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The Impact of the Federal Reserve Bank's Open Market Operations

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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, 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. Surprisingly, the Fed Time volatility is higher on days when open market operations are absent. In addition, little systematic differences in market impact are observed for reserve-draining versus reserve-adding operations. These results suggest that the financial markets correctly anticipate the purpose of open market operations but are unable to forecast the timing of the operations.

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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 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 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 analysis reveals that the Federal Reserve Bank's open market operations result in dramatic increases in volatility during the trading-time window, 11:30am–12:00 EST, known as 'Fed Time'. However, the elevated volatilities are surprisingly more pronounced 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,

[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.

the effects on returns of reserve-adding and reserve-draining operations cannot be reliably differentiated from one another. These results suggest that the market participants correctly forecast whether the Federal Reserve Bank intends to add or to drain reserves. However, the market participants are unable to anticipate the specific days when open market operations are conducted.

The importance of information about the Federal Reserve Bank's intentions is highlighted by a recent incident. 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 is 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 experiment has 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.

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 Federal Open Market Committee (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 20 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

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

[3] See the Federal Reserve Bulletin, December 1979.

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 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

[4] Before 1984, maintenance periods were one week long (Meulendyke (1988)).

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.

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

[5] There 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.

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.

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 8:30am 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 groups 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 10:30am. 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 11:15am. 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 minutes. 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 11:30am and 11:40am), the desk traders immediately contact the primary dealers and execute the day's program.

3. Data and methodology

3.1. Data

Data on the Federal Reserve Bank's daily open market operations were provided by the Federal Reserve Bank of New York. 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.

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[6] Hardcopies 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.

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 two-minute 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 two-minute returns for four half-hour intervals: 10:00am–10:30am, 10:30am–11:00am, 11:00am–11:30am, and 11:30am–12:00pm (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:

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

where $\boldsymbol{r}_t$ 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 $\boldsymbol{u}_t$ and $\boldsymbol{e}_t$ are the disturbance terms.

With four time intervals, there are 8 equations in (1) and 8 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

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

equality can be tested with:

$$\begin{aligned} \boldsymbol{u}_t &= \boldsymbol{r}_t - \boldsymbol{\mu} \\ \boldsymbol{e}_t &= (\boldsymbol{r}_t - \boldsymbol{\mu})^2 - \sigma^2 \otimes \boldsymbol{\iota} \end{aligned} \tag{2}$$

where σ^2 is a singleton parameter and $\boldsymbol{\iota}$ 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:

$$\begin{aligned} \boldsymbol{u}_{FT,t} &= \boldsymbol{r}_{FT,t} - \Big(\sum_{y=1982}^{1988} \sum_{j=1}^{6} \mu_{y,j} \boldsymbol{I}_{y,j,t}^{OMO} \Big) \\ \boldsymbol{e}_{FT,t} &= \boldsymbol{u}_{FT,t}^2 - \Big(\sum_{y=1982}^{1988} \sum_{j=1}^{6} \nu_{y,j} \boldsymbol{I}_{y,j,t}^{OMO} \Big) \end{aligned}, \tag{3}$$

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, $\boldsymbol{I}^{OMO}$ is an indicator variable for the open market operations. In this formulation, $\boldsymbol{r}_{FT,t}$ is a 15×1 vector of two-minute returns in Fed Time for time period t. $\boldsymbol{u}_{FT,t}$ and $\boldsymbol{e}_{FT,t}$ are the disturbance terms associated with the mean and variance equations. The parameters μ and ν 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. Indeed, we have effectively assumed that the market always expects no operation. 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 to C and for foreign currency contracts in Panels D to 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 [Harvey and Huang (1991, 1993), Ederington and Lee (1993), and Becker, Finnerty and Kopecky (1993)]. The intraday pattern also contrasts with the pattern observed in equity markets. For example, Wood, McInish and Ord (1983) 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 (1993)]. However, there is no study of the impact of open market operations on currencies at the level of transactions data. Indeed, the close 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 to 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 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, B, and 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.

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 yield as well as the volatility of the gap may yield information about the intensity of the open market operations. In 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 chi-square 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.

While not reported in the table, multivariate tests which include all the years were feasible for three contracts: Treasury bill, Eurodollar and the British pound.[8] 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 increased volatility during Fed Time is due not so much to the Federal Reserve Bank's open market operations as to the absence of these operations! The mere fact that the Fed designates a specific time slot for its trading desk operations is sufficient to generate ample uncertainty in the market place to increase volatility even when no operations are being conducted. These results can be examined in terms of market expectations. If the market expects daily open market operations but none occur, the resulting surprise could lead to higher market volatility. Thus, market volatility can be induced even if the Fed *does not enter* the market. On days that the Federal Reserve Bank accommodates the market expectations by con-

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[8] The size of the data matrix was too large for estimation on an IBM 4341 for the other contracts.

ducting reserve-draining or adding operations, surprises and market volatility are mitigated. Indeed, the lack of significance for specific open market operations in Table 4 may be interpreted as cases when market expectations are met on average.

In implementing its open market operations, the Federal Reserve Bank also tries to minimize any disruption to the market place. For example, 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."

To the extent that market volatility during Fed Time on days with operations is no higher than on days without operation, the Fed appears to have succeeded in decreasing the impact of market operations. However, it is interesting to note again that the stipulation of a Fed Time has already elevated market volatility above the adjacent time periods.

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.[9] 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 and viewed as more temporary by market participants, we exclude them from the addition category. However, these predictions may fail to materialize if the market participants are able to predict the type of open market operation the Fed plans to conduct.

The results show that for both fixed income and currency futures contracts,

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

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 well anticipated by the market place. In effect, the market participants are able to predict 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.

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 correctly forecasting the purpose of 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.

When the evidence in Table 5 is examined in conjunction with the results in Table 4, it provides an explanation for the lower volatility observed during Fed Time when open market operations occur. In particular, the ability to forecast the type of open market operations may account for the somewhat surprising finding that volatility is lower in Fed Time when the Fed does trade. If the market can forecast direction but not timing, the days with no operations may experience the highest forecast errors. These forecasts errors could induce volatility as market participants readjust their portfolios to incorporate the information revealed in the Fed's decision not to trade.

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, 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 financial markets are able to anticipate the type of open market operations the Federal Reserve Bank uses, but are unable to forecast correctly when the open market operations occur. This accounts for the lower volatility observed during Fed Time when the Fed conducts open market operations. However, financial markets unsuccessfully forecast the timing of open market operations. This accounts for the increase in volatility during Fed Time.

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Table 1

Interhour volatility in financial futures contracts

The model estimated is:

$$\mathbf{u}_{1t} = \mathbf{r}_t - \boldsymbol{\mu}$$

$$\mathbf{u}_{2t} = (\mathbf{r}_t - \boldsymbol{\mu})^2 - \boldsymbol{\sigma}^2$$

where $\mathbf{r}_t$ is the vector of returns over six hourly time intervals, $\boldsymbol{\mu}$ is the vector of mean estimates, $\boldsymbol{\sigma}^2$ is the vector of variance estimates, and $\mathbf{u}$ 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. 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
A: Treasury bill							
1982	253	17.765 (3.753)	5.322 (0.845)	3.085 (0.365)	8.222 (1.112)	6.136 (0.870)	5.068 (0.529)
1983	252	1.877 (0.195)	1.085 (0.223)	0.627 (0.078)	1.472 (0.237)	0.670 (0.075)	0.688 (0.077)
1984	253	3.790 (0.645)	0.962 (0.134)	0.702 (0.092)	1.760 (0.279)	1.132 (0.137)	0.847 (0.094)
1985	253	2.783 (0.385)	1.367 (0.246)	0.564 (0.062)	1.207 (0.185)	0.992 (0.148)	0.519 (0.058)
1986	253	1.519 (0.213)	0.495 (0.063)	0.421 (0.051)	0.503 (0.066)	0.336 (0.037)	0.343 (0.046)
1987	252	3.444 (1.233)	1.463 (0.272)	0.813 (0.159)	0.983 (0.184)	0.752 (0.106)	0.590 (0.084)
1988	90	2.117 (0.488)	0.515 (0.088)	0.249 (0.046)	0.544 (0.146)	0.269 (0.045)	0.376 (0.056)
1982–88	1586	3.490 (0.284)	1.976 (0.180)	0.985 (0.070)	2.062 (0.153)	1.624 (0.159)	1.375 (0.112)
B: Eurodollar							
1982	252	9.411 (1.207)	6.894 (0.961)	2.701 (0.313)	7.490 (0.770)	6.544 (0.901)	5.505 (0.574)
1983	245	1.334 (0.134)	1.089 (0.179)	0.672 (0.083)	1.283 (0.174)	0.697 (0.079)	0.789 (0.082)
1984	250	1.985 (0.240)	0.919 (0.099)	0.863 (0.181)	1.327 (0.201)	0.938 (0.133)	0.645 (0.069)
1985	250	3.018 (0.485)	1.040 (0.169)	0.428 (0.044)	0.849 (0.145)	0.810 (0.123)	0.315 (0.031)
1986	250	1.463 (0.210)	0.426 (0.056)	0.439 (0.052)	0.444 (0.049)	0.304 (0.042)	0.355 (0.042)
1987	249	4.183 (1.099)	1.890 (0.405)	1.014 (0.191)	1.335 (0.282)	0.774 (0.111)	0.893 (0.287)
1988	90	1.863 (0.373)	0.565 (0.096)	0.235 (0.041)	0.611 (0.138)	0.356 (0.056)	0.421 (0.096)
1982–88	1606	5.031 (0.649)	1.716 (0.156)	0.995 (0.070)	2.271 (0.200)	1.594 (0.151)	1.292 (0.096)
C: Treasury bond							
1982	155	188.269 (43.956)	98.921 (16.705)	48.470 (8.416)	88.606 (10.003)	88.651 (15.814)	258.380 (33.251)
1983	249	60.414 (5.428)	41.223 (4.602)	25.513 (3.826)	39.417 (4.645)	29.602 (2.805)	100.538 (11.275)
1984	252	78.206 (12.986)	54.264 (9.345)	30.442 (3.829)	44.747 (5.958)	37.843 (4.838)	134.034 (19.642)
1985	251	88.751 (17.977)	55.821 (7.069)	28.518 (3.814)	29.084 (3.240)	30.222 (3.233)	148.709 (25.518)
1986	253	128.499 (15.092)	101.588 (14.343)	69.054 (8.822)	63.127 (6.575)	62.157 (7.423)	248.966 (26.368)
1987	252	77.529 (13.130)	76.288 (9.002)	67.519 (11.353)	59.501 (11.765)	65.096 (10.495)	177.576 (20.484)
1988	93	57.762 (12.206)	46.933 (6.790)	21.906 (3.878)	24.333 (3.433)	22.637 (3.551)	142.235 (30.702)
1982–88	1505	96.103 (7.135)	68.514 (4.015)	43.629 (2.855)	50.324 (2.911)	48.292 (2.985)	171.369 (9.074)

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
D: British pound							
1982	225	18.319 (2.328)	21.848 (2.362)	37.115 (4.284)	50.083 (6.567)	37.461 (6.361)	27.113 (3.651)
1983	201	16.529 (2.122)	32.285 (3.593)	32.301 (3.589)	30.211 (4.393)	24.499 (3.204)	17.587 (1.911)
1984	211	53.365 (13.437)	34.946 (3.877)	48.661 (7.454)	48.439 (4.920)	55.109 (10.515)	35.216 (6.269)
1985	235	134.909 (29.906)	99.317 (12.211)	96.579 (12.687)	85.348 (9.434)	68.845 (10.291)	54.127 (8.228)
1986	223	52.138 (7.944)	42.128 (4.814)	56.659 (7.948)	49.648 (6.782)	54.464 (8.955)	34.318 (4.556)
1987	218	70.687 (17.491)	27.101 (3.285)	36.361 (5.509)	33.916 (5.138)	25.138 (4.495)	16.511 (2.670)
1988	84	195.176 (138.580)	22.823 (5.780)	27.544 (5.607)	26.398 (4.463)	11.031 (2.095)	7.601 (1.383)
1982–88	1397	67.314 (10.620)	42.597 (2.574)	51.126 (3.114)	49.003 (2.594)	42.780 (3.088)	30.043 (2.048)
E: Canadian dollar							
1982	213	17.848 (3.725)	11.475 (1.528)	7.470 (0.926)	11.814 (1.666)	11.666 (2.401)	7.600 (0.946)
1983	111	4.219 (0.614)	3.580 (0.542)	3.201 (0.561)	4.955 (2.074)	3.927 (0.886)	1.965 (0.298)
1984	75	10.522 (1.734)	7.588 (2.395)	7.014 (1.429)	5.444 (1.003)	3.897 (0.764)	3.724 (0.718)
1985	111	25.216 (4.259)	15.822 (3.762)	17.241 (5.156)	8.192 (1.346)	5.947 (0.919)	5.407 (1.083)
1986	132	19.328 (2.703)	13.788 (2.883)	10.499 (1.832)	6.728 (1.051)	7.434 (1.419)	9.286 (2.082)
1987	159	26.611 (11.554)	11.853 (3.631)	6.336 (0.924)	7.867 (1.271)	4.573 (0.614)	3.632 (0.469)
1988	66	11.337 (1.445)	5.384 (1.123)	2.850 (0.713)	4.989 (1.215)	2.392 (0.654)	2.327 (0.447)
1982–88	867	17.811 (2.433)	10.855 (1.059)	8.132 (0.821)	7.930 (0.611)	6.714 (0.696)	5.432 (0.444)
F: Deutschemark							
1982	239	24.278 (2.372)	28.165 (3.354)	38.592 (4.109)	44.328 (6.066)	28.180 (3.405)	24.318 (2.740)
1983	234	19.023 (2.068)	23.977 (2.917)	21.609 (2.523)	25.838 (2.906)	18.090 (2.535)	21.348 (3.060)
1984	247	64.253 (22.136)	41.044 (5.742)	53.757 (9.886)	44.903 (4.754)	51.200 (8.108)	32.776 (4.978)
1985	248	94.651 (18.391)	64.926 (8.265)	73.694 (12.671)	50.491 (5.404)	46.917 (6.501)	37.418 (4.853)
1986	251	64.721 (9.115)	44.481 (5.569)	54.542 (8.263)	50.606 (8.170)	36.386 (4.737)	27.234 (4.297)
1987	251	74.046 (16.931)	35.924 (6.806)	42.282 (6.570)	33.921 (5.115)	30.493 (6.515)	18.174 (2.052)
1988	86	171.137 (123.306)	19.991 (4.279)	18.367 (2.441)	21.175 (4.495)	12.395 (2.238)	7.819 (1.476)
1982–88	1556	63.795 (8.912)	39.015 (2.309)	46.634 (3.272)	40.788 (2.211)	34.237 (2.222)	26.189 (1.536)

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
G: Japanese yen							
1982	234	37.129 (3.455)	37.442 (3.433)	46.604 (5.022)	53.233 (7.172)	30.963 (2.980)	31.929 (5.447)
1983	236	31.146 (4.431)	27.365 (3.696)	21.307 (2.618)	27.367 (3.348)	22.147 (4.068)	27.279 (4.475)
1984	219	44.264 (14.473)	19.735 (4.645)	14.658 (2.174)	16.475 (3.332)	15.936 (2.958)	12.966 (2.851)
1985	213	42.880 (9.115)	20.421 (3.562)	26.098 (4.406)	19.810 (3.362)	21.088 (4.996)	16.145 (2.028)
1986	240	48.067 (8.136)	33.709 (5.993)	41.735 (9.755)	28.904 (5.819)	21.852 (3.993)	19.795 (2.873)
1987	243	82.773 (19.781)	28.283 (4.122)	40.231 (7.441)	27.485 (4.048)	21.199 (3.547)	16.175 (1.999)
1988	89	218.487 (149.011)	24.512 (4.553)	21.053 (6.944)	21.718 (5.682)	13.671 (2.807)	9.325 (1.676)
1982–88	1474	58.363 (10.174)	28.006 (1.708)	31.594 (2.370)	28.819 (1.908)	21.835 (1.478)	20.316 (1.389)
H: Swiss franc							
1982	247	46.877 (5.597)	47.466 (4.886)	59.735 (6.127)	78.461 (10.633)	51.923 (6.887)	79.492 (10.690)
1983	247	30.615 (3.582)	30.015 (3.843)	26.603 (2.714)	36.805 (4.371)	31.628 (3.926)	47.293 (7.146)
1984	246	50.962 (11.728)	30.274 (3.148)	47.144 (6.893)	42.023 (4.234)	44.603 (6.005)	39.595 (4.790)
1985	247	96.411 (13.527)	87.030 (10.989)	78.791 (10.777)	60.265 (6.863)	70.196 (13.267)	64.818 (7.549)
1986	252	76.481 (11.270)	59.758 (6.591)	66.912 (11.023)	62.845 (10.059)	48.589 (5.994)	42.164 (6.259)
1987	250	86.675 (17.649)	44.868 (6.603)	53.465 (7.532)	47.912 (7.409)	36.856 (6.735)	28.207 (2.780)
1988	86	198.343 (144.513)	34.139 (7.063)	27.280 (4.414)	31.522 (7.057)	16.734 (3.233)	10.863 (2.236)
1982–88	1575	72.195 (9.219)	49.181 (2.613)	54.330 (3.183)	53.536 (3.005)	45.796 (2.987)	48.768 (2.768)

The 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. Standard errors in parentheses are heteroskedasticity consistent.

Table 2

Intrahour volatility near Fed Time in financial markets

The model estimated is:

$$u_t = r_t - \mu$$
$$e_t = (r_t - \mu)^2 - \sigma^2 \qquad (2)$$

where r_t is a 1×4 vector of 2-minute returns at time t over the four half-hour intervals, μ are the means, σ are the variances, and u_t, e_t are the disturbances. This system is exactly identified and is estimates 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. 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 *Fed Time*	χ^2 Fed Time σ^2= 10-10:30 σ^2	χ^2 Fed Time σ^2= 10:30-11 σ^2	χ^2 Fed Time σ^2= 11-11:30 σ^2
A: Treasury bill							
1982	1.919 (0.064)	3.486 (0.149)	2.445 (0.078)	212.033 (59.118)	12.63 [<0.001]	12.44 [<0.001]	12.56 [<0.001]
1983	1.211 (0.020)	1.450 (0.060)	2.990 (1.752)	20.320 (5.763)	10.99 [<0.001]	10.71 [0.001]	8.27 [0.004]
1984	4.444 (2.289)	1.412 (0.052)	1.256 (0.030)	17.502 (4.189)	7.48 [0.006]	14.75 [<0.001]	15.04 [<0.001]
1985	5.247 (4.073)	2.514 (1.105)	1.362 (0.125)	35.248 (10.322)	7.31 [0.007]	9.94 [0.002]	10.77 [0.001]
1986	1.293 (0.168)	1.662 (0.479)	5.627 (2.747)	8.960 (2.886)	7.03 [0.008]	6.22 [0.012]	0.70 [0.403]
1987	4.166 (1.676)	7.867 (4.172)	18.166 (8.148)	54.930 (14.900)	11.46 [<0.001]	9.25 [0.002]	4.68 [0.030]
1988	1.273 (0.079)	1.314 (0.066)	1.399 (0.220)	1.439 (0.221)	0.54 [0.459]	0.33 [0.568]	0.02 [0.894]
B: Eurodollar							
1982	4.664 (0.303)	9.199 (0.764)	58.381 (50.545)	282.818 (129.650)	4.60 [0.032]	4.45 [0.034]	2.60 [0.107]
1983	1.412 (0.038)	3.994 (2.253)	16.704 (8.134)	83.686 (20.889)	14.41 [<0.001]	14.39 [<0.001]	8.928 [0.002]
1984	1.320 (0.027)	1.868 (0.103)	1.351 (0.035)	129.261 (42.102)	9.23 [0.002]	9.16 [0.002]	9.23 [0.002]
1985	1.150 (0.021)	1.504 (0.067)	2.284 (1.054)	77.147 (25.249)	9.05 [0.003]	8.97 [0.003]	8.77 [0.003]
1986	1.090 (0.015)	1.356 (0.234)	1.768 (0.386)	4.318 (0.930)	12.04 [<0.001]	9.51 [0.002]	6.41 [0.011]
1987	1.685 (0.149)	1.521 (0.096)	1.957 (0.348)	51.279 (16.290)	9.26 [0.002]	9.32 [0.002]	9.16 [0.002]
1988	1.081 (0.027)	1.128 (0.039)	3.313 (2.238)	11.560 (4.773)	4.82 [0.028]	4.77 [0.029]	2.44 [0.118]
C: Treasury Bond							
1982	29.695 (1.054)	54.619 (4.180)	33.723 (1.082)	133.157 (21.500)	23.10 [<0.001]	12.86 [<0.001]	21.33 [<0.001]
1983	19.687 (0.662)	26.868 (1.181)	29.114 (4.188)	104.393 (14.226)	35.37 [<0.001]	29.29 [<0.001]	25.76 [<0.001]
1984	23.325 (0.602)	32.664 (1.205)	24.996 (0.705)	168.808 (24.776)	34.45 [<0.001]	30.12 [<0.001]	33.60 [<0.001]
1985	20.027 (0.561)	24.793 (0.844)	27.297 (6.500)	274.90 (42.553)	35.68 [<0.001]	34.53 [<0.001]	33.08 [<0.001]
1986	24.865 (1.089)	30.142 (10.235)	26.751 (1.184)	115.128 (15.050)	35.76 [<0.001]	31.72 [<0.001]	34.25 [<0.001]
1987	28.364 (1.266)	26.905 (1.121)	29.054 (4.093)	188.189 (24.392)	42.81 [<0.001]	43.63 [<0.001]	41.39 [<0.001]
1988	17.775 (1.034)	18.244 (0.864)	15.728 (0.794)	169.182 (43.214)	12.27 [<0.001]	12.19 [<0.001]	12.61 [<0.001]
D: British pound							
1982	155.282 (18.334)	55.763 (5.087)	52.740 (5.475)	43.633 (4.263)	35.18 [<.001]	3.34 [0.068]	1.72 [0.189]
1983	147.057 (22.467)	49.907 (5.426)	43.743 (5.124)	51.096 (5.646)	17.16 [<.001]	0.02 [0.879]	0.93 [0.335]
1984	180.822 (19.317)	77.810 (7.377)	81.752 (7.804)	79.778 8.530)	22.89 [<.001]	0.03 [0.862]	0.03 [0.864]
1985	510.402 (66.216)	387.306 (33.173)	336.508 (31.718)	388.859 (35.051)	2.63 [0.105]	0.001 [0.974]	1.23 [0.268]
1986	505.473 (44.060)	440.832 (41.721)	391.196 (40.740)	457.620 (47.409)	0.55 [0.460]	0.07 [0.800]	1.13 [0.288]
1987	210.434 (22.341)	148.144 (16.569)	139.126 (16.362)	141.726 (17.797)	5.79 [0.016]	0.07 [0.792]	0.01 [0.914]
1988	249.748 (96.821)	79.751 (13.840)	92.396 (15.583)	107.284 (18.846)	2.09 [0.149]	1.39 [0.239]	0.37 [0.543]

Table 2 (continued)

Year	σ^2 10-10:30	σ^2 10:30-11	σ^2 11-11:30	σ^2 11:30-12 *Fed Time*	χ^2 Fed Time σ^2= 10-10:30 σ^2	χ^2 Fed Time σ^2= 10:30-11 σ^2	χ^2 Fed Time σ^2= 11-11:30 σ^2
E: Canadian dollar							
1982	98.767 (10.509)	61.827 (8.028)	66.069 (8.395)	68.592 (9.074)	4.72 [0.298]	0.31 [0.577]	0.42 [0.838]
1983	24.601 (2.654)	9.117 (0.937)	9.657 (1.181)	9.970 (1.0840)	33.46 [<.001]	0.17 [0.683]	0.33 [0.563]
1984	49.678 (4.927)	18.149 (2.659)	14.310 (2.508)	16.536 (2.925)	33.461 [<.001]	0.17 [0.683]	0.33 [0.563]
1985	3.277 (11.949)	71.448 (9.371)	68.613 (9.033)	96.097 (12.663)	0.97 [0.324]	2.45 [0.118]	3.12 [0.077]
1986	221.708 (24.139)	199.810 (24.935)	167.269 (23.671)	123.160 (20.879)	9.53 [0.002]	5.55 [0.018]	1.95 [0.162]
1987	75.786 (10.970)	31.176 (3.979)	49.328 (5.766)	39.898 (5.397)	8.62 [0.003]	1.69 [0.193]	1.43 [0.232]
1988	85.360 (13.940)	61.076 (13.085)	71.205 (13.968)	29.072 (9.097)	11.44 [0.001]	4.033 [0.045]	6.39 [0.011]
F: Deutschemark							
1982	508.324 (48.490)	483.245 (49.825)	372.397 (43.377)	389.342 (47.706)	3.06 [0.080]	1.85 [0.173]	0.07 [0.793]
1983	549.184 (45.306)	454.800 (41.875)	485.256 (43.501)	539.676 (48.587)	0.02 [0.886]	1.75 [0.186]	0.70 [0.404]
1984	480.527 (49.977)	450.335 (50.241)	586.071 (58.640)	532.197 (56.220)	0.47 [0.492]	1.18 [0.278]	0.44 [0.507]
1985	269.616 (22.745)	246.953 (21.781)	223.124 (21.195)	240.619 (22.072)	0.84 [0.36]	0.04 [0.838]	0.33 [0.568]
1986	129.095 (12.721)	109.550 (11.081)	127.262 (12.163)	121.908 (12.064)	0.17 [0.682]	0.57 [0.450]	0.10 [0.755]
1987	295.471 (26.204)	274.800 (25.468)	284.220 (27.547)	258.445 (26.053)	1.00 [0.316]	0.20 [0.654]	0.46 [0.497]
1988	275.506 (41.966)	226.840 (37.458)	167.476 (33.176)	267.355 (42.825)	0.02 [0.892]	0.51 [0.476]	3.40 [0.065]
G: Japanese Yen							
1982	750.677 (84.478)	638.280 (81.728)	563.849 (78.684)	619.812 (85.046)	1.19 [0.275]	0.02 [0.876]	0.23 [0.629]
1983	312.548 (27.171)	235.028 (22.127)	255.082 (23.409)	223.026 (22.385)	6.47 [0.110]	0.15 [0.703]	0.98 [0.322]
1984	506.277 (51.103)	535.286 (55.365)	492.196 (55.447)	446.177 (54.362)	0.65 [0.421]	1.32 [0.251]	0.35 [0.553]
1985	134.477 (13.920)	90.067 (10.804)	93.839 (11.554)	104.566 (12.618)	2.53 [0.111]	0.76 [0.383]	0.39 [0.531]
1986	131.239 (15.600)	74.283 (7.124)	79.635 (8.051)	82.841 (8.209)	7.54 [0.006]	0.62 [0.431]	0.078 [0.780]
1987	253.247 (23.340)	236.979 (21.831)	221.198 (21.339)	206.232 (21.047)	2.24 [0.135]	1.03 [0.311]	0.25 [0.618]
1988	106.961 (18.267)	117.595 (19.842)	112.695 (19.545)	111.678 (19.725)	0.03 [0.861]	0.04 [0.832]	0.001 [0.971]
H: Swiss franc							
1982	1048.757 (108.628)	1145.395 (114.897)	829.494 (99.231)	935.463 (108.374)	0.55 [0.460]	1.77 [0.184]	0.52 [0.471]
1983	700.218 (62.229)	615.311 (58.368)	760.909 (65.339)	599.749 (58.756)	1.38 [0.240]	0.04 [0.851]	3.36 [0.067]
1984	754.742 (78.845)	794.124 (81.363)	753.308 (80.438)	782.364 (84.799)	0.057 [0.81]	0.01 [0.920]	0.06 [0.804]
1985	237.654 (22.886)	228.861 (22.634)	251.798 (24.172)	265.855 (24.836)	0.70 [0.404]	1.21 [0.271]	0.165 [0.685]
1986	163.119 (17.065)	124.681 (12.622)	123.427 (13.384)	132.295 (13.619)	2.00 [0.158]	0.17 [0.682]	0.216 [0.642]
1987	276.364 (25.335)	224.603 (21.724)	221.984 (21.431)	237.804 (22.541)	1.29 [0.256]	0.18 [0.673]	0.26 [0.611]
1988	298.093 (60.293)	399.224 (70.378)	358.463 (66.522)	360.868 (68.596)	0.47 [0.492]	0.15 [0.696]	0.001 [0.980]

The variances are those of the relative price changes calculated as $\ell n(p_t/p_{t-1})$ 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. Standard errors in parentheses are heteroskedasticity consistent.

Table 3

Size and frequency of open-market operations (in billions)

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

Data begins on October 6, 1982 when the Federal Reserve switched its operating policies from money supply targeting to borrowed reserves/fed funds rate targeting.

Table 4

The effect of open market operations on volatility based on 2 minute returns during Fed Time

The model estimated is:

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

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

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, $\boldsymbol{I}^{OMO}$ is an indicator variable for the open market operations. In this formulation, $\boldsymbol{r}_{FT,t}$ is a 15×1 vector of two minute returns in Fed Time for time period t. $\boldsymbol{u}_{FT,t}$ and $\boldsymbol{e}_{FT,t}$ are the disturbance terms associated with the mean and variance equations. The parameters μ and ν are estimates of the means and variances by operation and by year. There is no intercept because the intercepts 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. The sample is October 6, 1982 to May 10, 1988.

Open market operation	1982	1983	1984	1985	1986	1987	1988
A: Treasury bill							
Matched sales purchases	36.292 (28.900)	1.129 (0.105)	10.569 (9.173)	1.427 (0.158)	1.059 (0.136)	1.302 (0.188)	2.387 (1.248)
Open market purchases	67.703 (63.294)	70.816 (67.745)	1.740 (0.318)	1.586 (0.333)	1.032 (0.125)	116.391 (110.083)	-
Open market sales	-	-	0.771 (0.517)	1.156 (0.126)	-	-	-
System repurchases	12.873 (8.104)	1.245 (0.058)	13.510 (8.201)	20.840 (11.703)	5.739 (4.662)	29.924 (20.473)	1.299 (0.282)
Customer repurchases	30.679 (17.137)	26.960 (10.755)	13.940 (7.470)	14.649 (6.847)	11.327 (5.533)	50.667 (28.952)	1.152 (0.109)
Days with operations	31.660 (12.175)	22.629 (8.268)	12.622 (4.574)	14.651 (5.259)	8.751 (3.673)	44.100 (17.617)	1.544 (0.372)
Days without operations	237.754 (67.484)	16.858 (7.335)	23.558 (7.456)	60.031 (21.701)	9.227 (4.614)	73.230 (26.743)	1.369 (0.249)
χ^2 test: σ^2(OMO)=σ^2(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]
B: Eurodollar							
Matched sales purchases	84.327 (71.479)	1.500 (0.318)	1.339 (0.089)	1.362 (0.155)	1.162 (0.140)	1.115 (0.047)	17.046 (15.377)
Open market purchases	175.063 (138.955)	588.237 (276.332)	1.783 (0.268)	2.794 (1.040)	1.023 (0.085)	1.055 (0.105)	1.027 (0.144)
Open market sales	-	-	-	1.157 (0.211)	-	-	-
System repurchases	3.151 (1.148)	61.168 (41.276)	19.888 (15.062)	74.990 (63.477)	3.220 (1.867)	1.682 (0.174)	1.129 (0.035)
Customer repurchases	44.685 (27.886)	33.758 (20.320)	159.035 (103.804)	80.434 (54.914)	2.415 (0.768)	47.049 (28.770)	21.171 (19.409)
Days with operations	55.294 (24.678)	60.180 (24.032)	68.203 (40.598)	66.458 (35.237)	2.602 (0.765)	22.228 (13.125)	14.415 (9.338)
Days without operations	327.535 (154.876)	119.767 (37.590)	197.312 (76.374)	89.477 (36.071)	6.520 (1.873)	103.422 (38.604)	9.633 (4.925)
χ^2 test: σ^2(OMO)=σ^2(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]
C: Treasury bond							
Matched sales purchases	189.007 (133.649)	112.839 (80.582)	96.498 (66.477)	269.858 (174.171)	28.905 (3.666)	221.015 (193.412)	359.241 (191.316)
Open market purchases	207.680 (177.905)	173.499 (110.702)	45.809 (7.831)	247.157 (214.869)	24.473 (4.801)	257.888 (152.040)	23.624 (6.891)
Open market sales	-	-	20.105 (4.420)	22.497 (5.768)	-	14.662 (4.915)	-
System repurchases	184.892 (112.340)	45.629 (17.796)	210.287 (70.737)	222.448 (92.093)	123.390 (36.492)	103.920 (27.883)	20.258 (3.308)
Customer repurchases	153.154 (67.235)	112.927 (23.380)	176.058 (43.581)	191.730 (64.858)	96.271 (23.362)	193.891 (44.249)	179.453 (91.950)
Days with operations	176.955 (53.310)	99.854 (17.928)	168.289 (32.148)	205.252 (49.813)	100.881 (18.601)	156.440 (26.827)	193.154 (70.499)
Days without operations	121.316 (23.201)	111.037 (23.236)	169.381 (38.273)	346.575 (69.342)	135.050 (25.024)	242.417 (47.462)	150.632 (53.826)
χ^2 test: σ^2(OMO)=σ^2(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]

Table 4 (continued)

Open market operation	1982	1983	1984	1985	1986	1987	1988
D: British pound							
Matched sales purchases	39.213 (13.986)	19.973 (3.031)	26.961 (2.584)	30.013 (5.544)	16.111 (2.100)	16.615 (4.670)	92.591 (47.857)
Open market purchases	22.464 (7.566)	64.127 (23.109)	31.059 (6.293)	562.188 (179.838)	23.208 (4.641)	16.474 (2.920)	9.690 (2.866)
Open market sales	-	-	21.091 (3.941)	38.207 (9.566)	-	12.092 (3.175)	-
System repurchases	15.763 (1.441)	25.379 (2.771)	139.854 (33.483)	204.889 (54.762)	117.364 (45.112)	66.822 (23.594)	14.095 (2.433)
Customer repurchases	13.224 (1.104)	46.174 (8.305)	82.596 (14.631)	325.599 (60.440)	403.033 (81.281)	261.380 (49.130)	48.324 (26.529)
Days with operations	19.089 (2.314)	40.651 (5.866)	90.254 (12.671)	243.838 (36.975)	285.751 (52.174)	154.217 (25.582)	53.429 (18.991)
Days without operations	47.488 (4.919)	66.744 (11.033)	67.827 (11.151)	540.682 (60.142)	681.032 (84.887)	120.914 (20.851)	148.426 (29.746)
χ^2 test: σ^2(OMO)=σ^2(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]
E: Canadian dollar							
Matched sales purchases	67.658 (61.759)	3.020 (0.670)	5.912 (0.714)	13.861 (6.606)	19.674 (7.550)	3.047 (0.479)	2.766 (0.396)
Open market purchases	4.997 (1.110)	7.271 (5.028)	5.065 (1.298)	139.108 (51.237)	3.060 (0.791)	4.517 (0.810)	2.415 (0.691)
Open market sales	-	-	-	5.354 (1.209)	-	2.473 (0.898)	-
System repurchases	4.150 (0.599)	4.256 (1.546)	7.902 (1.627)	36.207 (10.301)	24.088 (11.569)	9.277 (2.569)	4.751 (1.104)
Customer repurchases	66.373 (24.915)	7.918 (1.388)	9.276 (2.249)	93.757 (22.948)	154.724 (45.036)	36.427 (8.754)	30.243 (18.614)
Days with operations	44.818 (15.652)	6.862 (1.074)	8.113 (1.210)	63.697 (12.977)	105.587 (28.534)	23.230 (4.768)	17.960 (10.031)
Days without operations	72.358 (10.214)	14.271 (2.098)	25.255 (5.772)	134.390 (22.867)	144.186 (30.534)	67.257 (11.785)	38.125 (14.248)
χ^2 test: σ^2(OMO)=σ^2(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]
F: Deutschemark							
Matched sales purchases	153.733 (139.569)	10.998 (1.440)	19.752 (2.666)	18.918 (2.530)	11.145 (1.624)	9.542 (1.606)	516.103 (172.110)
Open market purchases	154.568 (141.497)	1639.951 (463.677)	29.880 (7.826)	302.181 (138.705)	12.529 (2.716)	13.438 (3.173)	12.041 (3.673)
Open market sales	-	-	9.557 (2.969)	27.665 (12.063)	-	9.868 (4.004)	-
System repurchases	10.266 (1.095)	287.645 (103.387)	379.157 (123.015)	129.491 (41.179)	99.629 (27.984)	42.742 (12.112)	11.317 (2.595)
Customer repurchases	331.670 (104.578)	382.393 (60.605)	715.231 (131.918)	199.567 (37.920)	103.561 (18.680)	242.192 (39.486)	148.445 (63.958)
Days with operations	215.196 (60.890)	407.668 (53.612)	491.560 (78.481)	149.611 (23.927)	96.453 (14.607)	139.491 (20.419)	221.579 (59.015)
Days without operations	418.962 (54.829)	731.768 (89.791)	577.530 (80.414)	333.173 (37.141)	155.292 (20.232)	452.249 (59.231)	304.160 (60.814)
χ^2 test: σ^2(OMO)=σ^2(no OMO)	6.184 [0.013]	9.605 [0.002]	0.585 [0.444]	17.262 [<0.001]	5.560 [0.018]	24.920 [<0.001]	0.950 [0.330]

Table 4 (continued)

Open market operation	1982	1983	1984	1985	1986	1987	1988
G: Japanese yen							
Matched sales purchases	127.868 (108.646)	7.365 (0.852)	8.020 (0.683)	9.749 (1.104)	9.626 (1.375)	7.430 (1.604)	103.125 (56.460)
Open market purchases	183.586 (113.351)	976.596 (263.804)	8.116 (1.453)	19.242 (3.984)	5.668 (1.003)	11.839 (2.450)	17.441 (3.837)
Open market sales	-	-	4.174 (1.165)	6.440 (0.003)	-	6.665 (2.324)	-
System repurchases	19.601 (6.417)	95.601 (37.548)	566.002 (166.987)	141.026 (42.739)	43.498 (14.309)	30.947 (8.572)	10.492 (1.598)
Customer repurchases	150.639 (53.360)	162.281 (28.883)	412.620 (101.437)	77.927 (23.008)	70.136 (12.747)	161.734 (30.813)	64.375 (29.646)
Days with operations	121.755 (34.280)	176.747 (25.825)	381.431 (72.009)	85.458 (17.772)	58.092 (9.162)	93.549 (15.620)	65.192 (22.565)
Days without operations	713.220 (100.667)	294.102 (40.514)	522.833 (82.552)	124.840 (17.890)	115.358 (14.646)	396.313 (49.559)	147.845 (30.264)
χ^2 test: σ^2(OMO)=σ^2(no OMO)	30.934 [<0.001]	5.966 [0.015]	1.666 [0.197]	2.439 [0.118]	10.988 [0.001]	33.949 [<0.001]	4.794 [0.029]
H: Swiss franc							
Matched sales purchases	2668.069 (1015.965)	15.533 (3.111)	14.844 (1.486)	20.223 (2.615)	12.210 (1.887)	10.459 (1.693)	851.934 (310.278)
Open market purchases	1854.819 (887.475)	1650.387 (525.712)	25.678 (4.975)	623.316 (239.116)	12.517 (1.970)	11.638 (2.385	17.191 (4.377)
Open market sales	-	-	5.986 (2.334)	9.945 (2.449)	-	12.559 (5.776)	-
System repurchases	14.168 (1.810)	110.280 (70.944)	1050.222 (265.532)	226.597 (61.475)	74.218 (25.798)	38.515 (8.690)	13.206 (2.168)
Customer repurchases	596.822 (233.529)	425.575 (78.465)	1089.353 (187.963)	127.983 (33.808)	100.723 (20.471)	212.000 (34.993)	59.220 (54.299)
Days with operations	847.831 (204.676)	400.601 (63.289)	892.553 (127.238)	141.165 (26.145)	86.817 (15.161)	124.170 (18.136)	258.603 (88.249)
Days without operations	950.960 (122.308)	895.223 (110.781)	655.981 (108.760)	395.084 (42.444)	191.730 (24.287)	426.900 (51.494)	440.736 (100.675)
χ^2 test: σ^2(OMO)=σ^2(no OMO)	0.187 [0.665]	15.030 [<0.001]	1.997 [0.158]	25.945 [<0.001]	13.427 [<0.001]	30.748 [<0.001]	1.851 [0.174]

The variances are those of the relative price changes calculated as $\ell n(p_t/p_{t-1})$ 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. Standard errors in parentheses are heteroskedasticity consistent.

Table 6

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

The model estimated is:

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

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

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 ν are estimates of the means and variances by purpose of operation and by year. There is no intercept because the intercepts 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. The sample is October 6, 1982 to May 10, 1988.

Open market operation	1982	1983	1984	1985	1986	1987	1988	Multivariate tests
A: Treasury bill								
Returns-Add	-5.612	-1.907	-1.505	-1.487	0.748	-6.293	2.199	
Returns-Drain	-1.065	1.131	-2.894	0.716	3.718	-3.248	-4.143	
χ^2 P-value	0.232 [0.630]	1.258 [0.262]	0.171 [0.679]	0.479 [0.489]	1.336 [0.248]	0.451 [0.502]	2.024 [0.155]	5.773 [0.557]
Variance-Add	28.350	15.527	11.493	19.386	5.049	42.184	1.255	
Variance-Drain	36.292	1.129	10.690	1.410	1.059	1.510	2.387	
χ^2 P-value	0.053 [0.819]	1.028 [0.311]	0.005 [0.944]	2.750 [0.097]	1.014 [0.314]	2.970 [0.085]	0.792 [0.374]	8.303 [0.307]
B: Eurodollar								
Returns-Add	-7.917	-20.720	-2.985	-3.998	-0.593	0.656	0.857	
Returns-Drain	-18.979	-3.606	-0.407	0.265	0.946	-0.919	-5.279	
χ^2 P-value	0.159 [0.690]	2.212 [0.137]	0.933 [0.334]	0.749 [0.387]	0.478 [0.489]	0.674 [0.412]	0.845 [0.358]	5.872 [0.554]
Variance-Add	59.259	130.851	15.990	68.650	2.954	1.650	1.093	
Variance-Drain	84.327	1.500	1.340	1.354	1.162	1.176	17.046	
χ^2 P-value	0.082 [0.775]	3.727 [0.054]	1.532 [0.216]	1.353 [0.245]	1.178 [0.278]	6.038 [0.014]	1.076 [0.300]	13.961 [0.052]
C: Treasury bond								
Returns-Add	-12.105	-5.149	-15.881	-13.847	-13.391	-8.615	5.341	
Returns-Drain	-0.074	-12.113	-6.969	-14.818	-2.278	-8.190	-26.881	
χ^2 P-value	0.312 [0.577]	0.389 [0.533]	1.159 [0.282]	0.006 [0.938]	3.340 [0.068]	0.001 [0.976]	3.021 [0.082]	8.102 [0.324]
Variance-Add	191.614	58.731	183.227	235.836	113.739	111.387	20.684	
Variance-Drain	189.007	112.839	96.562	254.380	28.905	190.399	359.241	
χ^2 P-value	0.000 [0.987]	0.417 [0.518]	0.951 [0.329]	0.010 [0.921]	6.557 [0.010]	0.223 [0.637]	3.131 [0.077]	11.244 [0.128]
D: British pound								
Returns-Add	5.816	-1.491	1.709	-10.839	0.316	0.519	0.060	
Returns-Drain	-1.422	-5.600	-0.779	-0.368	2.379	-3.285	-6.032	
χ^2 P-value	0.511 [0.475]	0.484 [0.486]	0.132 [0.716]	1.537 [0.215]	0.113 [0.737]	0.391 [0.532]	0.307 [0.579]	3.454 [0.840]
Variance-Add	18.827	30.316	122.965	275.017	107.025	64.210	14.019	
Variance-Drain	39.213	19.973	26.438	30.503	16.111	16.033	92.591	
χ^2 P-value	2.045 [0.153]	3.271 [0.071]	11.472 [0.001]	18.024 [<0.001]	5.132 [0.023]	4.472 [0.034]	2.690 [0.101]	44.478 [<0.001]

Table 5 (continued)

Open market operation	1982	1983	1984	1985	1986	1987	1988	Multivariate tests
E: Canadian dollar								
Returns-Add	1.463	0.323	1.297	-1.065	1.595	-2.592	-0.262	
Returns-Drain	14.375	3.494	-1.043	-1.464	1.926	2.074	-4.313	
χ^2	1.202	0.742	0.499	0.004	0.003	2.154	1.058	5.494
P-value	[0.273]	[0.389]	[0.480]	[0.952]	[0.958]	[0.142]	[0.304]	[0.600]
Variance-Add	4.593	3.939	7.528	60.057	21.794	8.914	4.737	
Variance-Drain	67.658	3.020	5.912	12.749	19.674	2.920	2.766	
χ^2	1.043	0.389	1.051	9.324	0.028	6.038	3.136	19.293
P-value	[0.307]	[0.533]	[0.305]	[0.002]	[0.868]	[0.014]	[0.077]	[0.007]
F: Deutschemark								
Returns-Add	9.649	3.223	1.815	-5.146	0.354	1.970	1.834	
Returns-Drain	-12.725	0.219	1.250	0.740	-2.744	-0.557	30.678	
χ^2	1.432	0.059	0.005	0.928	0.433	0.450	1.870	5.119
P-value	[0.231]	[0.808]	[0.943]	[0.335]	[0.510]	[0.502]	[0.171]	[0.645]
Variance-Add	56.025	561.482	322.924	165.280	90.770	41.444	10.588	
Variance-Drain	153.733	10.998	18.997	19.420	11.145	9.645	516.103	
χ^2	0.443	17.509	8.641	11.244	9.991	7.544	8.625	59.378
P-value	[0.506]	[<0.001]	[0.003]	[0.001]	[0.002]	[0.006]	[0.003]	[<0.001]
G: Japanese yen								
Returns-Add	-4.821	-8.423	-1.193	0.366	-0.296	0.826	0.013	
Returns-Drain	22.305	7.618	1.066	0.223	-2.830	-0.271	-4.741	
χ^2	2.397	4.245	0.044	0.001	0.414	0.104	0.243	7.202
P-value	[0.122]	[0.039]	[0.833]	[0.981]	[0.520]	[0.747]	[0.622]	[0.408]
Variance-Add	70.501	251.227	473.612	127.011	39.404	30.147	10.177	
Variance-Drain	127.868	7.365	8.033	9.592	9.626	7.545	103.125	
χ^2	0.251	14.557	11.114	9.673	5.389	7.538	2.708	48.055
P-value	[0.616]	[<0.001]	[0.001]	[0.002]	[0.020]	[0.006]	[0.100]	[<0.001]
H: Swiss franc								
Returns-Add	0.945	5.719	8.104	4.963	0.024	-0.279	-1.186	
Returns-Drain	57.525	0.979	1.739	-2.731	-2.541	-1.695	-9.172	
χ^2	0.643	0.230	0.251	1.024	0.337	0.140	0.093	2.707
P-value	[0.423]	[0.631]	[0.616]	[0.312]	[0.562]	[0.709]	[0.760]	[0.911]
Variance-Add	566.484	406.784	904.054	303.919	68.393	37.150	11.845	
Variance-Drain	2668.069	15.533	14.545	19.559	12.210	10.751	851.934	
χ^2	3.991	9.780	15.207	17.647	5.764	9.942	7.330	65.819
P-value	[0.046]	[0.002]	[<0.001]	[<0.001]	[0.016]	[0.002]	[0.007]	[<0.001]

The variances are those of the relative price changes calculated as $\ell n(p_t/p_{t-1})$ 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. 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. Standard errors in parentheses are heteroskedasticity consistent.