchange rate mean and volatility in the Markov-switching framework. The general finding is that the greater the probability of being in state 2, the informed-trading state, the greater the spread. This result is consistent with market-makers widening spreads to protect against adverse selection as the probability of quoting to an informed trader increases.

Overall, our evidence indicates that FOMC days provide a useful setting for examining important hypotheses regarding exchange rate determination in a microstructure setting. The market appears to generally anticipate meeting outcomes well before the conclusion of the meetings. Public information arrival cannot explain all the shifts to the informed trading states before meetings end. Relating our estimates of the probability of being in the informed trading state to quoted spreads, spreads appear to widen as the probability of quoting to an informed trader increases. Taken as a whole, it appears that exchange rates on FOMC days provide evidence of a) a market with normal periods of liquidity-motivated trading associated with exchange rates trading in a narrow band with low volatility and narrow spreads alternating with b) periods of informed trading activity where volatility is significantly higher and spreads are significantly wider. A particularly interesting finding is that the informed-trading regime tends to emerge during the time that the FOMC meets.

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Table 1: Descriptive Statistics for Exchange Rate Returns

The table presents descriptive statistics for the returns (first difference of the log times 10,000) on the mark/dollar exchange rate on days of FOMC meetings after a policy of announcing meeting outcomes was instituted. The data exhibit non-normality, as summarized by the statistically significant value of the Jarque-Bera statistic.

Date	Mean	Std. Dev.	Skewness	Kurtosis	Jarque-Bera (p-value)	
4 Feb. 94	0.603	8.347	-0.430	14.913	915.38 (0.00)	
22 Mar. 94	-0.128	6.005	-0.484	17.283	1221.1 (0.00)	
17 May 94	0.149	4.144	2.218	18.438	1419.0 (0.00)	
6 July 94	-0.097	5.942	0.300	4.408	12.791 (0.00)	
16 Aug 94	-0.447	11.393	0.233	16.865	946.18 (0.00)	
27 Sep. 94	-0.380	5.742	-1.833	15.376	901.55 (0.00)	
15 Nov 94	0.543	5.949	3.175	29.725	4433.0 (0.00)	
20 Dec 94	-0.090	2.210	0.054	3.961	5.498 (0.06)	
1 Feb. 95	-0.165	4.327	0.256	6.146	65.620 (0.00)	
28 Mar. 95	-0.877	5.535	-0.957	5.905	71.118 (0.00)	

Table 2. FOMC Meeting Days, Times, and Action

Date	Meeting time (GMT)**		Change in fed funds target	
	Starts	Ends	Expected*	Actual
4 Feb. 94	14:00	16:13 (16:45)	0.25%	0.25%
22 Mar. 94	14:00	19:29 (19:05)	0.25%	0.25%
17 May 94	13:00	18:34 (17:45)	0.50%	0.50%
6 July 94	13:00	18:26 (17:35)	0-0.25%	0.00%
16 Aug. 94	13:00	17:22 (17:30)	0-0.25%	0.50%
27 Sep. 94	13:00	18:24 (18:00)	0.00%	0.00%
15 Nov. 94	14:00	19:21 (19:05)	≥0.50%	0.75%
20 Dec. 94	14:00	19:19 (17:45)	0-0.50%	0.00%
1 Feb. 95	14:00	19:17 (20:20)	0.50%	0.50%
28 Mar. 95	14:00	19:15 (18:15)	0.00%	0.00%

* The expected change in the federal funds rate as reported in *The Wall Street Journal*
**Reuters reported time and (official ending time).

Table 3. Estimates of Bivariate Markov-Switching Models for Exchange Rate and Spread

The table reports estimates of a model of regime switching consistent with informed traders taking positions and increasing volatility on FOMC days. We assume that there exists an unobserved state variable $state_t$ that takes on the value one or two when the exchange rate returns and spread are drawn from a $N(\mu_1,\sigma_1^2)$ distribution or a $N(\mu_2,\sigma_2^2)$ distribution, respectively, where μ is a 2x1 vector and σ^2 is a 2x2 matrix. Only variances are reported in order to save space. State 1 is the usual state of liquidity-motivated trades where the exchange rate moves randomly with a relatively small variance. State 2 is the state containing the informed trades where the exchange rate change may be characterized by relatively large swings and variance is higher.

DATE	μ_1		μ_2		σ_1		σ_2		p_{11}	p_{22}	Log L
	ds	*SP*	*ds*	*SP*	*ds*	*SP*	*ds*	*SP*			
4 Feb. 94	0.046	6.436	0.925	9.008	5.214	1.318	109.6	4.155	0.859	0.907	-535
	(0.24)	(0.20)	(1.09)	(0.26)	(1.23)	(0.38)	(17.3)	(0.69)	(0.06)	(0.04)	
22 Mar 94	-0.149	6.906	0.322	8.931	8.714	2.925	133.7	1.885	0.974	0.890	-458
	(0.27)	(0.16)	(2.07)	(0.27)	(1.19)	(0.38)	(35.7)	(0.53)	(0.02)	(0.06)	
17 May 94	-0.125	6.032	0.826	8.139	6.565	2.828	61.17	2.394	0.975	0.880	-425
	(0.25)	(0.15)	(1.55)	(0.33)	(1.03)	(0.36)	(17.1)	(0.71)	(0.02)	(0.07)	
6 Jul 94	-0.720	5.758	0.697	8.491	15.21	1.380	42.84	2.174	0.780	0.817	-502
	(0.56)	(0.18)	(0.78)	(0.34)	(6.21)	(0.30)	(7.28)	(0.78)	(0.08)	(0.09)	
16 Aug 94	-0.218	7.085	0.819	9.456	7.053	3.350	257.8	5.178	0.991	0.986	-536
	(0.28)	(0.21)	(2.10)	(0.30)	(1.14)	(0.51)	(49.1)	(0.94)	(0.01)	(0.02)	
27 Sep 94	0.010	6.228	-2.270	7.167	5.131	2.983	133.6	1.766	0.975	0.873	-417
	(0.08)	(0.15)	(2.24)	(0.27)	(0.68)	(0.37)	(37.8)	(0.50)	(0.01)	(0.07)	
15 Nov 94	0.031	6.474	1.638	7.563	4.558	3.968	102.2	3.631	0.944	0.866	-475
	(0.21)	(0.20)	(1.50)	(0.33)	(1.16)	(0.55)	(26.5)	(0.77)	(0.03)	(0.07)	
20 Dec 94	-0.350	4.413	0.043	7.874	3.250	0.592	5.584	2.099	0.416	0.632	-371
	(0.28)	(0.14)	(0.29)	(0.24)	(0.693)	(0.15)	(0.83)	(0.50)	(0.08)	(0.07)	
1 Feb 95	-0.030	6.245	-1.073	9.280	12.21	2.527	60.51	1.869	0.984	0.879	-448
	(0.37)	(0.14)	(1.89)	(0.32)	(1.50)	(0.32)	(19.4)	(0.65)	(0.01)	(0.08)	
28 Mar 95	-0.290	6.802	-2.686	8.861	17.96	3.280	69.45	1.886	0.920	0.669	-501
	(0.41)	(0.21)	(1.83)	(0.42)	(2.56)	(0.50)	(21.2)	(0.58)	(0.05)	(0.17)	

note: standard errors are in parentheses

Table 4. Quote Frequency on FOMC Days and Control Days

The table reports the average number of mark/dollar quotes per minute posted on the Reuters indicative quoting screen during FOMC meetings. Meeting times are as given in Table 1 using the Reuters announcement of the ending time. For each meeting day, a control day is selected as one week later on the same day of the week. Control day quote frequency is computed using the mean meeting-ending time of 18:49 GMT across all meetings held during standard time and 18:11 for the mean ending time of the four meetings held during daylight saving time (May through September).

Meeting Day	Meeting	Control
4. Feb. 94	7.0	4.0
22 Mar. 94	4.3	4.0
17 May 94	3.9	4.5
6 July 94	4.0	4.7
16 Aug. 94	4.3	4.2
27 Sep. 94	4.7	4.2
15 Nov. 94	4.0	4.0
20 Dec. 94	2.3	1.2
1 Feb. 95	3.6	4.6
28 Mar. 95	2.7	2.8

Table 5. Intra-daily Spread Estimates

The table reports coefficient estimates of an intra-daily spread model for the mark-dollar exchange rate on FOMC days. The initial estimated equation is: $SP_{t,t-1} = a_0 + a_1 SP_{t-1,t-2} + a_3 \sigma_t^* + a_4 \sigma_t^* dumend_t + e_t$ where SP denotes the spread, σ^* is the state-probability-weighted variance of the exchange rate return, and *dumend* is a dummy variable that switches from zero to one at the end of the FOMC meeting each day. The second set of results replaces the interactive term with *dumend*. The third set of results replaces σ^* with pstate2, the probability of being in the informed trading state. Spreads equal 5 minute averages (asks-bids) on the mark price of the dollar. The lagged spread is included to guard against σ^*, which is a function of past information, simply capturing the persistence in the spread. Data are sampled at 5-minute intervals and run from 8:00GMT until 21:00GMT on each FOMC meeting day. P-values are in parentheses.

Date	$SP_{t-1,t-2}$	σ^*	$\sigma^* dumend$	*Log L*
4 Feb. 94	0.029	0.359	1.051	-2.973
	(0.71)	(0.29)	(0.00)	
	$SP_{t-1,t-2}$	σ^*	*dumend*	*Log L*
	-0.096	0.552	2.194	-2.905
	(0.22)	(0.02)	(0.00)	
	$SP_{t-1,t-2}$	*pstate2*	*dumend*	*Log L*
	-0.094	0.987	2.207	-2.906
	(0.23)	(0.02)	(0.00)	
22 Mar. 94	$SP_{t-1,t-2}$	σ^*	$\sigma^* dumend$	*Log L*
	-0.012	2.004	0.273	-2.809
	(0.880)	(0.00)	(0.59)	
	$SP_{t-1,t-2}$	σ^*	*dumend*	*Log L*
	-0.018	1.985	0.457	-2.806
	(0.82)	(0.00)	(0.28)	
	$SP_{t-1,t-2}$	*pstate2*	*dumend*	*Log L*
	-0.011	2.442	0.465	-2.806
	(0.88)	(0.00)	(0.27)	
17 May 94	$SP_{t-1,t-2}$	σ^*	$\sigma^* dumend$	*Log L*
	-0.048	5.960	-0.412	-2.785
	(0.53)	(0.00)	(0.71)	
	$SP_{t-1,t-2}$	σ^*	*dumend*	*Log L*
	-0.051	5.787	0.046	-2.785
	(0.51)	(0.00)	(0.89)	
	$SP_{t-1,t-2}$	*pstate2*	*dumend*	*Log L*
	-0.046	3.160	0.070	-2.778
	(0.53)	(0.00)	(0.83)	

Table 5 (continued)

Date				
6 Jul. 94	$SP_{t-1,t-2}$	σ^*	$\sigma^* dumend$	*Log L*
	-0.246	16.984	1.331	-2.328
	(0.00)	(0.00)	(0.03)	
	$SP_{t-1,t-2}$	σ^*	*dumend*	*Log L*
	-0.246	17.309	0.362	-2.333
	(0.00)	(0.00)	(0.07)	
	$SP_{t-1,t-2}$	*pstate2*	*dumend*	*Log L*
	-0.199	4.427	0.420	-2.193
	(0.00)	(0.00)	(0.02)	
16 Aug. 94	$SP_{t-1,t-2}$	σ^*	$\sigma^* dumend$	*Log L*
	0.015	0.420	0.978	-2.935
	(0.854)	(0.03)	(0.00)	
	$SP_{t-1,t-2}$	σ^*	*dumend*	*Log L*
	0.032	0.487	2.098	-2.945
	(0.69)	(0.01)	(0.00)	
	$SP_{t-1,t-2}$	*pstate2*	*dumend*	*Log L*
	0.033	1.194	2.116	-2.946
	(0.68)	(0.01)	(0.00)	
27 Sep. 94	$SP_{t-1,t-2}$	σ^*	$\sigma^* dumend$	*Log L*
	-0.112	0.781	0.642	-2.832
	(0.16)	(0.07)	(0.25)	
	$SP_{t-1,t-2}$	σ^*	*dumend*	*Log L*
	-0.104	1.124	-0.144	-2.835
	(0.19)	(0.00)	(0.67)	
	$SP_{t-1,t-2}$	*pstate2*	*dumend*	*Log L*
	-0.112	0.781	0.642	-2.832
	(0.16)	(0.07)	(0.25)	
15 Nov. 94	$SP_{t-1,t-2}$	σ^*	$\sigma^* dumend$	*Log L*
	0.101	0.410	2.109	-2.959
	(0.20)	(0.43)	(0.00)	
	$SP_{t-1,t-2}$	σ^*	*dumend*	*Log L*
	0.091	0.500	1.894	-2.953
	(0.25)	(0.31)	(0.00)	
	$SP_{t-1,t-2}$	*pstate2*	*dumend*	*Log L*
	0.092	0.473	1.899	-2.953
	(0.25)	(0.31)	(0.00)	

Table (continued)

20 Dec. 94	$SP_{t-1,t-2}$	σ^*	$\sigma^* dumend$	*Log L*
	0.044 (0.24)	183.05 (0.00)	1.098 (0.82)	-2.302
	$SP_{t-1,t-2}$	σ^*	*dumend*	*Log L*
	-0.065 (0.37)	12.196 (0.00)	-1.641 (0.01)	-2.702
	$SP_{t-1,t-2}$	*pstate2*	*dumend*	*Log L*
	0.033 (0.38)	4.171 (0.00)	-0.040 (0.86)	-2.291
1 Feb. 95	$SP_{t-1,t-2}$	σ^*	$\sigma^* dumend$	*Log L*
	-0.082 (0.25)	15.922 (0.00)	-6.091 (0.00)	-2.687
	$SP_{t-1,t-2}$	σ^*	*dumend*	*Log L*
	-0.065 (0.37)	12.196 (0.00)	-1.641 (0.01)	-2.702
	$SP_{t-1,t-2}$	*pstate2*	*dumend*	*Log L*
	-0.049 (0.49)	5.516 (0.00)	-1.371 (0.01)	-2.699
28 Mar. 95	$SP_{t-1,t-2}$	σ^*	$\sigma^* dumend$	*Log L*
	-0.330 (0.00)	12.546 (0.00)	0.374 (0.69)	-2.672
	$SP_{t-1,t-2}$	σ^*	*dumend*	*Log L*
	-0.332 (0.00)	12.559 (0.00)	0.262 (0.43)	-2.671
	$SP_{t-1,t-2}$	*pstate2*	*dumend*	*Log L*
	-0.239 (0.00)	5.525 (0.00)	0.224 (0.49)	-2.644

Table 6. Joint Estimation of the Spread and the Probability of the Informed-Trading State

The table reports coefficient estimates of a model of the intra-daily spread for the mark-dollar exchange rate and the probability of being in the high-volatility informed trading state on FOMC days. The estimated equations are: $SP_{t,t-1} = a_0 + a_1 SP_{t-1,t-2} + a_2 pstate2_t + e_t$ where SP denotes the spread, $pstate2$ is the probability of the informed trading state (state 2 of the Markov model), and $pstate2 = b_0 + b_1 dumend + b_2 dummeet + u_t$ where *dumend* is a dummy variable that switches from zero to one at the end of the FOMC meeting each day and *dummeet* is a dummy variable that equals one for the period of the FOMC meeting and is zero otherwise. Data are sampled at 5-minute intervals and run from 8:00GMT until 21:00GMT on each FOMC meeting day. P-values are in parentheses.

Date	Spread equation coefficients			Prob of state 2 coefficients		
	a_0	a_1	a_2	b_0	b_1	b_2
4 Feb 94	6.964	-0.093	5.716	0.107	0.490	0.118
	(0.00)	(0.24)	(0.00)	(0.00)	(0.00)	(0.04)
22 Mar 94	6.779	-0.010	3.141	0.012	0.541	0.283
	(0.00)	(0.90)	(0.00)	(0.73)	(0.00)	(0.00)
17 May 94	6.026	-0.056	4.083	0.018	0.273	0.317
	(0.00)	(0.46)	(0.00)	(0.59)	(0.00)	(0.00)
6 Jul 94	5.151	-0.198	6.440	0.485	0.179	0.082
	(0.00)	(0.00)	(0.03)	(0.00)	(0.07)	(0.42)
16 Aug 94	6.315	0.040	3.690	0.015	0.913	0.357
	(0.00)	(0.62)	(0.00)	(0.66)	(0.00)	(0.00)
27 Sep 94	6.860	-0.104	1.222	0.013	0.315	0.215
	(0.00)	(0.19)	(0.24)	(0.00)	(0.00)	(0.00)
15 Nov 94	5.087	0.092	3.792	0.216	****	0.572
	(0.00)	(0.25)	(0.00)	(0.00)	****	(0.00)
20 Dec 94	2.749	0.033	5.830	0.616	****	-0.024
	(0.70)	(0.38)	(0.62)	(0.00)	****	(0.82)
1 Feb 95	6.545	-0.049	3.457	0.031	****	0.666
	(0.00)	(0.50)	(0.00)	(0.03)	****	(0.00)
28 Mar 95	7.478	-0.241	7.644	0.174	****	0.151
	(0.00)	(0.00)	(0.00)	(0.00)	****	(0.02)

*Models for the last four days reported in the table were estimated with the *dumend* variable omitted from the *pstate2* equation. In these cases, the correlation matrix of the parameters revealed correlations of *dumend* with *dummeet* of -.099. The log-likelihood values were identical for the estimated models with and without *dumend*.