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The impact of the Federal Reserve Bank's open market operations[☆]

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Abstract

The Federal Reserve Bank has the ability to change the money supply and to shape the expectations of market participants through their open market operations. These operations may amount to 20% of the day's volume and are concentrated during the half hour known as "Fed Time". Using previously unavailable data on open market operations from 1982 to 1988, our paper provides the first comprehensive examination of the impact of the Federal Reserve Bank's trading on both fixed income instruments and foreign currencies. Our results detail a dramatic increase in volatility during Fed Time, consistent with market expectations of Fed intervention during this time interval. We find that there is little systematic difference in market impact between reserve-draining and reserve-adding operations. Additionally, Fed Time volatility is, on average, higher on days when open market operations are absent. These results suggest that the markets are potentially confused about the purpose of the open market operations during our sample period. The evidence is also consistent with the Fed

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operations conveying information which smooths market participants' expectations.
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1. Introduction

The goal of this paper is to investigate the impact of the Federal Reserve Bank's open market operations on the financial markets. These operations typically involve the purchase or sale of Treasury securities and can represent a substantial amount of any day's trading volume. Using new daily data on the operations, we are able to assess the impact on eight different financial markets: Treasury bill, Eurodollar, Treasury bond, and five U.S. dollar exchange rates.

The Federal Reserve Bank can be viewed as a trader with private information. This information is revealed to the market in many different ways: remarks by the Chairman of the Federal Reserve, testimony before the House and Senate Banking Committees, the release of the Beige book, the minutes of the Federal Open Market Committee (FOMC) meetings, changes in reserve requirements, changes in the discount rate, and open market operations. The last method is, by far, the primary and most actively employed policy tool of the Federal Reserve Bank in implementing its monetary policy. Therefore, our analysis provides a rare opportunity to study the effects of private information trading. Data on private trades are often unavailable and the identity of the informed traders is seldom known. In contrast, we are able to identify a major market participant with private information. We know the time interval of the day when this participant trades. We know the volume and the type of trade. With this information, we are in a position to assess the impact of the Federal Reserve Bank's operations on a number of important markets.¹

Our study contributes to the literature on the impact of Federal Reserve's monetary policy. Specifically, our sample period is nestled between two policy changes. Between 1979 and 1982, the Fed policy is to target monetary aggregates. During our sample period from 1982 to 1988, the policy target is a mixture of borrowed reserves and federal funds rates. During this period, the Fed is highly secretive about the policy making process as well as its actual policy. It believes that the release of such information is detrimental to the

¹ Formal models of market microstructure with privately informed traders are provided by Kyle (1985), Admati and Pfleiderer (1988), Foster and Viswanathan (1990), and others.

attainment of its monetary targets. It would not make public announcement of policy changes nor acknowledge its choice of policy targets. Moreover, it would frequently make policy adjustments between the regularly scheduled FOMC meetings. Beginning in December 1989, the Fed converted fully to federal funds targeting and began releasing information about its targets. This culminates with a new policy in 1994 to immediately announce changes in the federal funds rate, thereby removing the veil of secrecy surrounding monetary policy.

We examine a period in time when the Fed makes a conscious effort to hide its true intentions from the market. As such, we expect the market reaction to open market operations to be more pronounced than the period after 1989 when the Fed begins publishing information on policy targets. We expect policy changes after 1994, when the Fed begins making immediate announcements of policy targets, to be even more evident and predictable. Ulrich and Wachtel (2000) find that with the implementation of the new policy in 1994, the impact of policy changes on short-term interest rates have declined.

Our study also contributes to the literature on what moves financial asset prices and the process by which new information is incorporated into the prices. This literature considers the impact of private and public information on asset prices. However, research on macroeconomic news invariably focuses on public information. For example Jones et al. (1998) document that information revealed by announcements of producer price index and employment data have immediate effects on bond market volatility. Balduzzi et al. (1999) and Fleming and Remolona (1999) investigate the impact of macroeconomic news announcements on the U.S. Treasury market using the GovPX transactions data. Balduzzi, Elton, and Green examine 26 economic news announcements while Fleming and Remolona study announcements of consumer and producer price indices and employment data. Almost all the announcements generate significantly higher bond volatility. Andersen and Bollerslev (1998) and Ederington and Lee (2000) examine intraday volatility induced by public announcements, volatility persistence, and calendar effects. Andersen and Bollerslev address the deutsche mark–dollar volatility and Ederington and Lee consider interest rate and foreign exchange markets. Their results show that of the three effects, the release of economic news is the most important during high volatility periods.

In contrast to the public macroeconomic news literature, we examine the reaction of asset prices to private macroeconomic information. This is made possible by the availability of historical data on securities that are traded in the course of open market operations during Fed Time.

Our analysis reveals that the Federal Reserve Bank's open market operations result in dramatic increases in volatility during the trading-time window, 11:30 am–12:00 EST, known as "Fed Time". This is consistent with

the market expecting some type of Fed intervention during this time interval. However, there is some evidence of higher volatilities on days when there are no open market operations. We also examine the effects on the returns and the volatilities of specific operations that are designed to increase or decrease money supply. Contrary to expectations, the effects on returns of reserve-adding and reserve-draining operations cannot be reliably differentiated from one another. These results suggest that the market is unable to decode the Fed policy targets from the Fed participation in the market. Evidence of higher volatility on days without operations suggests that the conduct of open market operations likely acts to smooth market expectations.

There are many historical examples that point to the importance of the Federal Reserve Bank's open market operations. For example, beginning in February 1994, the Federal Reserve Bank starts announcing immediately changes in the Fed Funds target. Specifically, on February 4, 1994, the Federal Reserve Bank's Chairman Greenspan made the unusual move of announcing the Fed intentions to "tighten" one half-hour before Fed Time. This was the first "tightening" since February 1989. The action caused prices in the fixed income markets to plummet. The Fed's New York desk calmed the market by trading a \$1.5 billion dollar customer repurchase agreement which is a reserve-adding operation during Fed Time. The Chairman's new policy of pre-announcing Fed intentions added new impetus to those trying to understand the role of the Fed in the country's economic strategy, the specific actions available to the Fed as well as the impact of these actions. One would expect open market operations to be more informative when they are not pre-announced. Our sample period predates the pre-announcement policy.

The remainder of the paper is organized as follows. In the second section, we describe the mechanisms through which the Federal Reserve Bank's open market operations affect financial markets. In this section, we detail the type of open market operations that are available to the Federal Reserve Bank and the expected effect of each operation. The data sources and the econometric methodology are outlined in the third section. In the fourth section, the results are presented. Some concluding remarks are offered in the final section.

2. The Federal Reserve Bank's open market operations

2.1. Policy and implementation

Much has been written about the role of the Federal Reserve Bank in the economy. By exercising some control over the money supply, most believe that the Federal Reserve Bank has the ability to influence financial prices, in

particular, the short-term interest rates. This paper aims to provide direct evidence on the impact of open market operations on financial markets.

Before examining the specific actions that the Federal Reserve Bank takes, we first describe how policies are translated into actions.² At the highest level, the Full Employment and Balanced Growth Act of 1978 mandates that the Federal Reserve Bank set annual growth targets for monetary aggregates and justify these targets with respect to economic activity, inflation policy and employment outlook. As a result of this act, the Chairman of the Federal Reserve Bank appears before the House and Senate Banking committees twice a year to explain the Federal Reserve Bank Policy (known as the Humphrey-Hawkins hearings).

Of course, the testimony of the Chairman is based on policy and activities that has been preformulated. The body in charge of policy is the FOMC. This committee meets about eight times a year and consists of the presidents of the Federal Reserve Bank districts and the Board of Governors of the Federal Reserve Bank in Washington.

Over the past 25 years, several approaches have been followed to achieve the monetary objectives. For example, on October 6, 1979 the Chairman of the Federal Reserve Bank announced a policy shift to one that targeted reserves and deemphasized control of interest rates.³ Subsequently, the economy fell into a sharp recession and interest rates rose to historic levels. This led to the adoption of a new approach at the October 1982 meeting of the FOMC. After October 1982, M1 targeting was basically abandoned. In addition, the type of reserve targeting was altered (and will be described in detail later). Since these regime changes may confound the analysis of the Federal Reserve Bank's open market operations, our sample is confined to the post-October 1982 period.

Monetary policy can be implemented in a number of ways. The main options available to the Federal Reserve Bank are changes in required reserves, changes in the discount rate, and open market operations. The first two are drastic actions that are rarely implemented. The main vehicle of monetary policy is the open market operations.

To understand the impact of the open market operations, we must understand the relation between the operations and the reserve measures. Since October 1982, the Federal Reserve Bank targets the broad aggregates M2 and M3 by controlling the amount of borrowing from the Federal Reserve that banks undertake to maintain their reserve requirements.

The demand for reserves has two main components: required reserves (RR) and excess reserves (ER). Reserves required on transactions accounts range

²Our discussion draws from the detailed reviews of the Federal Reserve Bank provided by Broadhus (1988) and especially by Meulendyke (1989).

³See the Federal Reserve Bulletin, December 1979.

from 0% to 12% of the balances. Banks must keep enough reserves to meet these requirements *on average* over every two week maintenance period which ends every other Wednesday.⁴ Banks may also keep ER with the Federal Reserve Bank. Since the reserves at the Federal Reserve Bank provide a means for interbank transfers, it is not unusual for a bank's reserves to turnover 25 times a day. At the end of the day, the bank must cover any deficit. One means of doing this is to borrow from another bank with a surplus. This borrowing is done at the federal funds rate.

The supply of reserves has two categories: borrowed reserves (BR) and nonborrowed reserves (NBR). There are three types of BR which are available to banks through the Fed's discount window: adjustment credit, seasonal credit, and extended credit borrowing. The first two are reasonably common and the last category is only used if the bank is in trouble. More importantly, banks must try to obtain reserves from other means, such as the federal funds market, before using the discount window.

Nonborrowed reserves are obtained from sources that exclude the discount window. During the 1979–1982 regime, the Federal Reserve Bank attempted to control NBR in order to achieve their objectives for the growth in aggregates. Given an NBR target, a change in demand for reserves by banks had to be accommodated at the discount window. This borrowing heavily influenced the market for federal funds and produced large fluctuations in short-term interest rates. Since October 1982, the Federal Reserve Bank sets a level of borrowing that it believes is consistent with the goals for the monetary aggregates. Variation in institutions' demands for reserves are then accomplished through the open market operations. These NBR are primarily provided by the purchase of Treasury securities by the trading desk of the Federal Reserve Bank of New York.

Before detailing the specific operations, consider an example of how policy is implemented. Suppose the FOMC, concerned with heightened inflation, elects to increase reserve "pressure". The appropriate action is to *drain* reserves. An example of a draining operation is the New York desk *selling* Treasury securities. The immediate impact is the loss of reserves in the purchasers' banks. As the purchasers' banks try to make up the deficiency, all banks are affected. The purchasers' banks have a number of options: they could reduce transactions deposits (which would serve the policy objective but is difficult to implement in the short run), they could reduce their excess reserves (but they may not have any), or they could go to the federal funds market (which would bid up the federal funds rate). For the banking industry as a whole, going to the federal funds market would merely redistribute the shortage. In fact, borrowing reserves at the discount window may be the only possibility. This process leads to a gradual decline in the money growth.

⁴Before 1984, maintenance periods were one week long (Meulendyke, 1989).

2.2. Instruments of open-market operations

Open market operations involve the purchase or sale of Treasury securities. Sales drain reserves (increase reserve pressure) and purchases add to reserves (decrease reserve pressure). The trades can be permanent or temporary.

The Federal Reserve Bank permanently changes the reserve pressure by its *outright sales* and *purchases*. These outright operations could involve Treasury bills or bonds. They are usually large operations and it is not unusual for the operation to account for 10–20% of the day's trading volume.⁵ By way of comparison, these operations may involve daily dollar volumes greater than the value of stocks traded on the New York Stock Exchange.

The Federal Reserve Bank could add reserves temporarily with a *system repurchase agreement* (RP). Suppose that there is a forecast of a temporary shortage of NBR. The Federal Reserve Bank could execute an outright purchase of Treasury securities but the purchase would have to be reversed because the shortage of NBR is expected to be temporary. The RP provides a more efficient way to meet the policy objective since it obligates the primary dealers to return cash plus interest (at the repo rate) and to reacquire the security. In contrast to the outright, the list of eligible collateral for the RP is much more extensive. As a result, the average system RPs are much larger than the average outright purchases.

There are also *customer-related repurchase agreements*. A number of foreign institutions place some of their dollar holdings in the Federal Reserve Bank of New York's daily RP facility. These could be handled internally or passed to the market as a customer RP. The customer RP is on average smaller than the system RP and almost always has a one-day duration. Executing a customer RP is supposed to signal to the market that the reserve need is small and/or uncertain and of very short-term duration. Executing a system RP suggests that the reserve need is larger and longer lasting.

The opposite of the RP is the *matched-sale purchase* (MSP). This operation involves the desk selling Treasury bills from the system account for immediate delivery and, at the same time, agreeing to buy them back for delivery on a future date. This operation is designed to temporarily *drain* reserves.

Although it is difficult to generalize, one might characterize the outright open market sales and purchases as offensive operations whereas the repos and matched sales/purchases are more defensively oriented operations. One important issue for market participants is disentangling the actions of the

⁵There are also outrights that are executed for foreign accounts. While we also have data on these foreign outrights, we exclude them from our analysis since they are of a much smaller size and are unlikely to influence the market.

Fed. Given the lack of transparency during our sample, there is considerable uncertainty as to whether the Fed objectives are offensive or defensive.

2.3. The process of an open market trade

This section explores how the tools of open market operations are used on a day-by-day basis. The directives of the FOMC are carried out in the context of two-week maintenance periods. The Manager of the System Open Market Account is charged with achieving those objectives via the daily operations. The daily routine of the open market desk involves five steps as described in Meulendyke (1988).

The first step is to gather information. Most macroeconomic news is released at 8:30 am EST. Following the news releases, the desk telephones primary government security dealers and some large banks. The dealers tell the desk how they expect the day to proceed and how they will finance their securities positions. The large banks inform the desk about their reserve needs. In addition, there are three or four 15-minute meetings with a small group of dealers. The dealers provide information as to where they (and their clients) think rates are going. Some of the dealers are associated with large banks and they may reveal information about the strength of business loan demand and financing needs. While all this is going on, forecasters at the research departments of the New York Federal Reserve Bank and the Board of Governors gather data to provide forecasts of reserves.

The second step is the telephone call to the Treasury concerning its forecast of its balance for the day at about 10:30 am. By this time, the research department of the New York Federal Reserve Bank has a preliminary forecast of the size of NBR over the maintenance period in the absence of any open market operations. This estimate is made more precise using the information from the call to the Treasury.

The third step is to formulate the actions for the day. With the Treasury data, the forecasts for NBR are updated and interventions are formulated. The forecasts from the New York Federal Reserve Bank and the Board of Governors are combined and the trading plan is formulated.

The fourth step is a conference call at 11:15 am. This conference call links the Manager (and staff) to the Director of the Division of Monetary Affairs at the Board of Governors and to one of the Federal Reserve Bank presidents that also sits on the FOMC. The call usually lasts 15–20 min. The call reviews the information gathered and the views on where rates are going. At the end of the call, the proposed actions for the day are detailed.

The fifth step is execution. After the meeting is over (usually between 11:30 am and 11:40 am), the desk traders immediately contact the primary dealers and execute the day's program.

3. Data and methodology

3.1. Data

Historical data on the Federal Reserve Bank's daily open market operations were provided by the Federal Reserve Bank of New York for the 1982 to 1988 period. The tables have 10 columns of data for each day.⁶ The data include outright purchases and sales (classified by bill or coupon), system MSPs, and system RPs as well as redemptions of bills, coupons or agency issues. The duration of MSPs and the RPs are also provided. The data also include the purchase and the sales of foreign bills (which are executed away from the market) as well as MSPs which are arranged for foreign customers. Our analysis will concentrate on five categories: outright purchases, outright sales, MSPs, system RPs, and customer RPs.

To assess the effect of the operations on the financial markets, we use intraday price data from the futures markets. Our analysis includes Treasury bond futures (from the Chicago Board of Trade) and two money market instruments: Treasury bill and Eurodollar futures (both from the Chicago Mercantile Exchange). One of the main difficulties with fixed income instruments is the lack of homogeneity. A 90-day Treasury bill becomes an 89-day bill the following day. The volatility of a discount instrument usually decreases as time to maturity shortens. In addition, the market for off-the-run issues may be illiquid and transactions data are difficult to obtain. However, with the advent of futures trading, it is possible to study, in a highly liquid market, volatility patterns of fixed income instruments while holding time to maturity constant. In addition, we use data on five U.S. dollar currency futures from the Chicago Mercantile Exchange: Canadian dollar, Deutschemark, French franc, Japanese yen, and Swiss franc. While there are a whole host of foreign exchange interventions initiated by the Fed, we concentrate on the possible spillover of the interest rate-related operations to the currency markets.

Although we know the time interval and the day specific open market operations occurred, we do not know the precise time when a specific security is bought or sold. Earlier studies have shown that the reaction time to a public announcement is immediate. For example Jones et al. (1998) find that announcement-day bond volatility induced by news of producer price index and employment statistics does not persist at all and prices reflect public information quickly. Balduzzi et al. (1999) and Fleming

⁶Hardcopies of these tables were provided by the Federal Reserve Bank of New York. For 1987 and 1988, some computer worksheets (where the hardcopies had been loaded) were also provided. However, we found discrepancies between the worksheets and the hardcopies and, as a result, did not use the worksheets.

and Remolona (1999) document that U.S. government bond prices react to news in the major macroeconomic announcements almost instantaneously. Therefore, we have not examined asset price reaction to specific trades but instead focus on the reaction of asset prices *during* Fed Time.

3.2. Methodology

This paper uses transaction prices from the futures markets to study the impact of open market operations. The returns are the natural logarithm of the current price divided by the previous price. We estimate the volatility of hourly returns but focus on intrahour volatility using 2-min returns. This is because the variance of hourly returns may not pick up the volatility that occurs within the hour since only two points are used to calculate the hourly return and frequent information arrival may occur within the hour. We calculate the volatility of 2-min returns for four half-hour intervals: 10:00–10:30, 10:30–11:00, 11:00–11:30 am, and 11:30 am–12:00 pm (Fed Time). We also average the daily variances during Fed Time to obtain annual estimates.

We use heteroskedasticity-consistent standard errors of variances to test whether variances are elevated during the Fed Time interval. The model estimated is

$$\begin{aligned} \mathbf{u}_t &= \mathbf{r}_t - \boldsymbol{\mu}, \\ \mathbf{e}_t &= (\mathbf{r}_t - \boldsymbol{\mu})^2 - \boldsymbol{\sigma}^2, \end{aligned} \quad (1)$$

where \mathbf{r}_t represents a vector of returns over, for example, four half-hour intervals, $\boldsymbol{\mu}$ is a vector of mean returns over the time intervals, $\boldsymbol{\sigma}^2$ is a vector of variances, and \mathbf{u}_t and \mathbf{e}_t are the disturbance terms.

With four time intervals, there are eight equations in (1) and eight parameters. These parameters could be estimated with maximum likelihood. However, the standard errors would not be robust to conditional heteroskedasticity. Therefore, we use Hansen's (1982) generalized method of moments (GMM) to obtain heteroskedasticity-consistent standard errors of the variances and to conduct hypothesis tests on the parameters. The model is exactly identified when we condition on a vector of ones. One advantage of Hansen's approach is that only weak distributional assumptions are required.⁷

With the GMM methodology, it is straightforward to test the hypothesis that variances are different during a particular time period. For example, variance equality can be tested with

$$\begin{aligned} \mathbf{u}_t &= \mathbf{r}_t - \boldsymbol{\mu}, \\ \mathbf{e}_t &= (\mathbf{r}_t - \boldsymbol{\mu})^2 - \boldsymbol{\sigma}^2 \otimes \mathbf{1}, \end{aligned} \quad (2)$$

⁷Other studies that use these variance estimators include Richardson and Smith (1991), Harvey and Huang (1991, 1993) and Ronen (1997).

where σ^2 is a singleton parameter and $\mathbf{1}$ is a 1×4 vector of ones. This system is overidentified resulting in a χ^2 test with three degrees of freedom. Alternatively, Wald tests of parameter restrictions can be carried out on (1).

We also test for the effects of the open market operations on both the returns and the volatilities. This analysis is specialized to the Fed Time half-hour interval, denoted with the FT subscript. The following model is estimated:

$$\begin{aligned} \mathbf{u}_{\text{FT},t} &= \mathbf{r}_{\text{FT},t} - \left(\sum_{y=1982}^{1988} \sum_{j=1}^6 \mu_{y,j} \mathbf{I}_{y,j,t}^{\text{OMO}} \right), \\ \mathbf{e}_{\text{FT},t} &= \mathbf{u}_{\text{FT},t}^2 - \left(\sum_{y=1982}^{1988} \sum_{j=1}^6 v_{y,j} \mathbf{I}_{y,j,t}^{\text{OMO}} \right), \end{aligned} \quad (3)$$

where j represents the type of operation (outright purchase, outright sale, matched-sale purchase, system RP, customer RP, and no operation), y represents the year, \mathbf{I}^{OMO} is an indicator variable for the open market operations. In this formulation, $\mathbf{r}_{\text{FT},t}$ is a 15×1 vector of two-minute returns in Fed Time for time period t . $\mathbf{u}_{\text{FT},t}$ and $\mathbf{e}_{\text{FT},t}$ are the disturbance terms associated with the mean and variance equations. The parameters μ and v are estimates of the means and variances by operation and by year. There are no separate intercept terms in (3) because the indicator variables sum to unity.

The formulation in (3) allows for both the mean and the variance processes to vary by year and by operation. Furthermore, it is straightforward to conduct hypothesis tests on the parameters of interest. However, in practical terms, (3) may require a lot of data. With seven years of daily data and up to 15 observations per day, the estimation involves up to 20,000 observations with parameters for means and variances by year. Often, we specialize the estimation to examine one particular year or one particular operation.

We use (3) in a number of different ways. We estimate variances on the days when particular operations are initiated. We test whether variances during Fed operations are equal to variances on days with no operations. We also test whether returns on days when there are draining operations are equal to returns on days with adding operations.

Using indicator variables does not capture the effect of the magnitude of the operation. However, the magnitude of the operation is problematic for a number of reasons: the amount of reserves has grown through time, and more importantly, we do not know how much of the operation is unexpected.

The first problem is reasonably easy to solve. By looking at the data by year, we solve, to some extent, the problem of the size of the operations growing through time. Alternatively, since we have data on total reserves, the operations can be deflated by the total reserves to give a measure of relative size.

The last problem is more serious. Consider model (3). Variance might be high during Fed Time on a nonoperation day because the market expected an operation. The fact that no open market operation took place could be as important as an open market operation taking place. What impacts volatility is the unexpected component. In (3), we have combined both the unexpected and expected action. Unfortunately, there are no data on expected open market operations.

4. Results

4.1. Interhour volatility

Table 1 presents the hourly return variances and the heteroskedasticity-consistent standard errors for fixed income instruments in Panels A–C and for foreign currency contracts in Panels D–H. Panels A and B show distinct intraday patterns in the money market futures data. Volatility is highest at the open but declines until Fed Time hour when it elevates and declines thereafter.

From 1982 to 1988, the variance for the Treasury bill futures in the hour before Fed Time hour is 0.985. During the Fed Time hour, volatility more than doubles to 2.062. Based on the standard errors, the increase in volatility is statistically significant. In fact, volatility increases from the preceding period to Fed Time and decreases throughout the rest of the day in every year during the sample period. Similar results are found for the Eurodollar contract. For the full sample, volatility more than doubles from 10:30–11:30 period to 11:30–12:30 hour [from 0.995 to 2.271]. In some years, the increase in volatility during Fed Time is even more dramatic. Again, the volatility decreases after Fed Time in every year.

The opening hour return volatility is the highest of the day. This heightened volatility has been traced to the concentration of economic news announcements during this hour (Andersen and Bollerslev, 1998; Harvey and Huang, 1991, 1993; Ederington and Lee, 1993, 2000; Becker et al., 1993). The intraday pattern also contrasts with the pattern observed in equity markets. For example, Wood et al. (1985) documents a U-shaped intraday volatility pattern for the New York Stock Exchange.

Treasury bond futures also exhibit a rise in interhour volatility during Fed Time but the increase is much less dramatic. For example, from 1982 to 1988, it increases from 43.629 during the preceding hour to 50.234 during the Fed Time hour. In addition, the intraday pattern exhibits a W-shaped structure with an elevation at Fed Time rather than an inverted U-shaped structure.

The impact of the Federal Reserve Bank's foreign exchange interventions on the currency markets are well documented (see, for example, Kaminsky and Lewis, 1996). However, there is no study of the impact of open market operations on currencies at the level of transactions data. Indeed, the close

Table 1
Interhour volatility in financial futures contracts^a

The model estimated is

$$u_{1t} = r_t - \mu,$$

$$u_{2t} = (r_t - \mu)^2 - \sigma^2,$$

where r_t is the vector of returns over six-hourly time intervals, μ is the vector of mean estimates, σ^2 is the vector of variance estimates, and u is the vector of the disturbances with unconditional zero means. The system is exactly identified. Parameters are obtained by estimating both year by year and by a pooled estimation using the full sample. Heteroskedasticity-consistent standard errors are in parentheses. The data are from January 2, 1982–May 10, 1988.

Year	Obs.	Open–9:30	9:30–10:30	10:30–11:30	Fed Time 11.30–12:30	12:30–1:30	1.30–Close
<i>(A) Treasury bill</i>							
1982	253	17.77 (3.75)	5.32 (0.85)	3.09 (0.37)	8.22 (1.11)	6.14 (0.87)	5.07 (0.53)
1983	252	1.88 (0.20)	1.09 (0.22)	0.63 (0.08)	1.47 (0.24)	0.67 (0.08)	0.69 (0.08)
1984	253	3.79 (0.65)	0.96 (0.13)	0.70 (0.09)	1.76 (0.28)	1.13 (0.14)	0.85 (0.09)
1985	253	2.78 (0.39)	1.37 (0.25)	0.56 (0.06)	1.21 (0.19)	0.99 (0.15)	0.52 (0.06)
1986	253	1.52 (0.21)	0.50 (0.06)	0.42 (0.05)	0.50 (0.07)	0.34 (0.04)	0.34 (0.05)
1987	252	3.44 (1.23)	1.46 (0.27)	0.81 (0.16)	0.98 (0.18)	0.75 (0.11)	0.59 (0.08)
1988	90	2.12 (0.49)	0.52 (0.09)	0.25 (0.05)	0.54 (0.15)	0.27 (0.05)	0.38 (0.06)
1982–88	1586	3.49 (0.28)	1.98 (0.18)	0.99 (0.07)	2.06 (0.15)	1.62 (0.16)	1.38 (0.11)
<i>(B) Eurodollar</i>							
1982	252	9.41 (1.21)	6.89 (0.96)	2.70 (0.31)	7.49 (0.77)	6.54 (0.90)	5.51 (0.57)
1983	245	1.33 (0.13)	1.09 (0.18)	0.67 (0.08)	1.28 (0.17)	0.70 (0.08)	0.79 (0.08)
1984	250	1.99 (0.24)	0.92 (0.10)	0.86 (0.18)	1.33 (0.20)	0.94 (0.13)	0.65 (0.07)
1985	250	3.02 (0.49)	1.04 (0.17)	0.43 (0.04)	0.85 (0.15)	0.81 (0.12)	0.32 (0.03)
1986	250	1.46 (0.21)	0.43 (0.06)	0.44 (0.05)	0.44 (0.05)	0.30 (0.04)	0.36 (0.04)

Table 1 (continued)

Year	Obs.	Open–9:30	9:30–10:30	10:30–11:30	Fed Time 11.30–12:30	12:30–1:30	1.30–Close
1987	249	4.18 (1.10)	1.89 (0.41)	1.01 (0.19)	1.34 (0.28)	0.77 (0.11)	0.89 (0.29)
1988	90	1.86 (0.37)	0.57 (0.10)	0.24 (0.04)	0.61 (0.14)	0.36 (0.06)	0.42 (0.10)
1982–88	1606	5.03 (0.65)	1.72 (0.16)	1.00 (0.07)	2.27 (0.20)	1.59 (0.15)	1.29 (0.10)
<i>(C) Treasury bond</i>							
1982	155	188.27 (43.96)	98.92 (16.71)	48.47 (8.42)	88.61 (10.00)	88.65 (15.81)	258.38 (33.25)
1983	249	60.41 (5.43)	41.22 (4.60)	25.51 (3.83)	39.42 (4.65)	29.60 (2.81)	100.54 (11.28)
1984	252	78.21 (12.99)	54.26 (9.35)	30.44 (3.83)	44.75 (5.96)	37.84 (4.84)	134.03 (19.64)
1985	251	88.75 (17.98)	55.82 (7.07)	28.52 (3.81)	29.08 (3.24)	30.22 (3.23)	148.71 (25.52)
1986	253	128.50 (15.09)	101.59 (14.34)	69.05 (8.82)	63.13 (6.58)	62.16 (7.42)	248.97 (26.37)
1987	252	77.53 (13.13)	76.29 (9.00)	67.52 (11.35)	59.50 (11.77)	65.10 (10.50)	177.58 (20.48)
1988	93	57.76 (12.21)	46.93 (6.79)	21.91 (3.88)	24.33 (3.43)	22.64 (3.55)	142.24 (30.70)
1982–88	1505	96.10 (7.14)	68.51 (4.02)	43.63 (2.86)	50.32 (2.91)	48.29 (2.99)	171.37 (9.07)
<i>(D) British pound</i>							
1982	225	18.32 (2.33)	21.85 (2.36)	37.12 (4.28)	50.08 (6.57)	37.46 (6.36)	27.11 (3.65)
1983	201	16.53 (2.12)	32.29 (3.59)	32.30 (3.59)	30.21 (4.39)	24.50 (3.20)	17.59 (1.91)
1984	211	53.37 (13.44)	34.95 (3.88)	48.66 (7.45)	48.44 (4.92)	55.11 (10.52)	35.22 (6.27)
1985	235	134.91 (29.91)	99.32 (12.21)	96.58 (12.69)	85.35 (9.43)	68.85 (10.29)	54.13 (8.23)
1986	223	52.14 (7.94)	42.13 (4.81)	56.66 (7.95)	49.65 (6.78)	54.46 (8.96)	34.32 (4.56)
1987	218	70.69 (17.49)	27.10 (3.29)	36.36 (5.51)	33.92 (5.14)	25.14 (4.50)	16.51 (2.67)
1988	84	195.18 (138.58)	22.82 (5.78)	27.54 (5.61)	26.40 (4.46)	11.03 (2.10)	7.60 (1.38)

Table 1 (continued)

Year	Obs.	Open–9:30	9:30–10:30	10:30–11:30	Fed Time 11:30–12:30	12:30–1:30	1:30–Close
1982–88	1397	67.31 (10.62)	42.60 (2.57)	51.13 (3.11)	49.00 (2.59)	42.78 (3.09)	30.04 (2.05)
<i>(E) Canadian dollar</i>							
1982	213	17.85 (3.73)	11.48 (1.53)	7.47 (0.93)	11.81 (1.67)	11.67 (2.40)	7.60 (0.95)
1983	111	4.22 (0.61)	3.58 (0.54)	3.20 (0.56)	4.96 (2.07)	3.93 (0.87)	1.97 (0.30)
1984	75	10.52 (1.73)	7.59 (2.40)	7.01 (1.43)	5.44 (1.00)	3.90 (0.76)	3.72 (0.72)
1985	111	25.22 (4.26)	15.82 (3.76)	17.24 (5.16)	8.19 (1.35)	5.95 (0.92)	5.41 (1.08)
1986	132	19.33 (2.70)	13.79 (2.88)	10.50 (1.83)	6.73 (1.05)	7.43 (1.42)	9.29 (2.08)
1987	159	26.61 (11.55)	11.85 (3.63)	6.34 (0.92)	7.87 (1.27)	4.57 (0.61)	3.63 (0.47)
1988	66	11.34 (1.45)	5.38 (1.12)	2.85 (0.71)	4.99 (1.22)	2.39 (0.65)	2.33 (0.45)
1982–88	867	17.81 (2.43)	10.86 (1.06)	8.13 (0.82)	7.93 (0.61)	6.71 (0.70)	5.43 (0.44)
<i>(F) Deutsche mark</i>							
1982	239	24.28 (2.37)	28.17 (3.35)	38.59 (4.11)	44.33 (6.07)	28.18 (3.41)	24.32 (2.74)
1983	234	19.02 (2.07)	23.98 (2.92)	21.61 (2.52)	25.84 (2.91)	18.09 (2.54)	21.35 (3.06)
1984	247	64.25 (22.14)	41.04 (5.74)	53.76 (9.89)	44.90 (4.75)	51.20 (8.11)	32.78 (4.98)
1985	248	94.65 (18.39)	64.93 (8.27)	73.69 (12.67)	50.49 (5.40)	46.92 (6.50)	37.42 (4.85)
1986	251	64.72 (9.12)	44.48 (5.57)	54.54 (8.26)	50.61 (8.17)	36.39 (4.74)	27.23 (4.30)
1987	251	74.05 (16.93)	35.92 (6.81)	42.28 (6.57)	33.92 (5.12)	30.49 (6.52)	18.17 (2.05)
1988	86	171.14 (123.31)	19.99 (4.28)	18.37 (2.44)	21.18 (4.50)	12.40 (2.24)	7.82 (1.48)
1982–88	1556	63.80 (8.91)	39.025 (2.31)	46.63 (3.27)	40.79 (2.21)	34.24 (2.22)	26.19 (1.54)

Table 1 (continued)

Year	Obs.	Open–9:30	9:30–10:30	10:30–11:30	Fed Time 11.30–12:30	12:30–1:30	1.30–Close
<i>(G) Japanese yen</i>							
1982	234	37.13 (3.46)	37.44 (3.43)	46.60 (5.02)	53.23 (7.17)	30.96 (2.98)	31.93 (5.45)
1983	236	31.15 (4.43)	27.37 (3.70)	21.31 (2.62)	27.37 (3.35)	22.15 (4.07)	27.28 (4.48)
1984	219	44.26 (14.47)	19.74 (4.65)	14.66 (2.17)	16.48 (3.33)	15.94 (2.96)	12.97 (2.85)
1985	213	42.88 (9.12)	20.42 (3.56)	26.10 (4.41)	19.81 (3.36)	21.09 (4.10)	16.15 (2.03)
1986	240	48.07 (8.14)	33.71 (5.99)	41.74 (9.76)	28.90 (5.82)	21.85 (3.99)	19.80 (2.87)
1987	243	82.77 (19.78)	28.28 (4.12)	40.23 (7.44)	27.49 (4.05)	21.20 (3.55)	16.18 (1.10)
1988	89	218.49 (149.01)	24.51 (4.55)	21.05 (6.94)	21.72 (5.68)	13.67 (2.81)	9.33 (1.68)
1982–88	1474	58.36 (10.17)	28.01 (1.71)	31.59 (2.37)	28.82 (1.91)	21.84 (1.48)	20.32 (1.39)
<i>(H) Swiss franc</i>							
1982	247	46.88 (5.60)	47.47 (4.89)	59.74 (6.13)	78.46 (10.63)	51.92 (6.89)	79.49 (10.69)
1983	247	30.62 (3.58)	30.02 (3.84)	26.60 (2.71)	36.81 (4.37)	31.63 (3.93)	47.29 (7.15)
1984	246	50.96 (11.73)	30.27 (3.15)	47.14 (6.89)	42.02 (4.23)	44.60 (6.01)	39.60 (4.79)
1985	247	96.41 (13.53)	87.03 (10.99)	78.79 (10.78)	60.27 (6.86)	70.20 (13.27)	64.82 (7.55)
1986	252	76.48 (11.27)	59.76 (6.59)	66.91 (11.02)	62.85 (10.06)	48.59 (5.99)	42.16 (6.26)
1987	250	86.68 (17.65)	44.87 (6.60)	53.47 (7.53)	47.91 (7.41)	36.86 (6.74)	28.21 (2.78)
1988	86	198.34 (144.51)	34.14 (7.06)	27.28 (4.41)	31.52 (7.06)	16.73 (3.23)	10.86 (2.24)
1982–88	1575	72.20 (9.22)	49.18 (2.61)	54.33 (3.18)	53.54 (3.01)	45.80 (2.99)	48.77 (2.77)

^aThe variances are those of the relative price changes calculated as $(p_t/p_{t-1}) - 1$ and are multiplied by 10,000,000. The nearby contract is used until two weeks before expiration when we switch to the next-out contract. Beginning October 18, 1984 the Treasury bill opening was moved back from 8:00 CT to 7:30 CT. On October 15, 1985, both the Eurodollar and Treasury bill openings were moved back to 7:20 CT. The variances for the Eurodollar, Treasury bill and Treasury bond are estimated without the October 20, 1987 observation.

linkages between the fixed income markets and the currency markets are well-known. Given these interrelationships, the Federal Reserve Bank's open market operations that directly involve fixed income instruments may also impact the U.S. dollar exchange rates. However, the results in Panels D–H fail to reveal any elevation of hourly return volatility during Fed Time. Instead, the volatility in all the currency futures markets appears to decline throughout the day starting with the opening bell.

4.2. *Intrahour volatility*

The preceding section presents estimates based on hourly prices. However, an hourly return of zero may mask substantial fluctuation of prices during the hour. In this section, we report variances of two-minute returns to capture intrahour price movements. The results are reported in Table 2. The variances are calculated over half-hour periods and the analysis is concentrated on the time interval 10:00–12:00. The sample period for the two-minute results is October 6, 1982 to May 10, 1988 and, hence, 1982 and 1988 contain less than a full year of data.

Inferences based on the statistics in Table 2 are consistent with those based on Table 1. In short, volatility increases during Fed Time for fixed income instruments. However, the increase for fixed income contracts is far more dramatic. For Treasury bill futures, the volatility increases from 1.362 in the 11:00–11:30 interval to 35.248 during Fed Time in 1985. The variances follow similar patterns for the Eurodollar contract. In 1985, the variance increases from 2.284 in the 11:00–11:30 half hour to 77.147 during Fed Time. The Treasury bond volatilities are presented in the Panel C. In 1985, volatility increases from 27.297 to 274.900. The year 1985 is also not an exceptional year for the increased volatility during Fed Time. In almost every year for Treasury bill, Eurodollar, and Treasury bond futures, volatility rises by more than an order of magnitude. The heightened volatility during Fed Time is evident in the three panels of Fig. 1. The evidence for currency futures does not reveal a rise in volatility during Fed Time.

Table 2 also reports tests of the null hypothesis of equal variances between the Fed Time and the three preceding half hours. Not surprisingly, the null of variance equality is rejected in Panels A–C. Also as expected, tests of variance equality for the currency futures fail to reject the null with the notable exception of the Canadian dollar futures contract.

The results in Tables 1 and 2 suggest that the Federal Reserve Bank's practice of conducting open market operations during a designated time interval has induced changes in market participants' behavior. There are similarities to time intervals that experience regular macroeconomic news announcements. Volatility is higher during these times because any differences of opinion are resolved with the news announcement. There are also

Table 2
Intrahour volatility near Fed Time in financial markets^a

The model estimated is

$$\begin{aligned} \mathbf{u}_t &= \mathbf{r}_t - \boldsymbol{\mu}, \\ e_t &= (\mathbf{r}_t - \boldsymbol{\mu})^2 - \boldsymbol{\sigma}^2, \end{aligned} \tag{2}$$

where \mathbf{r}_t is a 1×4 vector of two-minute returns at time t over the four half-hour intervals, $\boldsymbol{\mu}$ are the means, $\boldsymbol{\sigma}$ are the variances, and \mathbf{u}_t, e_t are the disturbances. This system is exactly identified and is estimated by year. The hypothesis that the variance during Fed time is equal to the variance during one of the other half-hour periods is conducted with a Wald test. Heteroskedasticity-consistent standard errors are in parentheses. The sample is October 6, 1982 to May 10, 1988.

Year	σ^2 10–10:30	σ^2 10:30–11	σ^2 11–11:30	σ^2 11:30–12 <i>Fed Time</i>	χ^2 Fed Time $\sigma^2 =$ 10–10:30 σ^2	χ^2 Fed Time $\sigma^2 =$ 10:30–11 σ^2	χ^2 Fed Time $\sigma^2 =$ 11–11:30 σ^2
<i>(A) Treasury bill</i>							
1982	1.92 (0.064)	3.49 (0.15)	2.45 (0.08)	212.03 (59.12)	12.63 [<0.001]	12.44 [<0.001]	12.56 [<0.001]
1983	1.21 (0.02)	1.45 (0.06)	2.99 (1.75)	20.32 (5.76)	10.99 [<0.001]	10.71 [0.001]	8.27 [0.004]
1984	4.44 (2.29)	1.41 (0.05)	1.26 (0.03)	17.50 (4.19)	7.48 [0.006]	14.75 [<0.001]	15.04 [<0.001]
1985	5.25 (4.07)	2.51 (1.11)	1.36 (0.13)	35.25 (10.32)	7.31 [0.007]	9.94 [0.002]	10.77 [0.001]
1986	1.29 (0.17)	1.66 (0.48)	5.63 (2.75)	8.96 (2.89)	7.03 [0.008]	6.22 [0.012]	0.70 [0.403]
1987	4.17 (1.68)	7.87 (4.17)	18.17 (8.15)	54.93 (14.90)	11.46 [<0.001]	9.25 [0.002]	4.68 [0.030]
1988	1.27 (0.08)	1.31 (0.07)	1.40 (0.22)	1.44 (0.22)	0.54 [0.459]	0.33 [0.568]	0.02 [0.894]
<i>(B) Eurodollar</i>							
1982	4.66 (0.30)	9.20 (0.76)	58.38 (50.55)	282.82 (129.65)	4.60 [0.032]	4.45 [0.034]	2.60 [0.107]
1983	1.41 (0.04)	3.99 (2.25)	16.70 (8.13)	83.69 (20.89)	14.41 [<0.001]	14.39 [<0.001]	8.928 [0.002]
1984	1.32 (0.03)	1.87 (0.10)	1.35 (0.04)	129.26 (42.10)	9.23 [0.002]	9.16 [0.002]	9.23 [0.002]
1985	1.15 (0.02)	1.50 (0.07)	2.28 (1.05)	77.15 (25.25)	9.05 [0.003]	8.97 [0.003]	8.77 [0.003]
1986	1.09 (0.02)	1.36 (0.23)	1.77 (0.39)	4.32 (0.93)	12.04 [<0.001]	9.51 [0.002]	6.41 [0.011]
1987	1.69 (0.15)	1.52 (0.10)	1.96 (0.35)	51.28 (16.29)	9.26 [0.002]	9.32 [0.002]	9.16 [0.002]
1988	1.08 (0.03)	1.13 (0.04)	3.31 (2.24)	11.56 (4.77)	4.82 [0.028]	4.77 [0.029]	2.44 [0.118]

Table 2 (continued)

Year	σ^2 10–10:30	σ^2 10:30–11	σ^2 11–11:30	σ^2 11:30–12 <i>Fed Time</i>	χ^2 Fed Time $\sigma^2 =$ 10–10:30 σ^2	χ^2 Fed Time $\sigma^2 =$ 10:30–11 σ^2	χ^2 Fed Time $\sigma^2 =$ 11–11:30 σ^2
<i>(C) Treasury bond</i>							
1982	29.70 (1.05)	54.62 (4.18)	33.72 (1.08)	133.16 (21.50)	23.10 [<0.001]	12.86 [<0.001]	21.33 [<0.001]
1983	19.69 (0.66)	26.87 (1.18)	29.11 (4.19)	104.39 (14.23)	35.37 [<0.001]	29.29 [<0.001]	25.76 [<0.001]
1984	23.33 (0.60)	32.66 (1.21)	24.10 (0.71)	168.81 (24.78)	34.45 [<0.001]	30.12 [<0.001]	33.60 [<0.001]
1985	20.03 (0.56)	24.79 (0.84)	27.30 (6.50)	274.90 (42.55)	35.68 [<0.001]	34.53 [<0.001]	33.08 [<0.001]
1986	24.87 (1.09)	30.14 (10.24)	26.75 (1.18)	115.13 (15.05)	35.76 [<0.001]	31.72 [<0.001]	34.25 [<0.001]
1987	28.36 (1.27)	26.91 (1.12)	29.05 (4.09)	188.19 (24.39)	42.81 [<0.001]	43.63 [<0.001]	41.39 [<0.001]
1988	17.78 (1.03)	18.24 (0.86)	15.73 (0.79)	169.18 (43.21)	12.27 [<0.001]	12.19 [<0.001]	12.61 [<0.001]
<i>(D) British pound</i>							
1982	155.28 (18.33)	55.76 (5.09)	52.74 (5.48)	43.63 (4.26)	35.18 [<0.001]	3.34 [0.068]	1.72 [0.189]
1983	147.06 (22.47)	49.91 (5.4)	43.74 (5.12)	51.10 (5.65)	17.16 [<0.001]	0.02 [0.879]	0.93 [0.335]
1984	180.82 (19.32)	77.81 (7.38)	81.75 (7.80)	79.78 (8.53)	22.89 [<0.001]	0.03 [0.862]	0.03 [0.864]
1985	510.40 (66.22)	387.31 (33.17)	336.51 (31.72)	388.86 (35.05)	2.63 [0.105]	0.001 [0.974]	1.23 [0.268]
1986	505.47 (44.06)	440.83 (41.72)	391.20 (40.74)	457.62 (47.41)	0.55 [0.460]	0.07 [0.800]	1.13 [0.288]
1987	210.43 (22.34)	148.14 (16.57)	139.13 (16.36)	141.73 (17.80)	5.79 [0.016]	0.07 [0.792]	0.01 [0.914]
1988	249.75 (96.82)	79.75 (13.84)	92.40 (15.58)	107.28 (18.85)	2.09 [0.149]	1.39 [0.239]	0.37 [0.543]
<i>(E) Canadian dollar</i>							
1982	98.77 (10.51)	61.83 (8.03)	66.07 (8.40)	68.59 (9.07)	4.72 [0.298]	0.31 [0.577]	0.42 [0.838]
1983	24.60 (2.65)	9.12 (0.94)	9.66 (1.18)	9.97 (1.08)	33.46 [<0.001]	0.17 [0.683]	0.33 [0.563]
1984	49.68 (4.93)	18.15 (2.66)	14.31 (2.51)	16.54 (2.93)	33.461 [<0.001]	0.17 [0.683]	0.33 [0.563]

Table 2 (continued)

Year	σ^2 10–10:30	σ^2 10:30–11	σ^2 11–11:30	σ^2 11:30–12 <i>Fed Time</i>	χ^2 Fed Time $\sigma^2 =$ 10–10:30 σ^2	χ^2 Fed Time $\sigma^2 =$ 10:30–11 σ^2	χ^2 Fed Time $\sigma^2 =$ 11–11:30 σ^2
1985	3.28 (11.95)	71.45 (9.37)	68.61 (9.03)	96.10 (12.66)	0.97 [0.324]	2.45 [0.118]	3.12 [0.077]
1986	221.71 (24.14)	199.81 (24.94)	167.27 (23.67)	123.16 (20.88)	9.53 [0.002]	5.55 [0.018]	1.95 [0.162]
1987	75.79 (10.97)	31.18 (3.98)	49.33 (5.77)	39.90 (5.40)	8.62 [0.003]	1.69 [0.193]	1.43 [0.232]
1988	85.36 (13.94)	61.08 (13.09)	71.21 (13.97)	29.07 (9.10)	11.44 [0.001]	4.033 [0.045]	6.39 [0.011]
<i>(F) Deutsche mark</i>							
1982	508.32 (48.49)	483.25 (49.83)	372.40 (43.38)	389.34 (47.71)	3.06 [0.080]	1.85 [0.173]	0.07 [0.793]
1983	549.18 (45.31)	454.80 (41.88)	485.26 (43.50)	539.68 (48.59)	0.02 [0.886]	1.75 [0.186]	0.70 [0.404]
1984	480.53 (49.98)	450.34 (50.24)	586.07 (58.64)	532.20 (56.22)	0.47 [0.492]	1.18 [0.278]	0.44 [0.507]
1985	269.62 (22.75)	246.95 (21.78)	223.12 (21.20)	240.62 (22.07)	0.84 [0.36]	0.04 [0.838]	0.33 [0.568]
1986	129.10 (12.72)	109.55 (11.08)	127.26 (12.16)	121.10 (12.06)	0.17 [0.682]	0.57 [0.450]	0.10 [0.755]
1987	295.47 (26.20)	274.80 (25.47)	284.22 (27.55)	258.45 (26.05)	1.00 [0.316]	0.20 [0.654]	0.46 [0.497]
1988	275.51 (41.97)	226.84 (37.46)	167.48 (33.18)	267.36 (42.83)	0.02 [0.892]	0.51 [0.476]	3.40 [0.065]
<i>(G) Japanese yen</i>							
1982	750.68 (84.48)	638.28 (81.73)	563.85 (78.68)	619.81 (85.05)	1.19 [0.275]	0.02 [0.876]	0.23 [0.629]
1983	312.55 (27.17)	235.03 (22.13)	255.08 (23.41)	223.03 (22.39)	6.47 [0.110]	0.15 [0.703]	0.98 [0.322]
1984	506.28 (51.10)	535.29 (55.37)	492.20 (55.45)	446.18 (54.36)	0.65 [0.421]	1.32 [0.251]	0.35 [0.553]
1985	134.48 (13.92)	90.07 (10.80)	93.84 (11.55)	104.57 (12.62)	2.53 [0.111]	0.76 [0.383]	0.39 [0.531]
1986	131.24 (15.60)	74.28 (7.12)	79.64 (8.05)	82.84 (8.21)	7.54 [0.006]	0.62 [0.431]	0.078 [0.780]
1987	253.25 (23.34)	236.98 (21.83)	221.20 (21.34)	206.23 (21.05)	2.24 [0.135]	1.03 [0.311]	0.25 [0.618]
1988	106.96 (18.27)	117.60 (19.84)	112.70 (19.55)	111.68 (19.73)	0.03 [0.861]	0.04 [0.832]	0.001 [0.971]

Table 2 (continued)

Year	σ^2 10–10:30	σ^2 10:30–11	σ^2 11–11:30	σ^2 11:30–12 <i>Fed Time</i>	χ^2 Fed Time $\sigma^2 =$ 10–10:30 σ^2	χ^2 Fed Time $\sigma^2 =$ 10:30–11 σ^2	χ^2 Fed Time $\sigma^2 =$ 11–11:30 σ^2
<i>(H) Swiss franc</i>							
1982	1048.76 (108.63)	1145.40 (114.90)	829.50 (99.23)	935.46 (108.37)	0.55 [0.460]	1.77 [0.184]	0.52 [0.471]
1983	700.22 (62.23)	615.31 (58.37)	760.91 (65.34)	599.75 (58.76)	1.38 [0.240]	0.04 [0.851]	3.36 [0.067]
1984	754.74 (78.85)	794.12 (81.36)	753.31 (80.44)	782.36 (84.80)	0.057 [0.81]	0.01 [0.920]	0.06 [0.804]
1985	237.65 (22.89)	228.86 (22.63)	251.80 (24.17)	265.86 (24.84)	0.70 [0.404]	1.21 [0.271]	0.165 [0.685]
1986	163.12 (17.07)	124.68 (12.62)	123.43 (13.38)	132.30 (13.62)	2.00 [0.158]	0.17 [0.682]	0.216 [0.642]
1987	276.36 (25.34)	224.60 (21.72)	221.98 (21.43)	237.80 (22.54)	1.29 [0.256]	0.18 [0.673]	0.26 [0.611]
1988	298.09 (60.29)	399.22 (70.38)	358.46 (66.52)	360.87 (68.60)	0.47 [0.492]	0.15 [0.696]	0.001 [0.980]

^a The variances are those of the relative price changes calculated as $\ln(p_t/p_{t-1})$ and are multiplied by 10,000,000. The nearby contract is used until 2 weeks before expiration when we switch to the next-out contract.

differences. Market participants know the Fed will intervene during the Fed Time interval but they do not know the particular day that they will intervene. In addition, even if the Fed is active during Fed Time, it is not transparent to the market what the policy goals are. Hence, it makes sense that volatility during the Fed Time interval is high, irrespective of whether the Fed is actually intervening on a particular day.

4.3. Open market operations: returns and volatility

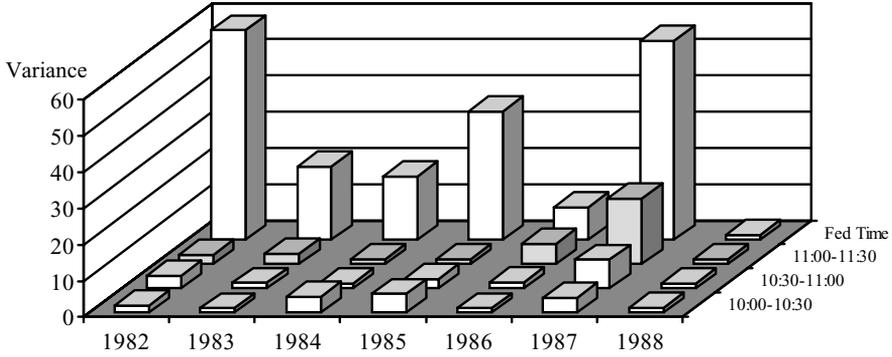
This section examines the impact of the specific open market operations. Some summary statistics on the open market operations are presented in Table 3. Five operations are presented: MSPs, outright sales, outright purchases, system RPs, and customer RPs. Data on foreign purchases and sales are also available but are not included as they tend to be small and are unlikely to impact the financial markets.

Table 3 also presents data on the average federal funds rate during the period, the target federal funds rate and the standard deviation of the gap. Differences in the rate and the target as well as the volatility of the gap may yield information about the intensity of the open market operations. In

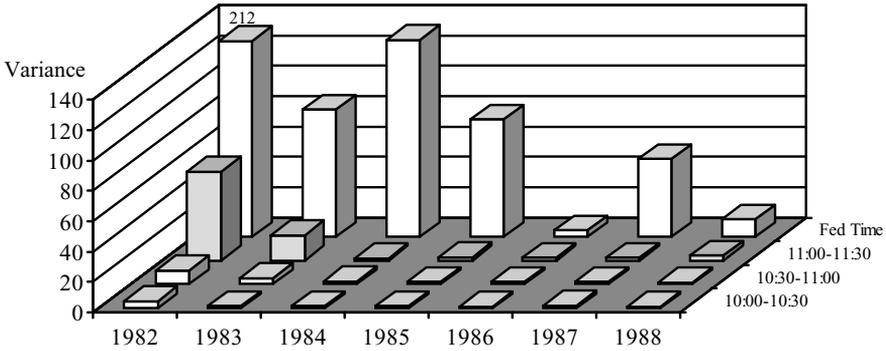
Intrahour Volatility

Based on two-minute returns in half-hour

A. Treasury bill futures



B. Eurodollar futures



C. Treasury bond futures

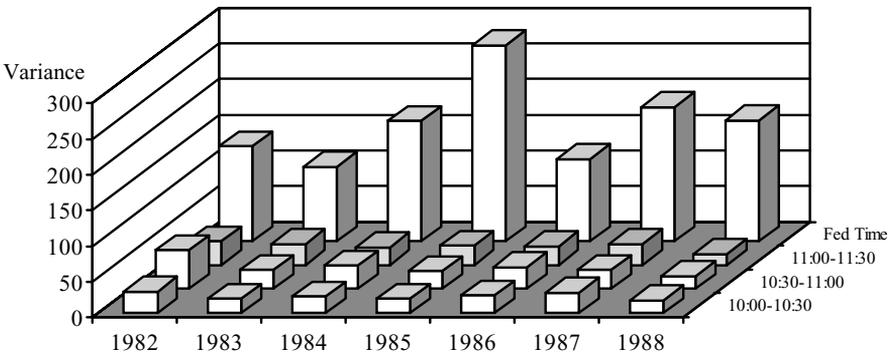


Fig. 1. Intrahour volatility of financial futures contracts.

Table 3
Size and frequency of open-market operations (in billions)^a

Year/operation	Matched sales-purchases	Outright purchases	Outright sales	System repos	Customer repos	Actual Fed Funds rate	Target Fed Funds rate	Std. dev. Fed Funds gap	Total reserves
1982 [days]	2.02 [4]	0.83 [4]	— [0]	2.75 [10]	1.37 [19]	9.23	9.21	0.570	41.16
1983 [days]	1.76 [8]	1.34 [8]	— [0]	4.7 [31]	1.52 [105]	9.10	9.00	0.320	48.85
1984 [days]	2.75 [20]	1.67 [8]	1.08 [1]	4.67 [38]	1.69 [75]	10.25	10.24	0.500	47.84
1985 [days]	2.44 [15]	2.14 [8]	1.5 [1]	4.91 [40]	1.72 [68]	8.11	8.05	0.481	42.83
1986 [days]	2.35 [9]	2.37 [6]	— [0]	4.2 [48]	1.82 [88]	6.81	6.64	0.866	50.84
1987 [days]	4.09 [6]	2.79 [8]	1.53 [1]	5.81 [66]	1.83 [81]	6.63	6.54	0.274	59.28
1988 [days]	2.82 [10]	4.29 [2]	— [0]	4.21 [11]	1.62 [22]	6.72	6.66	0.210	61.29
1982–88 [days]	2.52 [72]	1.99 [44]	1.37 [3]	4.39 [245]	1.69 [458]	8.13	8.05	0.520	46.72

^aData begins on October 6, 1982 when the Federal Reserve switched its operating policies from money supply targeting to borrowed reserves/Fed Funds rate targeting.

addition, to appreciate the magnitude of the operations, data on total reserves of the banking sector are presented year by year.

The summary statistics show that the largest operation is the system RP averaging \$4.39 billion over the sample. There are 245 occurrences of this operation from 1982–1988. Given that the average total reserves are \$46.72 billion over the sample, this specific operation represents almost 10% of the total reserves.

The MSP is the second largest operation averaging \$2.52 billion followed by the outright purchases at \$1.99 billion. The customer repos are most frequently used for a total of 458 occurrences with an average size of \$1.69 billion. In the sample, there are only three outright sales. As a result, we drop this open market operation from further analysis.

The effect of the operations on the volatilities of two-minute returns during Fed Time is reported in Table 4. The table shows average yearly volatilities on days when specific operations are conducted, on days combining all the open market operations, and on days without open market operations. A χ^2 test of the equality of variances between days with and without operations is also provided. In contrast to (3), these estimates are obtained using data one year at a time.

The first five rows of each panel in the table show the volatility and the significance of specific operations by year. The results for Treasury bill, Eurodollar and Treasury bond contracts show that there are swings in the precision of the variance estimates by year and by operation. In contrast, the foreign currency volatilities for individual operations are generally significant for the five exchange rates.

The last three rows of each panel in Table 4 compare volatilities between days with and without operations. They reveal a striking pattern. With minor exceptions, the volatility on days with open market operations is *less* than the volatility on days without open market operations for all three fixed income instruments and five foreign currency contracts. When the exceptions do occur, a formal test cannot reject the null hypothesis of equal volatility in every case. The pattern is observed for every year in the sample. The results are more pronounced for currency futures than for fixed income contracts in that the null of variance equality is generally rejected.

These results are surprising because most models of actual volatility presume that it is due to news arrival, i.e., that volatility is high when there is considerable news and low when there is little news. A lack of Fed action when action was expected would provide some information and move markets somewhat. This might explain why volatility is higher during the normal Fed time even on days when the Fed does not take actions. The puzzle is why is volatility higher during Fed Time on days when the Fed does not act compared to days when it takes actions.

While not reported in the table, multivariate tests which include all the years were feasible for three contracts: Treasury bill, Eurodollar and the British

Table 4

The effect of open market operations on volatility based on two-minute returns during Fed Time^a

The model estimated is

$$\mathbf{u}_{FT,t} = \mathbf{r}_{FT,t} - \left(\sum_{y=1982}^{1988} \sum_{j=1}^6 \mu_{y,j} \mathbf{I}_{y,j,t}^{OMO} \right),$$

$$\mathbf{e}_{FT,t} = \mathbf{u}_{FT,t}^2 - \left(\sum_{y=1982}^{1988} \sum_{j=1}^6 v_{y,j} \mathbf{I}_{y,j,t}^{OMO} \right),$$

where j represents the type of operation (outright purchase, outright sale, matched-sale purchase, system repo, customer repo, and no operation), y represents the year, \mathbf{I}^{OMO} is an indicator variable for the open market operations. In this formulation, $\mathbf{r}_{FT,t}$ is a 15×1 vector of two-minute returns in Fed Time for time period t . $\mathbf{u}_{FT,t}$ and $\mathbf{e}_{FT,t}$ are the disturbance terms associated with the mean and variance equations. The parameters μ and v are estimated of the means and variances by operation and by year. There is no intercept because the indicator variables sum to unity. The system is exactly identified. For most of the results, the system is estimated year by year. For the test of whether the variance is different on days with operations versus days without operations, the system is estimated with two mean and two variance parameters. A Wald test is conducted on the variance parameters. Heteroskedasticity-consistent standard errors are in parentheses. The sample is October 6, 1982 to May 10, 1988.

Open market operation	1982	1983	1984	1985	1986	1987	1988
<i>(A) Treasury bill</i>							
Matched sales purchases	36.29 (28.90)	1.13 (0.11)	10.57 (9.17)	1.43 (0.16)	1.06 (0.14)	1.30 (0.189)	2.39 (1.25)
Open market purchases	67.70 (63.29)	70.82 (67.75)	1.74 (0.32)	1.59 (0.33)	1.03 (0.13)	116.39 (110.08)	—
Open market sales	—	—	0.77 (0.52)	1.16 (0.13)	—	—	—
System repurchases	12.87 (8.10)	1.25 (0.06)	13.51 (8.20)	20.84 (11.70)	5.74 (4.66)	29.92 (20.47)	1.30 (0.28)
Customer repurchases	30.68 (17.14)	26.96 (10.76)	13.94 (7.47)	14.65 (6.85)	11.33 (5.53)	50.67 (28.95)	1.15 (0.11)
Days with operations	31.66 (12.18)	22.63 (8.27)	12.62 (4.57)	14.65 (5.26)	8.75 (3.67)	44.10 (17.62)	1.54 (0.37)
Days without operations	237.75 (67.48)	16.86 (7.34)	23.56 (7.46)	60.03 (21.70)	9.23 (4.61)	73.23 (26.74)	1.37 (0.26)
χ^2 test: $\hat{\sigma}^2(OMO) = \hat{\sigma}^2(\text{no OMO})$	9.033 [0.003]	0.273 [0.602]	1.563 [0.211]	4.130 [0.042]	0.007 [0.936]	0.827 [0.363]	0.152 [0.697]
<i>(B) Eurodollar</i>							
Matched sales purchases	84.33 (71.48)	1.50 (0.32)	1.34 (0.09)	1.36 (0.16)	1.16 (0.14)	1.12 (0.05)	17.05 (15.38)
Open market purchases	175.06 (138.96)	588.24 (276.33)	1.78 (0.27)	2.79 (1.04)	1.02 (0.09)	1.06 (0.11)	1.03 (0.14)

Table 4 (continued)

Open market operation	1982	1983	1984	1985	1986	1987	1988
Open market sales	—	—	—	1.16 (0.21)	—	—	—
System repurchases	3.15 (1.15)	61.17 (41.28)	19.89 (15.06)	74.99 (63.48)	3.22 (1.87)	1.68 (0.174)	1.13 (0.04)
Customer repurchases	44.69 (27.89)	33.76 (20.32)	159.04 (103.80)	80.43 (54.91)	2.42 (0.77)	47.05 (28.77)	21.17 (19.41)
Days with operations	55.29 (24.68)	60.18 (24.03)	68.20 (40.60)	66.46 (35.24)	2.60 (0.77)	22.23 (13.13)	14.45 (9.34)
Days without operations	327.55 (154.88)	119.77 (37.59)	197.31 (76.37)	89.48 (36.07)	6.52 (1.87)	103.42 (38.60)	9.63 (4.93)
χ^2 test: $\sigma^2(\text{OMO}) = \sigma^2(\text{no OMO})$	3.013 [0.083]	1.784 [0.182]	2.228 [0.136]	0.208 [0.648]	3.750 [0.053]	3.965 [0.046]	0.205 [0.651]
<i>(C) Treasury bond</i>							
Matched sales purchases	189.01 (133.65)	112.84 (80.58)	96.50 (66.48)	269.86 (174.17)	28.91 (3.67)	221.02 (193.41)	359.24 (191.32)
Open market purchases	207.68 (177.91)	173.50 (110.70)	45.81 (7.83)	247.16 (214.87)	24.47 (4.80)	257.89 (152.04)	23.62 (6.89)
Open market sales	—	—	20.11 (4.42)	22.50 (5.77)	—	14.66 (4.92)	—
System repurchases	184.89 (112.34)	45.63 (17.80)	210.29 (70.74)	222.45 (92.09)	123.39 (36.49)	103.92 (27.88)	20.26 (3.31)
Customer repurchases	153.15 (67.24)	112.93 (23.38)	176.06 (43.58)	191.73 (64.86)	96.27 (23.36)	193.89 (44.25)	179.45 (91.95)
Days with operations	176.95 (53.31)	99.85 (17.93)	168.29 (32.15)	205.25 (49.81)	100.88 (18.60)	156.44 (26.83)	193.15 (70.50)
Days without operations	121.32 (23.20)	111.04 (23.24)	169.38 (38.27)	346.58 (69.34)	135.05 (25.02)	242.42 (47.46)	150.63 (53.83)
χ^2 test: $\sigma^2(\text{OMO}) = \sigma^2(\text{no OMO})$	0.916 [0.339]	0.145 [0.703]	0.000 [0.983]	2.740 [0.098]	1.201 [0.273]	2.487 [0.115]	0.230 [0.632]
<i>(D) British pound</i>							
Matched sales purchases	39.21 (13.99)	19.97 (3.03)	26.96 (2.59)	30.01 (5.54)	16.11 (2.10)	16.62 (4.67)	92.59 (47.86)
Open market purchases	22.46 (7.57)	64.13 (23.11)	31.06 (6.29)	562.19 (179.84)	23.21 (4.64)	16.47 (2.92)	9.69 (2.87)
Open market sales	—	—	21.09 (3.94)	38.21 (9.57)	—	12.09 (3.18)	—
System repurchases	15.76 (1.44)	25.38 (2.77)	139.85 (33.48)	204.89 (54.76)	117.36 (45.11)	66.82 (23.59)	14.10 (2.43)

Table 4 (continued)

Open market operation	1982	1983	1984	1985	1986	1987	1988
Customer repurchases	13.22 (1.10)	46.17 (8.31)	82.60 (14.63)	325.60 (60.44)	403.03 (81.28)	261.38 (49.13)	48.32 (26.53)
Days with operations	19.09 (2.31)	40.65 (5.87)	90.25 (12.67)	243.84 (36.98)	285.75 (52.17)	154.22 (25.58)	53.43 (18.99)
Days without operations	47.49 (4.92)	66.74 (11.03)	67.83 (11.15)	540.68 (60.14)	681.03 (84.89)	120.91 (20.85)	148.43 (29.75)
χ^2 test: $\sigma^2(\text{OMO}) = \sigma^2(\text{no OMO})$	27.294 [<0.001]	4.361 [0.037]	1.765 [0.184]	17.679 [<0.001]	15.738 [<0.001]	1.018 [0.313]	7.246 [0.007]
<i>(E) Canadian dollar</i>							
Matched sales purchases	67.66 (61.76)	3.02 (0.67)	5.91 (0.71)	13.86 (6.61)	19.67 (7.55)	3.05 (0.48)	2.77 (0.40)
Open market purchases	4.10 (1.11)	7.27 (5.03)	5.07 (1.30)	139.11 (51.24)	3.06 (0.79)	4.52 (0.81)	2.42 (0.69)
Open market sales	—	—	—	5.35 (1.21)	—	2.47 (0.10)	—
System repurchases	4.15 (0.60)	4.26 (1.55)	7.90 (1.63)	36.21 (10.30)	24.09 (11.57)	9.28 (2.57)	4.75 (1.10)
Customer repurchases	66.37 (24.92)	7.92 (1.39)	9.28 (2.25)	93.76 (22.95)	154.72 (45.04)	36.43 (8.75)	30.24 (18.61)
Days with operations	44.82 (15.65)	6.86 (1.07)	8.11 (1.21)	63.70 (12.98)	105.59 (28.53)	23.23 (4.77)	17.96 (10.03)
Days without operations	72.36 (10.21)	14.27 (2.10)	25.26 (5.77)	134.39 (22.87)	144.19 (30.53)	67.26 (11.79)	38.13 (14.25)
χ^2 test: $\sigma^2(\text{OMO}) = \sigma^2(\text{no OMO})$	2.171 [0.141]	9.883 [0.002]	8.448 [0.004]	7.229 [0.007]	0.853 [0.356]	11.993 [0.001]	1.339 [0.247]
<i>(F) Deutsche mark</i>							
Matched sales purchases	153.73 (139.57)	10.10 (1.44)	19.75 (2.67)	18.92 (2.53)	11.15 (1.62)	9.54 (1.61)	516.10 (172.11)
Open market purchases	154.57 (141.50)	1639.95 (463.68)	29.88 (7.83)	302.18 (138.71)	12.53 (2.72)	13.44 (3.17)	12.04 (3.67)
Open market sales	—	—	9.56 (2.97)	27.67 (12.06)	—	9.87 (4.00)	—
System repurchases	10.27 (1.10)	287.65 (103.39)	379.16 (123.02)	129.49 (41.18)	99.63 (27.98)	42.74 (12.11)	11.32 (2.60)
Customer repurchases	331.67 (104.58)	382.39 (60.61)	715.23 (131.92)	199.57 (37.92)	103.56 (18.68)	242.19 (39.49)	148.45 (63.96)
Days with operations	215.20 (60.89)	407.67 (53.61)	491.56 (78.48)	149.61 (23.93)	96.45 (14.61)	139.49 (20.42)	221.58 (59.02)
Days without operations	418.96 (54.83)	731.77 (89.79)	577.53 (80.41)	333.17 (37.14)	155.29 (20.23)	452.25 (59.23)	304.16 (60.81)

Table 4 (continued)

Open market operation	1982	1983	1984	1985	1986	1987	1988
χ^2 test:	6.184	9.605	0.585	17.262	5.560	24.920	0.950
$\sigma^2(\text{OMO}) = \sigma^2(\text{no OMO})$	[0.013]	[0.002]	[0.444]	[<0.001]	[0.018]	[<0.001]	[0.330]
<i>(G) Japanese yen</i>							
Matched sales purchases	127.87 (108.65)	7.37 (0.85)	8.02 (0.68)	9.75 (1.10)	9.63 (1.38)	7.43 (1.60)	103.13 (56.46)
Open market purchases	183.59 (113.35)	976.60 (263.80)	8.12 (1.45)	19.24 (3.98)	5.67 (1.00)	11.84 (2.45)	17.44 (3.84)
Open market sales	—	—	4.17 (1.166)	6.44 (0.00)	—	6.67 (2.32)	—
System repurchases	19.60 (6.42)	95.60 (37.55)	566.00 (166.99)	141.03 (42.74)	43.50 (14.31)	30.95 (8.57)	10.49 (1.60)
Customer repurchases	150.64 (53.36)	162.28 (28.88)	412.62 (101.44)	77.93 (23.01)	70.14 (12.75)	161.73 (30.81)	64.38 (29.65)
Days with operations	121.76 (34.28)	176.75 (25.83)	381.43 (72.01)	85.46 (17.77)	58.09 (9.16)	93.55 (15.62)	65.19 (22.57)
Days without operations	713.22 (100.67)	294.10 (40.51)	522.83 (82.55)	124.84 (17.89)	115.36 (14.65)	396.31 (49.56)	147.85 (30.26)
χ^2 test:	30.934	5.966	1.666	2.439	10.988	33.949	4.794
$\sigma^2(\text{OMO}) = \sigma^2(\text{no OMO})$	[<0.001]	[0.015]	[0.197]	[0.118]	[0.001]	[<0.001]	[0.029]
<i>(H) Swiss franc</i>							
Matched sales purchases	2668.07 (1015.97)	15.53 (3.11)	14.84 (1.49)	20.22 (2.62)	12.21 (1.89)	10.46 (1.69)	851.93 (310.28)
Open market purchases	1854.82 (887.48)	1650.39 (525.71)	25.68 (4.98)	623.32 (239.12)	12.52 (1.97)	11.64 (2.39)	17.19 (4.38)
Open market sales	—	—	5.99 (2.33)	9.95 (2.45)	—	12.56 (5.77)	—
System repurchases	14.17 (1.81)	110.28 (70.94)	1050.22 (265.53)	226.60 (61.48)	74.22 (25.80)	38.52 (8.69)	13.21 (2.17)
Customer repurchases	596.82 (233.53)	425.58 (78.47)	1089.35 (187.96)	127.98 (33.81)	100.72 (20.47)	212.00 (34.99)	59.22 (54.30)
Days with operations	847.83 (204.68)	400.60 (63.29)	892.55 (127.24)	141.17 (26.15)	86.82 (15.16)	124.17 (18.14)	258.60 (88.25)
Days without operations	950.96 (122.301)	895.22 (110.78)	655.98 (108.76)	395.08 (42.44)	191.73 (24.29)	426.90 (51.49)	440.74 (100.68)
χ^2 test:	0.187	15.030	1.997	25.945	13.427	30.748	1.851
$\sigma^2(\text{OMO}) = \sigma^2(\text{no OMO})$	[0.665]	[<0.001]	[0.158]	[<0.001]	[<0.001]	[<0.001]	[0.174]

^aThe variances are those of the relative price changes calculated as $\ln(p_t/p_{t-1})$ and are multiplied by 10,000,000. The nearby contract is used until 2 weeks before expiration when we switch to the next-out contract.

pound. In the year by year univariate tests for the Treasury bill, volatility equality on days with and without operations was rejected in two of the seven years. The multivariate test rejects the null hypothesis of variance equality with a p -value of 0.026. Similar results are obtained with the Eurodollar. For all the years together, the equality of the Eurodollar variance on days with operations and on nonoperation days is rejected at the 0.033 level. The results for the British pound suggest that the null of equal variances can be rejected at the 0.001 level.

The evidence presented in Table 4 indicates that the decreased volatility during Fed Time is due not so much to the absence of the Federal Reserve Bank's open market operations, as to the presence of these operations! These results can be examined in terms of Fed behavior. The Fed may have chosen to conduct its open market operations at times when it thinks markets would be too volatile otherwise. It is also possible that they select days when not much is happening in the market. There is qualitative evidence that supports this interpretation. Meulendyke (1988) notes that:

Desk officers also take market conditions into account in choosing the day to arrange an outright operation. They try to avoid conducting operations in rapidly rising or falling markets, not wishing either to add to market volatility or to impede price adjustment.

While it is clear that volatility is lower when the Fed is conducting operations, it is important to remember that Fed Time has already elevated market volatility above the adjacent time periods.

An issue that arises is whether our results are due to the day-of-the-week effect. Perhaps the higher volatility on days when the Fed does not take action is due to something other than Fed's action or inaction. In particular, it has often been observed that market volatility is higher on Fridays. Evidence from earlier research is inconsistent with this possibility because the higher volatility on Fridays can be traced to public macroeconomic announcements. Harvey and Huang (1991) examine volatility in the foreign currency futures market during the 1980s by time of the day and day of the week. Their results show that Fridays have the highest volatilities. However, the higher Friday volatilities are due to higher volatilities around 7:30 am to 8:30 am Central Time and coincide with the release of U.S. macroeconomic news. Ignoring the opening time of the futures market, Friday volatilities do not appear elevated. Harvey and Huang (1994) find that Fridays do not exhibit the highest volatility during the 1980s for Eurodollar and Treasury bill futures. In investigating the intraday Deutsche mark-dollar volatility patterns, Andersen and Bollerslev (1998) find that "the clustering of public information releases on certain weekdays explains the day-of-week effect". Ederington and Lee (2000) also conclude that "most of the high volatility on Friday seems due to the tendency for major macroeconomic announcements to be released on Fridays".

Table 5 further classifies open market operations into reserve-draining and reserve-adding operations and examines their impact on returns and volatilities during Fed Time.⁸ For this analysis, all days with both reserve-adding and reserve-draining operations are thrown out. Outright sales and MSPs drain reserves and should increase interest rates, reducing prices and producing negative returns. Outright purchases and system RPs add to reserves and should increase market prices. Customer RPs also add to reserves but given that they are smaller than the system RPs, we exclude them from the addition category.⁹ However, these predictions may fail to materialize if the market participants are unable to discern the Fed's policy targets.

The results show that for both fixed income and currency futures contracts, the estimated returns often have the wrong signs. For example, negative returns are observed for every year in the sample for Treasury bonds for reserve-adding operations contrary to prediction. More interestingly, Table 5 also reports tests of return equality for reserve-adding and reserve-draining operations. For every financial market that we examine, the test results show that the impact on returns of reserve-adding operations cannot be distinguished reliably from reserve-draining operations. Multivariate tests of whether the year-by-year means are the same for draining and adding operations combining all seven years of data also fail to reject the null hypothesis for all contracts. Thus, it appears that over our sample period, open market operations do not have the predicted impact on market returns. These results suggest that when open market operations are conducted, their purposes are not well anticipated by the market place. Indeed, the market participants are unable to infer the type of intervention the Federal Reserve Bank intends to apply.

A similar analysis is conducted for volatilities in Table 5. In particular, year-by-year tests of variance equality generally do not reject the null hypothesis of equal volatility for fixed income instruments. For both Treasury bill and Eurodollar contracts, market volatility when reserves are added is greater than the volatility when reserves are drained for five of seven years but are only significantly different at the 10% level in two of these years. A multivariate test of variance equality across all the years jointly rejects the hypothesis that the variances are the same at the 5% level of significance for Eurodollar futures. However, for Treasury bill futures, the multivariate test fails to reject the null hypothesis of equal variance. For Treasury bonds, adding volatility is significantly greater than draining volatility in 1986, but the multivariate test fails to reject the hypothesis of equal volatility with a p -value of 0.12.

⁸The results for the impact of individual operations on returns are available from the authors on request.

⁹When the Fed purchase U.S. government securities for a customer, such as a foreign central bank, the primary dealers do not know who the customer is. The primary dealers also do not know with any certainty that the trade is for a customer and not for the Fed's own account. Indeed, even settlement of the trade is masked so that the exact counterparty cannot be determined.

The results for currency futures are different. For the years 1983 to 1987, reserve-adding volatilities significantly exceed reserve-draining volatilities in almost all cases. The variances for 1982 and 1988 with less than full year's data are insignificantly different between the two types of operations. For all the years, the multivariate tests easily reject the null hypothesis of equal variances at the 0.001 level of significance.

The evidence in Table 5 is consistent with market participants' inability to identify the purpose of the open market operations. This would account for the inability of our tests to distinguish the impact on the financial contract's returns of reserve-adding versus reserve-draining operations. However, there appears to be an asymmetric effect on volatility. It is possible that adding operations signal some fundamental information about weakness in the economy which translates into market volatility.

5. Conclusions

The Federal Reserve Bank is a unique trader whose actions reveal information about monetary policy. The trading is concentrated during the half-hour known as Fed Time. We find that market volatility is dramatically higher during this half hour than surrounding times. However, this increased volatility is independent of whether the Fed actually trades in the market. In fact, there is some evidence that volatility is lower during Fed Time when the Fed trades than when it does not trade.

We also examine how the market differentiates between reserve-adding and reserve-draining operations by the Federal Reserve Bank. Reserve-adding volatility appears to be higher than reserve-draining volatility for both fixed income and currency futures. More startling is the result that the effects on futures returns of reserve-draining and reserve-adding operations are statistically indistinguishable from one another.

Our results suggest that from 1982 to 1988, the markets try to infer the Fed's policy by its behavior during Fed Time. Volatility is high during this interval because of uncertainty as to whether the Fed will intervene during a particular day and difficulty (and disagreement) in interpreting Fed actions or inactions. Indeed, our results suggest that the Fed is successful in keeping secret the conduct of its monetary policy. Interestingly, we find that volatility is lower during Fed Time when the Fed conducts open market operations than when it does not. This is consistent with the Fed actions smoothing the expectations of market participants.

There are many other research paths that could be undertaken with richer data. For example, there is the endogeneity issue of Fed reacting to market volatility and Fed inducing market volatility. There is the challenge of disentangling the effects of Fed's defensive operations from offensive operations. These two issues also may not be independent of one another. Is it the case that

Table 5

The effect of reserve adding and draining operations on returns and volatility^a

The model estimated is

$$u_{FT,t} = r_{FT,t} - \left(\sum_{y=1982}^{1988} \sum_{i=1}^3 \mu_{y,i} I_{y,i,t}^{FLOW} \right),$$

$$e_{FT,t} = u_{FT,t}^2 - \left(\sum_{y=1982}^{1988} \sum_{i=1}^3 v_{y,i} I_{y,i,t}^{FLOW} \right),$$

where i represents the purpose of the operation: Addition (outright purchase, system repo); Drain (outright sale, matched sale-purchase); No action. Customer repos are also an addition operation, however, they are less likely to be viewed as linked to policy and we do not include them in the addition category. y represents the year and the indicator $I_{y,i}^{FLOW}$ takes on a value of one during year y and for operation purpose i . In this formulation, $r_{FT,t}$ is up to a 15×1 vector of two minute returns in Fed Time for time period t . $u_{FT,t}$ and $e_{FT,t}$ are the disturbance terms associated with the mean and variance equations. The parameters μ and v are estimates of the means and variances by purpose of operation and by year. There is no intercept because the indicator variables sum to unity. The system is exactly identified. For most of the results, the system is estimated year by year. A Wald test is conducted to test the equality of variances and means. The parameters for days with no operations are not reported. If there is a day with both an adding and draining operation, the day is omitted from the sample. Heteroskedasticity-consistent standard errors are in parentheses. The sample is October 6, 1982 to May 10, 1988.

Open market operation	1982	1983	1984	1985	1986	1987	1988	Multivariate tests
<i>(A) Treasury bill</i>								
Returns-add	-5.61	-1.91	-1.51	-1.49	0.75	-6.29	2.20	
Returns-drain	-1.07	1.13	-2.89	0.72	3.72	-3.25	-4.14	
χ^2	0.232	1.258	0.171	0.479	1.336	0.451	2.024	5.773
p -Value	[0.630]	[0.262]	[0.679]	[0.489]	[0.248]	[0.502]	[0.155]	[0.557]
Variance-add	28.35	15.53	11.49	19.39	5.05	42.18	1.26	
Variance-drain	36.29	1.13	10.69	1.41	1.06	1.51	2.39	
χ^2	0.053	1.028	0.005	2.750	1.014	2.970	0.792	8.303
p -Value	[0.819]	[0.311]	[0.944]	[0.097]	[0.314]	[0.085]	[0.374]	[0.307]
<i>(B) Eurodollar</i>								
Returns-add	-7.92	-20.72	-2.99	-3.10	-0.59	0.66	0.86	
Returns-drain	-18.98	-3.61	-0.41	0.27	0.95	-0.92	-5.28	
χ^2	0.159	2.212	0.933	0.749	0.478	0.674	0.845	5.872
p -Value	[0.690]	[0.137]	[0.334]	[0.387]	[0.489]	[0.412]	[0.358]	[0.554]

Variance-add	59.26	130.85	15.99	68.65	2.95	1.65	1.09	
Variance-drain	84.33	1.50	1.34	1.35	1.16	1.18	17.05	
χ^2	0.082	3.727	1.532	1.353	1.178	6.038	1.076	13.961
<i>p</i> -Value	[0.775]	[0.054]	[0.216]	[0.245]	[0.278]	[0.014]	[0.300]	[0.052]
<i>(C) Treasury bond</i>								
Returns-add	-12.11	-5.15	-15.88	-13.85	-13.39	-8.62	5.34	
Returns-drain	-0.07	-12.11	-6.97	-14.82	-2.28	-8.20	-26.88	
χ^2	0.312	0.389	1.159	0.006	3.340	0.001	3.021	8.102
<i>p</i> -Value	[0.577]	[0.533]	[0.282]	[0.938]	[0.068]	[0.976]	[0.082]	[0.324]
Variance-add	191.61	58.73	183.23	235.84	113.74	111.39	20.68	
Variance-drain	189.01	112.84	96.56	254.38	28.91	190.40	359.24	
χ^2	0.000	0.417	0.951	0.010	6.557	0.223	3.131	11.244
<i>p</i> -Value	[0.987]	[0.518]	[0.329]	[0.921]	[0.010]	[0.637]	[0.077]	[0.128]
<i>(D) British pound</i>								
Returns-add	5.82	-1.49	1.71	-10.84	0.32	0.52	0.06	
Returns-drain	-1.42	-5.60	-0.78	-0.37	2.38	-3.29	-6.03	
χ^2	0.511	0.484	0.132	1.537	0.113	0.391	0.307	3.454
<i>p</i> -Value	[0.475]	[0.486]	[0.716]	[0.215]	[0.737]	[0.532]	[0.579]	[0.840]
Variance-add	18.83	30.32	122.97	275.02	107.03	64.21	14.02	
Variance-drain	39.21	19.97	26.44	30.50	16.11	16.03	92.59	
χ^2	2.045	3.271	11.472	18.024	5.132	4.472	2.690	44.478
<i>p</i> -Value	[0.153]	[0.071]	[0.001]	[<0.001]	[0.023]	[0.034]	[0.101]	[<0.001]
<i>(E) Canadian dollar</i>								
Returns-add	1.46	0.32	1.30	-1.07	1.60	-2.59	-0.26	
Returns-drain	14.38	3.49	-1.04	-1.46	1.93	2.07	-4.31	
χ^2	1.202	0.742	0.499	0.004	0.003	2.154	1.058	5.494
<i>p</i> -Value	[0.273]	[0.389]	[0.480]	[0.952]	[0.958]	[0.142]	[0.304]	[0.600]
Variance-add	4.59	3.94	7.53	60.06	21.79	8.91	4.74	
Variance-drain	67.66	3.02	5.91	12.75	19.67	2.92	2.77	
χ^2	1.043	0.389	1.051	9.324	0.028	6.038	3.136	19.293
<i>p</i> -Value	[0.307]	[0.533]	[0.305]	[0.002]	[0.868]	[0.014]	[0.077]	[0.007]
<i>(F) Deutsche mark</i>								
Returns-add	9.65	3.22	1.82	-5.15	0.35	1.97	1.83	
Returns-drain	-12.73	0.22	1.25	0.740	-2.74	-0.56	30.68	
χ^2	1.432	0.059	0.005	0.928	0.433	0.450	1.870	5.119
<i>p</i> -Value	[0.231]	[0.808]	[0.943]	[0.335]	[0.510]	[0.502]	[0.171]	[0.645]
Variance-add	56.03	561.48	322.92	165.28	90.77	41.44	10.59	
Variance-drain	153.73	10.10	18.10	19.42	11.15	9.65	516.10	

Table 5 (continued)

Open market operation	1982	1983	1984	1985	1986	1987	1988	Multivariate tests
χ^2	0.443	17.509	8.641	11.244	9.991	7.544	8.625	59.378
<i>p</i> -Value	[0.506]	[<0.001]	[0.003]	[0.001]	[0.002]	[0.006]	[0.003]	[<0.001]
<i>(G) Japanese yen</i>								
Returns-add	−4.82	−8.42	−1.19	0.37	−0.30	0.83	0.01	
Returns-drain	22.31	7.63	1.07	0.22	−2.83	−0.27	−4.74	
χ^2	2.397	4.245	0.044	0.001	0.414	0.104	0.243	7.202
<i>p</i> -Value	[0.122]	[0.039]	[0.833]	[0.981]	[0.520]	[0.747]	[0.622]	[0.408]
Variance-add	70.50	251.23	473.61	127.01	39.40	30.15	10.18	
Variance-drain	127.87	7.37	8.03	9.59	9.63	7.55	103.13	
χ^2	0.251	14.557	11.114	9.673	5.389	7.538	2.708	48.055
<i>p</i> -Value	[0.616]	[<0.001]	[0.001]	[0.002]	[0.020]	[0.006]	[0.100]	[<0.001]
<i>(H) Swiss franc</i>								
Returns-add	0.95	5.72	8.10	4.96	0.02	−0.28	−1.19	
Returns-drain	57.53	0.98	1.74	−2.73	−2.54	−1.70	−9.17	
χ^2	0.643	0.230	0.251	1.024	0.337	0.140	0.093	2.707
<i>p</i> -Value	[0.423]	[0.631]	[0.616]	[0.312]	[0.562]	[0.709]	[0.760]	[0.911]
Variance-add	566.48	406.78	904.05	303.92	68.39	37.15	11.85	
Variance-drain	2668.07	15.53	14.55	19.56	12.21	10.75	851.93	
χ^2	3.991	9.780	15.207	17.647	5.764	9.942	7.330	65.819
<i>p</i> -Value	[0.046]	[0.002]	[<0.001]	[<0.001]	[0.016]	[0.002]	[0.007]	[<0.001]

^a The variances are those of the relative price changes calculated as $\ln(p_t/p_{t-1})$ and are multiplied by 10,000,000. The nearby contract is used until 2 weeks before expiration when we switch to the next-out contract. The multivariate variance equality tests are conducted by estimating the system of equations for the means and variance across all years and restricting the variance parameters for draining and adding operations to be equal in each year. There are seven overidentifying conditions. The multivariate returns equality tests are conducted by estimating only the mean equations across all years and restricting the means for draining and adding operations to be equal in each year. There are seven overidentifying conditions. Variances of the 2-min relative price changes for the Treasury bill, Eurodollar and Treasury bond are multiplied by 10,000,000. We exclude the observations for October 20, 1987 in the variance calculation. The data are from January 2, 1982–May 10, 1988.

the Fed uses its defensive operations primarily when markets are unstable or is it the case that offensive Fed operations move the market more, leading to higher volatility than defensive operations? To properly analyze these important issues, we require data on the exact time (as opposed to a time interval) that the Fed operations are executed as well as the exact instrument that is employed at the time. Returns would then be matched with volatility to link the Fed objective with the volatility impact. We leave these analyses for future research.

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