NBER WORKING PAPER SERIES

ARE FOREIGN EXCHANGE
INTERVENTION AND MONETARY
POLICY RELATED AND
DOES IT REALLY MATTER?

Karen K. Lewis

Working Paper No. 4377

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
June 1993

ARE FOREIGN EXCHANGE
INTERVENTION AND MONETARY
POLICY RELATED AND
DOES IT REALLY MATTER?

ABSTRACT

The relationship between foreign exchange intervention and monetary policy underlies the question of whether sterilized interventions can affect the exchange rate. In this paper, I examine this relationship using data on U.S. foreign exchange interventions from 1985 to 1990, recently made publicly available. I examine whether interventions could be viewed as "signalling" changes in future monetary policy variables. I also consider whether changes in monetary policy may induce interventions in an effort to "lean against the wind" of exchange rate movements. Interestingly, I find evidence both that interventions help predict monetary policy variables, and that monetary variables help predict interventions. These relationships matter for understanding exchange rate behavior only if monetary variables indeed affect the exchange rate. Therefore, I also study the response of exchange rates to shocks in various monetary policy variables. The results provide new evidence on the relationship between exchange rates, monetary policy, and foreign exchange interventions.

Karen K. Lewis
Wharton School
University of Pennsylvania
Philadelphia, PA 19104-6367
and NBER

Over the last two decades, the question of how sterilized interventions can affect the exchange rate has been the focus of a great deal of attention both in academic and policy-making circles. Central to this debate has been the observation that sterilized interventions do not alter the relative money supplies of countries, and therefore should not have any obvious impact upon the exchange rate. In the seventies and early eighties, it was thought that these interventions might affect the exchange rate through a "portfolio balance" channel. Subsequent empirical research has found this story to be highly implausible, however.[1]

An alternative possibility, suggested by Mussa (1981), is that intervention may signal changes in future monetary policy. This explanation would say that central banks may signal a more contractionary future monetary policy by buying domestic currency in the foreign exchange market today. Therefore, the expectations of future tighter monetary policy will make the exchange rate appreciate, even though the monetary effects of the intervention are currently offset. Since this signalling story was first proposed, a number of academic studies have emphasized it and Federal Reserve publications have even claimed signalling to be a reason for and against intervening.[2]

If intervention provides a signal of future monetary policy, then the intervention should indeed be followed by changes in monetary policy variables. Therefore, in this paper, I ask whether interventions help predict changes in monetary policy by examing the relationship between

---

[1] For example, Rogoff (1984), Lewis (1988), and others as surveyed in Edison (1992) find no evidence of a portfolio balance channel. On the other hand, Dominguez and Frankel (1990) find some support for this cannel under the assumptions that an international CAPM model holds and that exchange rate expectations can be measured with survey data.

[2] For empirical studies discussing signalling, see Dominguez (1987) as well as other references in Edison (1992). Signalling has been noted as a reason for intervening in the New York Federal Reserve Bulletin (1991) and has been used a a reason against intervention at Federal Open Market Committee meetings (e.g., the FOMC Meeting Minutes, August 1989 in Board of Governors of the Federal Reserve Annual Report (1989)).

1

intervention and monetary policy variables.[3] Despite the obvious importance of this issue, its direct analysis has only recently been made possible by the release of actual intervention data to the public.

In Section 1, I begin with an illustrative example of how intervention can affect the exchange rate through changing expectations of future monetary policy. I then test this relationship with Granger-Causality tests of intervention upon various U.S. monetary policy variables. These monetary policy variables include M1, monetary base, non-borrowed reserves and the Fed funds rate, as well as the differential between the Fed funds rate relative to some foreign interest rates. For most cases, there is a significant relationship between intervention and changes in monetary aggregates. However, innovations to intervention are generally correlated with changes in monetary aggregates only within a short two week period.

I then ask in Section 2 whether intervention is instead a response to economic conditions as reflected in the monetary variables. In this case, all of the variables except monetary base appear to explain intervention. These basic results continue to hold when intervention is treated as a limited dependent variable. Again, however, these relationships hold only within a two week period.

One reason why intervention and monetary policy may be correlated during the two week period is the way in which sterilized intervention takes place. Section 3 describes how the nature of the Federal Reserve operating procedures together with foreign exchange intervention can induce a lag between intervention and sterilization, particularly during two week intervals corresponding to required reserves accounting periods. When the Granger-Causality tests are performed after

---

[3]Kaminsky and Lewis (1992) use market observations of days when central banks were intervening to test whether market participants would have considered intervention to be a signal. We used these observations to estimate a regime-switching process for money supply, and found intervention to provide a significant signal. However, on-average the signals were in the opposite direction implied by the nature of the intervention. In a similar vein, Klein and Rosengren (1991, 1992) examine the relationship between market observations of intervention and discount rate changes by the Group of Three countries.

2

lagging intervention by one to two weeks, there is no longer much evidence that intervention helps predict monetary aggregates.

In Section 4, I consider whether a correlation between intervention and monetary policy would help explain the exchange rate anyway. That is, the signalling story presumes that changes in the money supply in fact affect the exchange rate, while empirical studies have found little evidence that money supply changes are statistically related to the exchange rate.[4]

The findings mirror early empirical findings that money supplies innovations induce a positive or insignificant effect upon the interest rates.[5] These findings have recently been criticized on the grounds that broad monetary aggregates typically used by the early studies contain a significant component that is not under the control of the Federal Reserve. Christiano and Eichenbaum (1991,1992a,b) argue that non-borrowed reserves provide a better measure of money supply innovations.[6] By contrast, Bernanke and Blinder (1992) propose the Federal funds rates as a monetary policy indicator and find that this measure is a better predictor of real economic activity than any monetary aggregate.

This debate suggests a re-examination of the monetary policy shock and exchange rate relationship as well. Broader monetary aggregates may include money demand shocks that are innappropriate for evaluating the effects of money supply innovations upon the exchange rate. Therefore, in this paper, I ask whether non-borrowed reserves or federal funds rates provide different implications than M1 for this relationship over the period of study. In particular, I

---

[4]See, for example, Meese and Rogoff (1983). On the other hand, in this conference Mark (1992) finds a significant relationship between money supplies and exchange rates over long horizons.

[5]See for example, Mishkin (1981, 1982) and the references in Christiano and Eichenbaum (1991).

[6]Interestingly, they find that innovations to non-borrowed reserves induce negative responses in interest rates, even though innovations to M1 do not.

3

estimate the impulse response functions of the DM/dollar and the Yen/dollar exchange rates in response to these monetary shocks. Interestingly, I find that *both* monetary variables affect the DM/dollar rate in the expected direction, while the federal funds rate does not. On the other hand, none of the variables are significantly related with the Yen/dollar rate, although all variables move in the direction suggested by a monetary model.

These results provide new results as well as new questions on the relationship between exchange rates, monetary variables, and intervention. The paper concludes by noting the limitations of these results and pointing to some important directions for future research.

1. Does Intervention Help "Signal" Future Monetary Variables?

The "signalling hypothesis" states that interventions induce traders in the market to alter their expectations of future monetary policy. This hypothesis implies that interventions are in fact related to monetary variables in a systematic way. In this section, I first provide a simple example to illustrate what people may mean when they talk about this hypothesis.[7] I then present evidence on the relationship between intervention and monetary policy.

A. A Simple Example of the Signalling Hypothesis

Consider a standard asset pricing model of the equation:

(1) $s_t = (1 - \Theta) \sum_{j=0}^{\infty} \Theta^j E_t f_{t+j}$

where s is the log exchange rate, f is the log of "fundamentals", and Θ is a discount factor. In

---

[7] To my knowledge, no one has developed an explicit model of this signalling story.

4

monetary models of the exchange rate, $\theta = \alpha/(1+\alpha)$ where α as the semi-elasticity of money demand.[8] More specifically, let f_t be given by:

(2) $f_t = (m_t - m_t^*) + v_t$

where m and m^* are the domestic and foreign monetary policy variables and v measures other fundamentals out of the control of the monetary authorities. For simplicity, I will assume that m^* and v are exogenous and without loss in generality set their values equal to zero so that $f_t = m_t$. To correspond roughly with the empirical analysis above, I will treat the process of fundamentals as autoregressive.[9]

(3) $m_t = \rho_m \, m_{t-1} + \beta \, n_{t-k} + u_t$,

where ρ_m is the autoregressive coefficient of fundamentals on their own lag, n_t is foreign exchange intervention at time t, and β is a parameter relating intervention k periods in the past with a current change in money supply. The variable n is measured as purchases of domestic currency (sales of foreign currency) by the central bank. If the central bank is "signalling" with interventions consistent with subsequent changes in money supplies, then an increase in n at t-k will be correlated with a decrease in m in the future at time t. Therefore, β would be negative.

   Calculating the expectations in the exchange rate equation (1) requires a process for

---

[8]See, for example, Mussa (1982) and Frenkel and Mussa (1980).

[9]Technically, the money supply is empirically autoregressive in growth rates and includes a constant term. I abstract from these complications in order to make the example extremely simple. Lewis (1989) describes a present value model of the exchange rate when the growth rate of fundamentals is autoregressive and includes a constant term.

intervention. In keeping with the autoregressive structure above, this process is assumed to follow:[10]

(4) $n_t = \rho_n n_{t-1} + e_t$,   where $E(e_t u_t) = 0$.

Consider the simplest case where the period between intervention and the subsequent change in money supply is one period. In other words, the lag on intervention in equation (3) is one so that $k = 1$. In this case, the solution of the exchange rate is:

$$(5) \quad s_t = \mu \, [m_t + \frac{\Theta \beta}{(1 - \Theta \rho_n)} n_t]$$

where $\mu = (1 - \Theta)/(1 - \Theta \rho_m)$, a constant reflecting the discounted present value effect of current money supply in all future periods. As equation (5) shows, current intervention n_t affects the exchange rate according to the term: $\Theta \beta/(1 - \theta \rho_n)$. In the numerator, θ reflects the discounted effect of the current intervention on money supply one period ahead, while β measures the magnitude of the expected effect. The denominator discounts the effects of current changes in intervention upon all expected future levels of intervention.

As this example shows, current interventions affect the exchange rate according to their discounted present value effects on future money supply. If the lag between intervention and money

---

[10]This process treats intervention as a continuous process for simplicity. As will be seen below, there are many days in the data when no intervention occurs, however. Kaminsky and Lewis (1992) provide a slightly more realistic example in which the occurrence of intervention affects the future money supply relative to its level in the absence of intervention. In this case, the exchange rate depends upon the probability of intervention occuring.

6

supply changes, k, is longer than one period, then the example becomes more complicated but these basic features remain. In addition, the longer is k, the farther in the future current interventions are expected to affect the money supply and, therefore, the less impact interventions will have upon the exchange rate (current interventions are carry a weight of Θ^k instead of Θ in the numerator of (5)). Despite details of the nature of interventions and future changes in monetary policy, it is clearly necessary that a correlation exist between the two variables for this "signalling" story to be valid. If $\beta = 0$, current interventions will not affect future money supplies and sterilized interventions would have no apparent effect.

B. Are Interventions Related to Future Monetary Policy Variables?

I now examine whether intervention empirically helps predict future changes in monetary policy. The intervention series are daily interventions by the Federal Reserve from 1985 to 1990. The U.S. monetary policy variables studied are M1, monetary base, non-borrowed reserves, and the federal funds rate. These data are available at different frequencies. The frequency of the Fed funds rate is daily and that of M1 is weekly, but monetary base and non-borrowed reserves are only available bi-weekly. The data appendix gives the sources of these variables.

Figure 1 shows some of these measures of monetary policy during the period of study. The top panel plots weekly observations of M1 money supply together with the Fed funds rate. As the picture shows, the growth rate of M1 accelerated during 1985 and 1986. At the same time, the Fed funds rate trended downward, in tandem with other interest rates. From mid-1984 to the end of 1986, most interest rates declined 5 to 6 percentage points. These downward movements were accomodated by two discount rate cuts in April and August of 1986. Monetary policy was quite different during the period from 1987 through late 1988. Largely in response to an increase in inflation, the Federal Reserve began tightening reserves in the second quarter of 1987, and as a

7

result most of the monetary aggregates rose at much smaller rates. The top panel of Figure 1 shows the sharp deceleration in the growth rate of M1 as well as the upward trend in the Fed funds rate extending into 1988. This tightening of monetary policy was accentuated with discount rate increases in October 1987, August 1988, and February 1989.

Recent empirical studies have emphasized that movements in broad monetary aggregates such as M1 can be misleading measures of monetary policy, relative to non-borrowed reserves. Panel B of Figure 1 depicts non-borrowed reserves against M1 and Fed funds, observed only bi-weekly.

To test whether intervention helps predict these monetary policy variables, bivariate vector-autoregressions were estimated for each monetary variable and intervention. In other words, equations were estimated for the systems:

(6) $(\Delta M(i)_t, n_t)' = B(L)(\Delta M(i)_t, n_t)' + \epsilon_t,$

$E(\epsilon_t \epsilon_t') = V$

where $M(i)$ is the monetary aggregate, for i = M1, Monetary Base (MB), Non-Borrowed Reserves (NBR), or Fed Funds (FF) and where $B(L)$ is a polynomial matrix in the lag operator, L, and where ϵ_t is a bivariate i.i.d. random variable with mean vector zero.[11]

In order to combine intervention and monetary aggregates at different frequencies, several intervention series were formed. First, since M1 is measured from Monday to Monday, the daily intervention series were cumulated over the same period. These data together with Monday Fed

---

[11]Note that first-differencing the monetary aggregates in the VAR imposes the condition that intervention is a stationary variable.

8

funds rates were used as the weekly frequency data series. Second, since monetary base and non-borrowed reserves are measured Wednesday to the second following Wednesday, a second intervention series was cumulated over the same period. These data were used as the bi-weekly frequency data series.[12]

The maximum lag length of these VARs were first tested with a Wald test of zero restrictions at each lag. As reported in Table A in the appendix, these lag lengths were quite short. Except for the monetary base, the maximum lag length of these VARs were two weeks or less.

Table 1 reports the results of Granger-causality tests of intervention on the monetary policy variables.[13] Interestingly, the hypothesis that intervention does not help predict monetary policy at the bi-weekly frequency is rejected at the 90% confidence level for all four monetary measures and at the 95% confidence level for non-borrowed reserves. Furthermore, intervention is significantly related to the federal funds rate at the weekly frequency.

The theoretical example above illustrated that U.S. monetary policy *relative* to foreign monetary policy is the important variable for determining the exchange rate. Therefore, it may seem inappropriate to focus upon U.S. monetary variables alone. Unfortunately, foreign money supply data are typically available only at a monthly frequency. Since the data sample is short, I cannot use monthly money supply data with much confidence.

As an alternative, I considered the interest differentials between the U.S. and two countries: Germany and Japan. The German and Japanese call money rates were used to correspond to an overnight interbank rate as is the Fed funds rate. These variables were then used instead of the

---

[12]M1 and Fed funds were also used with this series. Experimentation with cumulating intervention from M1 from Monday to the second Monday and using Wednesday Fed funds rates did not alter the basic conclusions below.

[13]It should be noted that, while I use the standard terminology of "causality", the usual caveat applies here that correlation does not imply causality.

U.S. monetary policy variables above to, first, test the lag lengths and then to conduct Granger-causality tests. The lag length tests are reported in Table B in the appendix. As with the U.S. monetary policy variables, the lag lengths are quite short. Except for the differential between the Fed funds rate and the German rate, the lag lengths were all two weeks or less.[14]

Table 2 reports the results of Granger causality of intervention on these interest differentials. However, the hypothesis that intervention provides no information concerning future interest differentials cannot be rejected in any case.

2. Do Monetary Variables Help "Signal" Intervention?

An alternative view of the correlation between intervention and monetary policy is that central banks intervene to try to maintain a monetary policy that is inconsistent with their targets of the exchange rate. In this case, changes in monetary policy with domestic targets in mind may induce counterproductive movements in the exchange rate. These movements in the exchange rate may, in turn, induce central bankers to intervene in order to try to "lean against the wind."

Indeed, this type of behavior seemed to characterize Federal Reserve policy for periods during 1988 through 1990. In particular, while monetary policy remained relatively contractionary well into 1989 as noted above, the Federal Reserve intervened heavily to sell dollars for most of the period. Starting on June 27, 1988, the Federal Reserve sold dollars in the foreign exchange market, totalling 5 billion dollars by September 26. A second round of heavy dollar selling began on January 6, 1989, despite the fact that monetary policy remained relatively tight.

The conflict between the objectives to fight inflation by the Fed and to keep the dollar from

---

[14]The Fed funds/German rate appeared to be somewhat sensitive to the day of the week that the variables were sampled. When the series were sampled on Wednesdays instead of Mondays, the lag length was one week. The longer lag structure is used in the estimation results below in order to provide more conservative estimates.

strengthening, deemed desirable by the Treasury, became evident in meetings of the Federal Open Market Committee. During early 1989, debate increased among the governors on the Federal Reserve Board concerning intervention carried out at the behest of the Treasury and the appropriateness of its signal toward monetary policy. By the FOMC meeting on May 16, 1989, intervention had become an important item of discussion as large purchases of foreign currency assets by the New York Federal Reserve Bank had increased its holdings beyond the legal limit. By the August 22 FOMC meeting, many governors were critical of the intervention policy. Governors Angell and Johnson dissented on a move that would allow further intervention stating "intervention confuses market participants concerning the policy commitment toward price stability." (Minutes of FOMC meeting, August 22, 1989).

A. Is There a Relationship between Monetary Policy and Future Interventions?

As this discussion suggests, intervention and monetary policy may be related by a "leaning against the wind" policy in which monetary policy helps predict future changes in intervention. To evaluate this possibility, Table 3 reports marginal significance levels from Granger-Causality tests of intervention on the monetary aggregates in each column. Interventions appear to be predictable at the bi-weekly frequency both from Federal funds rate changes and from non-borrowed reserves changes, although this relationship is less apparent from the broader monetary aggregates. On the other hand, Federal funds rate changes at the higher frequencies of weekly and daily appear to contain no information about intervention changes.

As reported in Table 4, this pattern is reversed when Granger Causality tests of Fed funds differentials with foreign rates are used instead. In this case, weekly changes in interest differentials of the Fed funds against the Japanese and German call money rates provide no information about interventions. However, daily movements in these differential appear to predict intervention movements, particularly for the Japanese case.

11

Overall, the evidence appears to be that movements in Federal funds and non-borrowed reserves are useful for predicting intervention at longer horizons of two weeks, while interest differentials are useful for predicting intervention at intervals less than a week.

B. *Treating Intervention as a Limited Dependent Variables*

The analysis above treated intervention as a continuous random variable since it can take any value on the real line. However, there were many days in which no intervention occurs, so that much of the distribution of intervention observations is concentrated at zero. The errors from regressions of intervention on other variables may therefore be far from normally distributed in small samples. For this reason, I also treat intervention as a limited dependent variable that is a function of lagged monetary policy variables.

Intervention was classified into three cases defined as follows:

$I_t = 0$	No Intervention
$I_t = -1$	Dollar Sales
$I_t = 1$	Dollar Purchases.

Using this measure of intervention, the probability of intervention was treated as a logistic probability function given by:

$$(7a) \quad \text{Prob}(I_t = 0) = \frac{\exp(g_0 + \Sigma_{t=1}^{k} g_t \, \Delta M(i)_{t-t})}{1 + \exp(g_0 + \Sigma_{t=1}^{k} g_t \, \Delta M(i)_{t-t}) + \exp(c_0 + \Sigma_{t=1}^{k} c_t \, \Delta M(i)_{t-t})}$$

$$(7b) \quad \text{Prob}(I_t = -1) = \frac{\exp(c_0 + \Sigma_{t=1}^{k} c_t \, \Delta M(i)_{t-t})}{1 + \exp(g_0 + \Sigma_{t=1}^{k} g_t \, \Delta M(i)_{t-t}) + \exp(c_0 + \Sigma_{t=1}^{k} c_t \, \Delta M(i)_{t-t})}$$

12

$$(7c) \quad \text{Prob}(I_t = 1) = \frac{1}{1 + \exp(g_0 + \Sigma_{t=1}^{\hat{}} g_t \, \Delta M(i)_{t-t}) + \exp(c_0 + \Sigma_{t=1}^{\hat{}} c_t \, \Delta M(i)_{t-t})}$$

where $M(i)$ is the monetary variables, $i = M1$, MB, NBR, FF, as before, and where k is the maximum lag in the vector autoregression estimated above for each bivariate system.

The intuition behind these equations can be seen more readily by taking the logarithms of these probabilities, forming the odds ratios, and focusing upon the case where $k = 1$.

$$(8a) \quad \log(\text{Prob}(I_t = -1)/\text{Prob}(I_t = 1)) = c_0 + c_1 \, \Delta M(i)_{t-1}$$

$$(8b) \quad \log(\text{Prob}(I_t = 0)/\text{Prob}(I_t = 1)) = g_0 + g_1 \, \Delta M(i)_{t-1}.$$

$$(8b) \quad \log(\text{Prob}(I_t = -1)/\text{Prob}(I_t = 0)) = (c_0 - g_0) + (c_1 - g_1) \, \Delta M(i)_{t-1}.$$

Now suppose that large increases in monetary variables induce a depreciation in the currency and, thus, a dollar purchase intervention in response. If the Fed is "leaning against the wind," an increase in $\Delta M(i)$, for $i = M1$, MB, and NBR will increase the probability of a dollar purchase intervention ($I_t = 1$) relative to a dollar sale intervention ($I_t = -1$), so that we would expect $c_1 < 0$. Similarly, the increase in $M(i)$ should increase the probability of a dollar purchase intervention relative to no intervention in (8b), so that $g_1 < 0$. Finally, the increase in $M(i)$ may decrease the probability of a dollar sale intervention in (8c) relative to no intervention so that $c_1 - g_1 < 0$. For $i = $ Fed funds, a similar relationship applies but with the opposite sign.

The constant coefficients in (8) have a similarly intuitive interpretation. If $\Delta M(i) = 0$, then

13

the probabilities are simply:

(9a) $\text{Prob}(I_t = 0) = \exp(g_0)/(1 + \exp(g_0) + \exp(c_0))$

(9b) $\text{Prob}(I_t = -1) = \exp(c_0)/(1 + \exp(g_0) + \exp(c_0))$

(9c) $\text{Prob}(I_t = 1) = \exp(0)/(1 + \exp(g_0) + \exp(c_0)) = 1/(1 + \exp(g_0) + \exp(c_0))$.

Thus, the relationship between g_0, c_0, and 0 indicates the probabilities of each intervention type when the monetary aggregate does not change.

Table 5 reports the results of estimating the logistic probabilities for each monetary aggregate examined in Tables 1 and 3. As column 1 shows, movements in M1 are significant explanatory variables for the probability of intervention. Interestingly, both c_1 and a_1 are negative, as predicted by the "leaning against the wind" explanation. However, $c_1 - g_1 > 0$ so that the increase in M(i) increases the probability of a dollar sale intervention relative to no intervention.

The first lag of monetary base also suggests "leaning against the wind" behavior. Both c_1 and a_1 are significantly negative. Furthermore, in this case, $c_1 - g_1$ is also negative, consistent with the view that increases in the monetary base reduce the probability of dollar sales interventions relative to no intervention. However, the second lags do not appear to significantly effect the likelihood of intervention.

Despite the significant effects of M1 and monetary base, neither non-borrowed reserves nor fed funds appear to affect the probability of intervention. This pattern reverses the finding in Table 3 where M1 and monetary base did not significant predict the intervention variable while Fed funds and non-borrowed reserves did. A reason may be that the logit estimation focuses upon whether

14

intervention occurs or not while the Granger-causality tests in Table 3 analyze the magnitudes of intervention. Variations in the endogenous components in M1 and monetary base may affect the decision to intervene, while movements in the monetary policy variables such as non-borrowed reserves and Fed funds may influence the magnitudes of intervention.

3. Is the Operating System Responsible?

A feature of the relationship between intervention and monetary aggregates found above is that the maximum lags in the vector autoregressions are typically two weeks. Of course, while an autoregressive process implies that shocks today persist indefinitely, moving average processes with innovations that disappear at fixed lags can look much like autoregressive processes. Thus, the relationships found above suggest a possible alternative explanation for the apparent correlation between monetary variables and intervention.

To understand this explanation, it is necessary to examine the operating system of the Federal Reserve together with intervention operations. The domestic monetary policy is based upon a borrowed reserves targeting procedure. Under this procedure, the FOMC selects a level of borrowed reserves to be used as an operating target, based upon an assumed relationship between the Federal funds rate and borrowed reserves. On a day-to-day basis, open market operations are primarily guided by an interim target for non-borrowed reserves based upon an estimated demand for total reserves (subtracting out the borrowed reserves component.) The non-borrowed reserves target is changed on a daily basis as revised estimates of required reserves are received and, less frequently, as excess reserve estimates are reviewed.[15]

---

[15]See Smith and Madigan (1987) for more details on this procedure as well as its interaction with foreign exchange interventions. It should be noted, however, that the nature of the operating procedure changed during the sample period. Since late 1987, the Federal Reserve trading desk has adopted a more flexible approach to pursuing the borrowing objective, due to a striking instability in the behavior of borrowed reserves during that year. See, Federal Reserve Board

15

Foriegn exchange intervention affects the supply of non-borrowed reserves when the Federal Reserve receives payment by debiting the reserve account of a purchasers' depository institution. However, this intervention does not affect non-borrowed reserves targets.[16] Depending upon the elasticity of short-term reserves demand, the purchaser of foreign exchange can either allow his dollar reserve level to fall temporarily or else try to increase the reserve level to its former level. If the banking system as a whole is willing to allow reserves to fall in the short run, then the intervention may not be effectively sterilized immediately. However, given the bi-weekly accounting for required reserves, the demand for reserves will likely return to its previous level over the two week period.

As a result of this complicated interaction of shocks to reserve supply induced by foreign exchange intervention and short run demand for reserves, the effects of intervention upon reserves may not be completely sterilized immediately. Rather, sterilization may occur only over time as the demand for reserves returns to its previous level.

If this story holds true, then the relationship between monetary aggregates and intervention during two week intervals may reflect in part the evolution of reserve demand. In this case, the correlations between monetary aggregates and intervention may have nothing to do with intentional signalling by the Federal Reserve.

As a simple check on this possibility, the vector autoregressions in Tables 1 and 3 were repeated, after lagging intervention by one period. If the relationships between intervention and money are due to the nature of the operating system, then lagging intervention will increase the likelihood that the sterilization process has been completed.

_____

(1991).

[16]The OMO desk uses this information to update its forecasts of reserves on the settlement date. For most currencies, settlement takes place two days from agreeing to buy or sell foreign exchange.

Table 6 reports these results. As the table shows in Panel A, the hypothesis that intervention does not Granger-cause monetary variables cannot be rejected at the 95% confidence level for any variable except the Fed funds rate at a weekly frequency. Also, the hypothesis that monetary variables do not Granger-cause intervention cannot be rejected for any of the monetary variables.

Although this evidence is only suggestive, it supports the notion that the correlation between intervention and monetary aggregates may arise from a timing lag in the sterilization process.

4. Does It Matter Anyway?

To this point, I have examined the relationship between intervention and monetary aggregates. The evidence indicates both that intervention helps predict changes in monetary aggregates and that monetary aggregates help predict intervention. Once intervention is lagged one period to help reduce the likelihood that the sterilization of the intervention has not been completed, intervention continues to help explain Fed funds movements. However, none of the monetary variables help explain intervention. This evidence suggests that intervention may indeed help explain future movements in monetary policy, at least as characterized by Fed funds movements.

I now consider a more basic question: does it matter if intervention explains monetary indicators? In the simple example described in Section 1, intervention moves the exchange rate because its relationship with future monetary policy induces traders to revise their forecasts of future monetary variables, and these *monetary variables affect the exchange rate*. This signalling story relies on the underlying presumption that money matters for determining the exchange rate.

Although all standard theoretical models use monetary variables as key ingredients of exchange rate determination, empirical evidence has found little evidence of such a relationship.

17

A recent exception is the paper analyzing long term movements by Nelson Mark in this conference. However, the signalling story depends upon a relationship between exchange rates and money supplies at higher frequencies. Thus, an important question is -- does it really matter?

A. Does the Exchange Rate Really Depend Upon U.S. Monetary Variables?

To address this question, I estimated bi-variate VARs of U.S. monetary policy variables together with the German mark/dollar rate and the Japanese yen/dollar rate and examined the impulse response functions of exchange rates to the monetary variable. Given the recent debate on the monetary transmission mechanism, it is interesting to compare the effects of different monetary indicators. I therefore examine the impulse response functions from three different measures of monetary policy.

M1 has been the most frequently used measure of money supply in previous studies. For comparison with these studies, the first monetary variable used is M1.

The second monetary variable is motivated by the recent debate concerning the appropriate measure of monetary policy. Christiano and Eichenbaum (1992a,b) argue that early studies of the relationship between interest rates and money supplies were incorrect because they used M1 and other broad measures of monetary aggregates. Both of these aggregates include borrowed reserves which is *positively* correlated with the fed funds rate and other interest rates since increases in these rates induce banks to borrow more at the discount window. Although borrowed reserves are a very small component of M1 and monetary base, it displays considerable variability. As a result, M1 is frequently found to be positively correlated with interest rates, while subtracting out borrowed reserves gives a negative relationship with interest rates. Christiano and Eichenbaum find that when non-borrowed reserves are used as monetary measures instead of M1 or monetary base, then innovations to non-borrowed reserves imply negative responses of interest rates, as a liquidity

channel would suggest.

If M1 contains a significant component that varies positively with interest rates, then this variable may also be inappropriate for studies based upon a monetary model of the exchange rate that depends upon a liquidity effect.[17] Therefore, it is interesting to ask whether non-borrowed reserves innovations will provide stronger evidence of a monetary channel than M1. For this reason, the second monetary aggregate I use is non-borrowed reserves.

The third monetary indicator examined is the Federal funds rate. Bernanke and Blinder (1992) find that this rate is a stronger predictor of real economic activity than monetary variables.[18] They argue that the Fed funds rate is relatively exogenous in the short run as a result of Federal Reserve targeting and is the appropriate monetary policy indicator.[19]

B. Empirical Implementation

To examine the effects of each of these three monetary variables, I estimated bivariate VARs of the logarithm of their levels together with the logarithm of the levels of the exchange rates. In order to compare the effects upon exchange rates with studies of effects upon interest rates, I follow the practice in the literature of estimating these VARs in levels with the monetary indicator as the first component in the vector.[20] In order to determine the lag length, I follow a

---

[17]For example, money demand equations underly the model in Mussa (1982) such that shocks to money supply should imply a negative relationship with interest rates, consistent with the liquidity effect. If M1 shocks contain mostly money demand shocks, then shocks to M1 should be associated with an appreciation of the domestic currency.

[18]They also use various spreads of this rate relative to a long term rate and a commercial paper rate, not studied here.

[19]They also argue that the monetary transmission mechanism works because reductions in reserves by the Federal Reserve reduces the amount of loans made to customers and, therefore, aggregated demand falls. For more on the arguement, see Bernanke and Blinder (1992).

[20]It is usually argued that this practice allows for possible cointegration among the variables.

procedure similar to the lag length tests above. Given a maximum lag length of ten bi-weekly periods, I calculate the Wald test of zero coefficients for all lags greater than or equal to successively shorter lags until the hypothesis is rejected at the 95% confidence level. As before, the variance-covariance matrix allows for conditional heteroskedasticity, an important allowance in these systems since exchange rates are well-known to be heteroskedastic. The lag lengths and their marginal significance levels are reported in Table C in the appendix.

Given these lag lengths, the VARs were estimated similar to equation (6) above:

(10) $(m(i)_v \ s_t)' = B(L)(m(i)_v \ s_t)' + e_v$

$E(e_t \ e_t') = \Sigma$

where now $m(i)$ is the logarithm of the monetary indicator, i = M1, NBR, FF, and s is the logarithm of the exchange rate for either the DM/dollar rate, or the Yen/dollar rate.[21] From the estimates of these VARs, the impulse response functions were calculated.

In order to evaluate the significance of the responses in exchange rates, Monte Carlo experiments were performed to generate the empirical distribution of the impulse response functions. The Monte Carlo experiments were implemented as follows. First, the VAR in (10) above was estimated and the parameter estimates, $B(L)$, and the fitted residuals, e_v, were saved. From these estimates, the covariance matrix, Σ, was formed. The Cholesky decomposition of Σ was then calculated and its lower triangular matrix form, G, was saved.

Then, these next steps were followed repeatedly. (i) Generate a two dimensional random

---

[21]The logarithm of the Fed funds rate was used to correspond to its treatment in Christiano and Eichenbaum (1992b). The essential results below are unchanged when using the level of the Fed funds rate.

variable, v_t, the length of the number of observations. (ii) Premultiply by G to obtain: $G' v_t = \hat{e}_t$. (iii) Add these values for e_t to the right-hand side of (10), and generate the left-hand side variables, $(\hat{m(i)}_t, \hat{s}_t)'$. (iv) Estimate the vector-autoregression in (10) and save the parameter estimates, $\hat{B}(L)$. (v) Using $\hat{B}(L)$, form the moving average representation of the vector autoregression, and generate the impulse response functions. (vi) Save the impulse responses and repeat 300 times.[22] From these observations, the 95% bounds on the empirical distribution were obtained.

Figure 2 shows the estimates of the impulse response functions together with the 95% confidence intervals for the DM/dollar rate. The top panel shows the effect of a one percent shock in M1. As would be predicted by a monetary model, the value of the dollar declines immediately and stays lower. However, the confidence intervals show that the depreciation in the dollar is significant only between 4 and 16 weeks after the shock. Nevertheless, the significant effect of the shock of M1 on the exchange rate is somewhat surprising given previous research on exchange rates.

The middle panel of Figure 2 shows the effects when non-borrowed reserves are used as monetary indicators. Unlike the M1 measure, the non-borrowed reserves shock has no immediate impact upon the exchange rate. But quite interestingly, the depreciating effects upon the exchange rate become significant after four weeks and remain significant even after 20 weeks!

The last column shows the effects of a shock in the Federal funds rate. Like non-borrowed reserves, there is no immediate effect upon the exchange rate. The point estimates imply that the rise in Fed funds induces an appreciation in the dollar after two weeks. However, these estimates are never statistically different than at the 95% level (although they are at the 90% level).

While these estimates would suggest that monetary measures might explain the exchange rate as standard models predict, the response functions for the Yen/dollar rate in Figure 3 give a

---

[22]Experimentation with the distributions from 2000 repetitions for several of the VARs indicated that the results were little changed by more repetitions.

different story. A shock to M1 induces very little variation in the Yen/dollar rate and the confidence intervals are quite large. The point estimates of impulse responses to non-borrowed reserves shocks and Fed funds shocks generally imply movements in the exchange rate in the direction suggested by a monetary model with liquidity effects. But the estimates are never significantly different than zero.

C. Does the Exchange Rate Depend Upon Relative Monetary Policies?

The focus of the previous analysis upon U.S. monetary policy variables alone is an important shortcoming. As discussed above, monetary models would imply that exchange rates depend upon relative money supplies. While the lack of high frequency money supply data preclude an investigation of money supply differentials over the short sample period, interest rate data can provide some information about the stance of foreign monetary policy.

Therefore, I estimated trivariate vector autoregressions similar to those examined in Figures 2 and 3, but including the German and Japanese call money rates. In particular, the system estimated was:

$$(11) \quad (m(i)_v \; r^*_v \; s_t)' = B(L)(m(i)_v \; r^*_v \; s_t)' + e_v$$

where r^* is the logarithm of the German call money rate when the exchange rate is the DM/dollar rate and the Japanese call money rate when the exchange rate is the Yen/dollar rate. Thus, the exchange rate was placed as last in the VAR order. These VARs were estimated, the impulse response functions calculated, and the Monte Carlo distributions generated as above.

Figure 4 depicts the impulse response functions of the DM/dollar rate from shocks to U.S. monetary aggregates controlling for the German interest rates. Strikingly, the basic pattern found

22

in Figure 2 continues to emerge. A shock in M1 is related to an immediate depreciation in the dollar. This decline is now statistically significant and continues for about 12 weeks. The non-borrowed reserves shock continues to imply a depreciation in the dollar even at 20 weeks. And finally, the Fed funds shock now becomes statistically significant after six weeks.

Figure 5 depicts these same impulse response functions for the Yen/dollar rate. As before, none of the impulse responses are significantly different than zero at the 95% level, although at the 90% level non-borrowed reserves is significant for some periods.

Overall, the evidence suggests that changes in monetary policy affect the exchange rate in the direction implied by standard monetary models. Except for M1, however, there is little evidence of a contemporaneous effect.

Concluding Remarks

This paper has provided two new sets of empirical findings. First, it examined the relationship between foreign exchange intervention and U.S. monetary policy variables during the period from 1985 to 1990. The evidence suggests that there were significant correlations in both directions between the two variables. Second, the paper analyzed the effects upon exchange rates of innovations to different measures of monetary policy variables suggested by the recent debate on the domestic monetary transmission mechanism. Interestingly, positive innovations in non-borrowed reserves appear to be more systematically related to depreciation in the dollar exchange rates than M1. This finding is consistent with the Christiano-Eichenbaum view that M1 contains a larger endogenous component relative to non-borrowed reserves.

Generally, this paper has produced new empirical findings in the relationship between monetary variables, foreign exchange intervention, and exchange rates. A continuing challenge for international researchers is to provide theoretical explanations for these relationships. In addition,

23

the evidence in this paper leaves open several particular issues and questions.

First, the innovations in monetary policy variables did not control for real economic activity. The money supply decision presumably depends upon variables such as the inflation rate and income growth. The short sample period of intervention precluded an analysis based upon real variables measured monthly or quarterly. However, an issue for future research will be to re-examine the effect upon the exchange rate using different measures of monetary policy controlling for real economic policy objectives.

Second, the analysis in this paper focused upon the behavior of U.S. monetary variables, while the exchange rate should depend upon relative monetary variables. Once foreign monetary variables are introduced, the current debate concerning the monetary transmission mechanism is doubled. The parallel question of what variables to use as foreign monetary policy indicators arises as does how these variables feed into real economic behavior. These questions also raise the issue of whether individual country monetary transmission processes can generate international feedback effects.

Third, while this paper has only documented the empirical relationship between intervention and the money supply, the reason for this correlation is not yet apparent. Although I have suggested that lags in the sterilization process implicit in borrowed reserves targeting may be responsible, future research should analyze more specifically the source of this correlation.

24

REFERENCES

Bernanke, B., and Blinder, A., "The Federal Funds Rate and the Channels of Monetary Transmission," *American Economic Review*, September, 1992.

Christiano, L.J., and Eichenbaum, M., "Identification and the Liquidity Effect of a Monetary Policy Shock," *National Bureau of Economic Research Working Paper Series*, No. 3920, December 1991.

Christiano, L.J., and Eichenbaum, M., "Liquidity Effects and the Monetary Transmission Mechanism," *American Economic Review Papers and Proceedings*, May, 1992a.

Christiano, L.J., and Eichenbaum, M., "Liquidity Effects, Monetary Policy, and the Business Cycle," *Federal Reserve Bank of Chicago Working Paper*, No. 92-15, 1992b.

Coslett, S. and Lee, L., "Serial Correlation in Latent Discrete Variable Models," *Journal of Econometrics*, 1985, 27, 79-97.

Dominguez, K., "Does Sterilized Intervention Influence Exchange Rates? A Test of the Signalling Hypothesis," working paper, Harvard University, Cambridge, 1987.

Dominguez, K., "Market Responses to Coordinated Central Bank Intervention," in *Carnegie Rochester Conference Series on Public Policy*, Allan Meltzer (ed.), Spring 1990, 32, 121-164.

Dominguez, K., and Frankel, J., "Does Foreign Exchange Intervention Matter? Disentangling the Portfolio and Expectations Effects for the Mark," *National Bureau of Economic Research Working Paper*, No. 3299, 1990.

Economic Report of the President, U.S. Government Printing Office, Washington, D.C., various issues.

Federal Reserve Board, *Board of Governors of the Federal Reserve System Annual Report*, U.S. Government Printing Office, Washington, D.C., 1987 to 1990.

25

Federal Reserve Board, *Briefing Book for Governor Designate*, Federal Reserve System, U.S. Government Printing Office, Washington, D.C., 1991.

Frenkel, J., and M.L. Mussa, "The Efficiency of Foreign Exchange Markets and Measures of Turbulence," *American Economic Review*, May 1980, *70*: 374-381.

Funabashi, Y., *Managing the Dollar: From the Plaza to the Louvre*, Institute for International Economics, Washington, D.C., 1988.

Klein, M., and Rosengren, E., "What Do We Learn From Foreign Exchange Intervention," manuscript, 1991.

Klein, M., and Rosengren, E., "Foreign Exchange Intervention as a Signal of Monetary Policy," Clark University Working Paper, No. 90-13, 1991.

Lewis, K.K., "Testing the Portfolio Balance Model: A Multi-Lateral Approach," *Journal of International Economics*, 1988, *24*, 109-127.

Lewis, K.K., "Can Learning Affect Exchange Rate Behavior? The Case of the Dollar in the Early 1980s," *Journal of Monetary Economics*, 1989, *23*, 79-100.

Meese, R., and K. Rogoff, "Empirical Exchange Rate Models of the 1970s: Do They Fit Out of Sample?" *Journal of International Economics*, 1983, *14*, 3-24.

Mishkin, F., "Monetary Policy and Long Term Interest Rates: An Efficient Markets Approach," *Journal of Monetary Economics*, 1981, 29-55.

Mishkin, F., "Monetary Policy and Short Term Interest Rates: An Efficient Markets Rational Expectations Approach," *Journal of Finance*, 1982, 63-72.

Mussa, M.L., "The Role of Official Intervention," Group of Thirty Occasional Papers, No. 6, Group of Thirty, New York, 1981.

Mussa, M.L., "A Model of Exchange Rate Dynamics," *Journal of Political Economy*, February 1982, *90*, 75-104.

Newey, W.K., and K.D. West, "A Simple, Positive Semi-definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix," *Econometrica*, 1987, *55*, 703-708.

Rogoff, K. "On the Effects of Sterilized Intervention: An Analysis of Weekly Data," *Journal of Monetary Economics*, 1984, *14*, 133-150.

Smith, R.W., and B.F. Madigan, "Exchange Rate Management and Monetary Policy in the United States," Federal Reserve Board, 1987, 188-199.

DATA APPENDIX

The main sources of the data and their abbreviations are:

Federal Reserve Bulletin (FRB)

Bank of International Settlements (BIS)

The individual series were:

M1 from FR H.6 "Money Stock Measures and Liquid Assets" (FRB Table 1.21), average of daily figures of week ending Monday.

Monetary Base from FR H.3 "Aggregate Reserves of Depository Insitutions and the Monetary Base," (FRB), average of daily figures ending bi-weekly Wednesdays.

Non-Borrowed Reserves from FR H.3 "Aggregate Reserves of Depository Insitutions and the Monetary Base," (FRB), average of daily figures ending bi-weekly Wednesdays.

Federal Funds Rate from FRB

German Call Money Rate from BIS
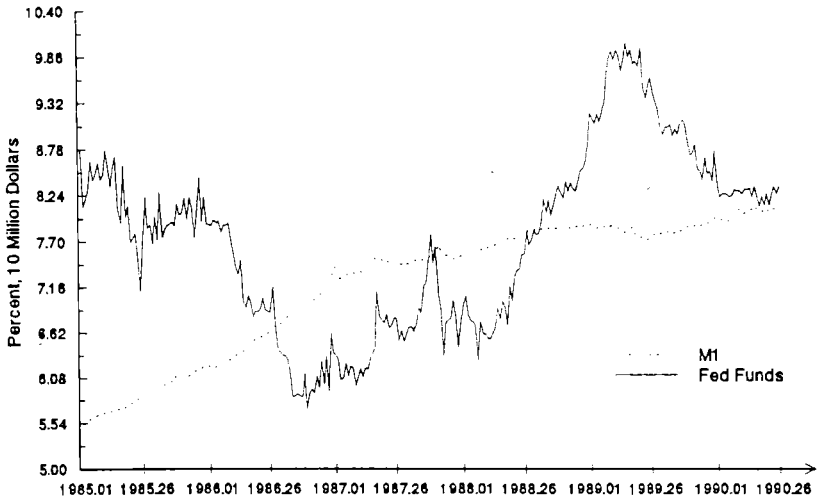
Japanese Call Money Rate from BIS

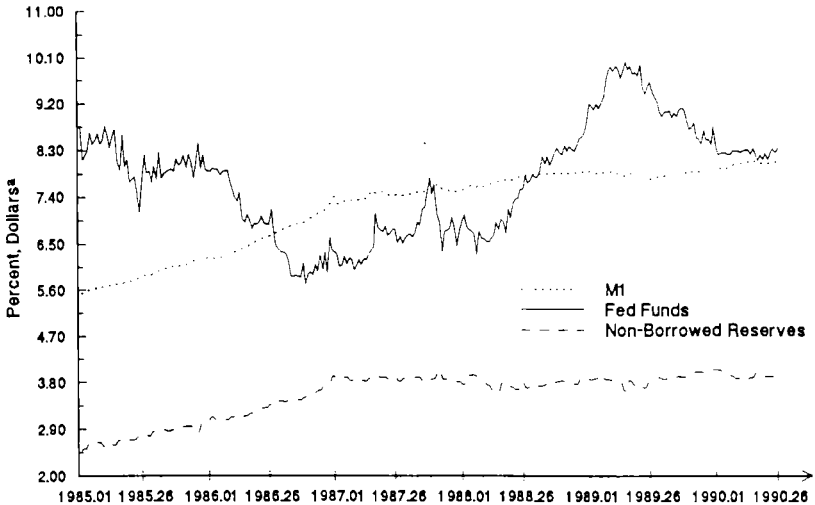German mark/Dollar Exchange Rate from FR G.5 "Foreign Exchange Rates" weekly averages.

Japanese yen/Dollar Exchange Rate from FR G.5 "Foreign Exchange Rates" weekly averages.

Figure 1: Relationship Between Monetary Variables

A. Weekly Series

B. Bi-Weekly Series

ªNon-borrowed reserves are in millions,
M1 is in 10 million dollar units.

Figure 2: Impulse Response Functions of DM/$ Exchange Rate from U.S. Monetary Shocks

Figure 3: Impulse Response Functions of Yen/$ Exchange Rate from U.S. Monetary Shocks
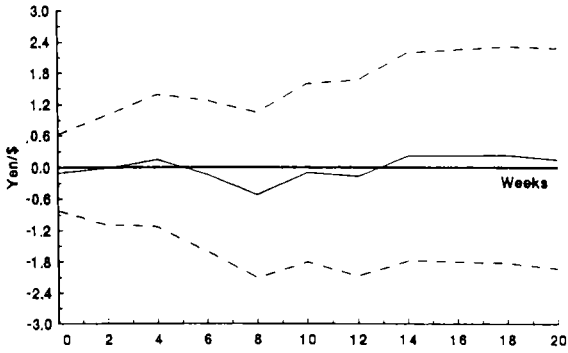
M1 Shock
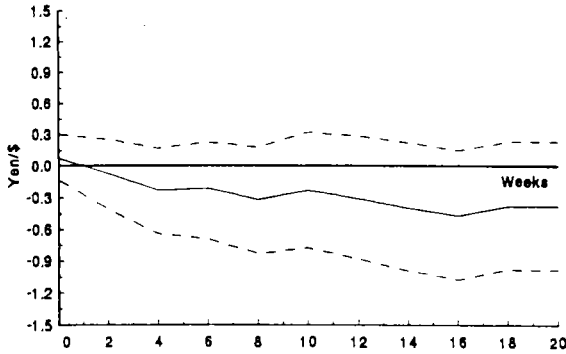
NBR Shock

Fed Funds Shock

- - - 95% confidence interval from Monte Carlo Distribution
— Impulse response estimates

Figure 4: Impulse Response Functions of DM/$ Exchange Rate from U.S. Monetary Shocks Controlling for German Interest Rates

M1 Shock

NBR Shock

Fed Funds Shock

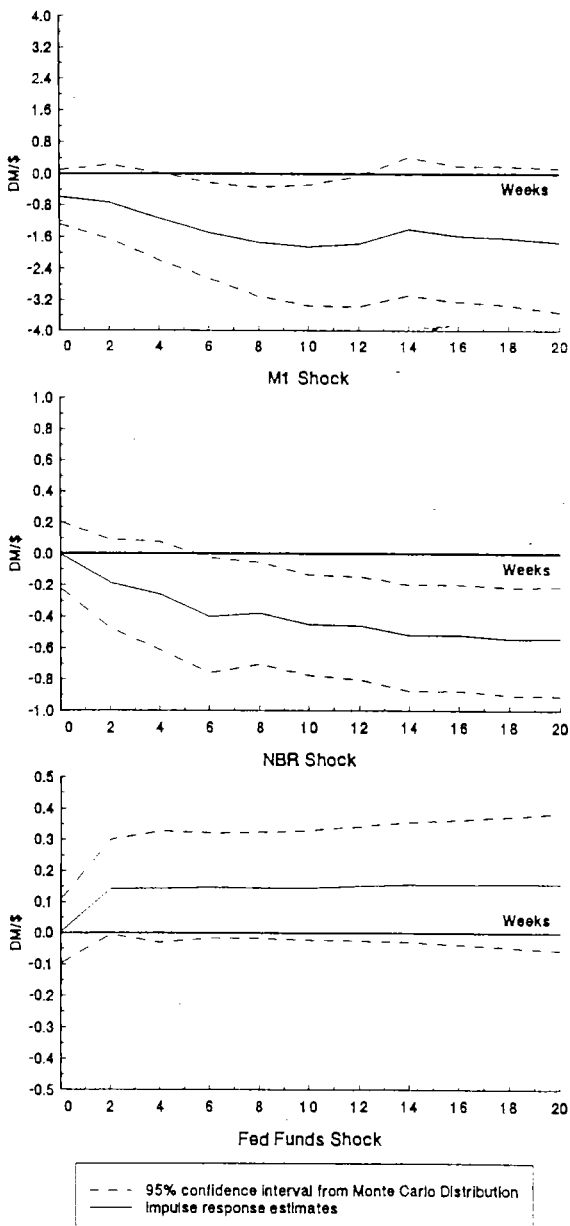- - - 95% confidence interval from Monte Carlo Distribution
—— impulse response estimates

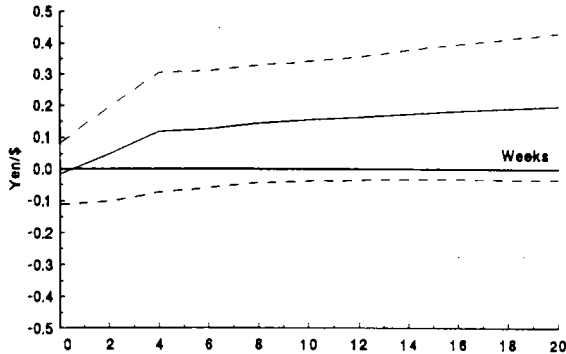**Figure 5: Impulse Response Functions of Yen/$ Exchange Rate from U.S. Monetary Shocks Controlling for Japanese Interest Rates**
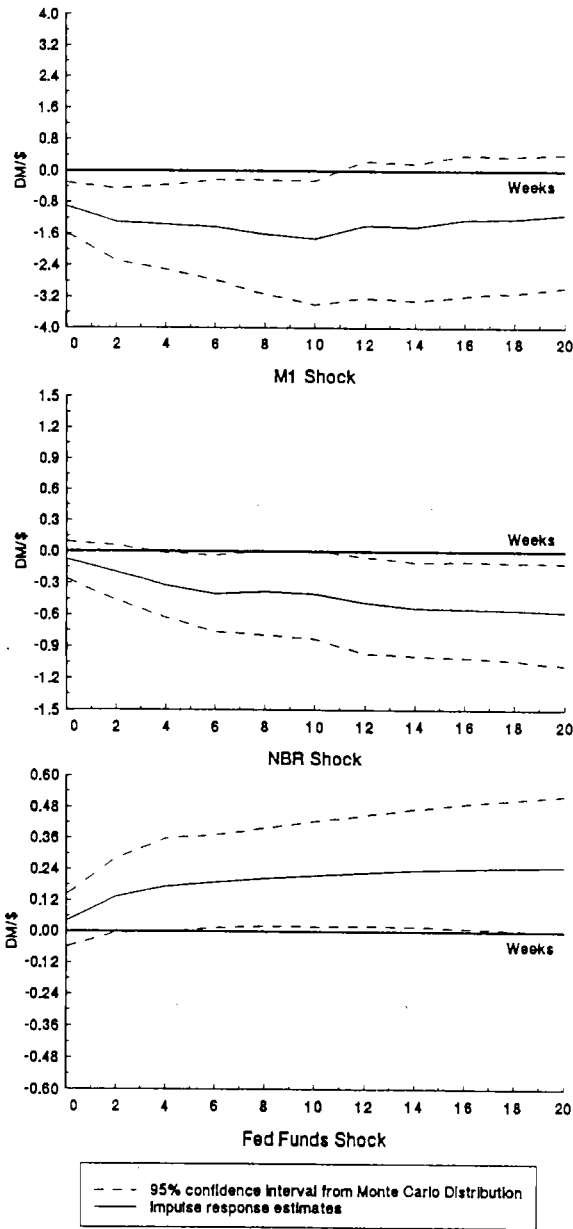

M1 Shock

NBR Shock

Fed Funds Shock

- - - 95% confidence interval from Monte Carlo Distribution
——— Impulse response estimates
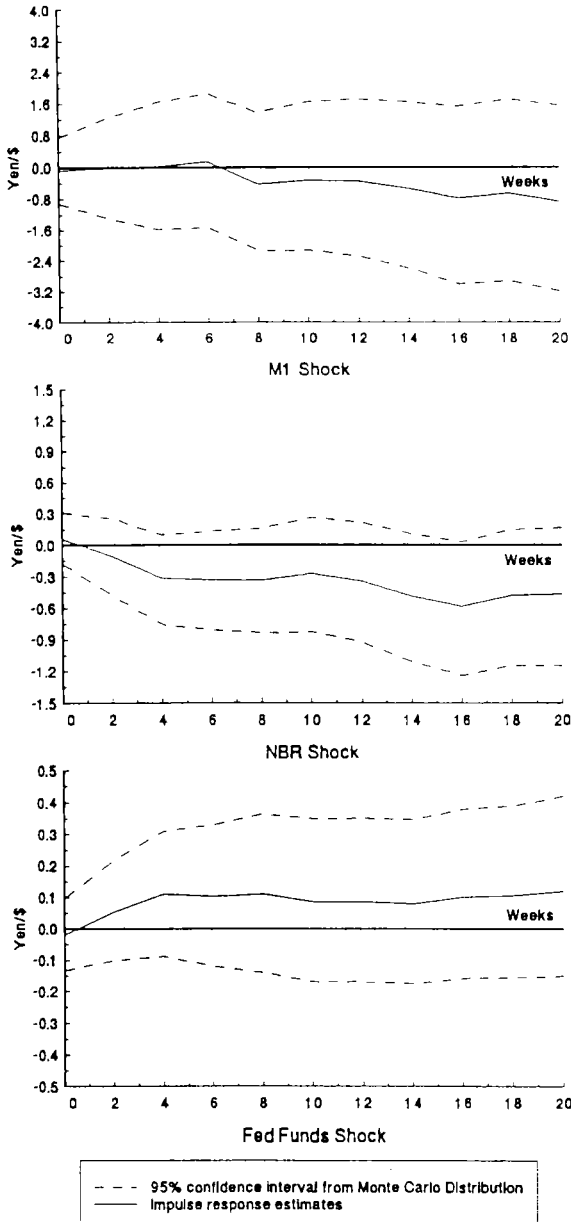
Table 1: Granger Causality Tests of Intervention
on U.S. Monetary Variables

Frequency	Predicted Variables			
	$\Delta M1$	ΔMB	ΔNBR	ΔFF
Daily	–	–	–	.318
Weekly	.306	–	–	.006
Bi-Weekly	.093	.059	.039	.053

Notes: Table reports marginal significance levels of the hypothesis that all lagged coefficients of intervention equal zero in a projection of the column variable on lagged own variables and intervention. Lag lengths were chosen by estimating a VAR with a maximum of ten lags and forming a Wald statistic that all lags greater than or equal to k are zero, for $k = 10, 9, \dots$. The first lag that rejected this restriction was used as the lag length. Covariance matrix was corrected for conditional heteroskedasticity using Newey-West. These tests are reported in the appendix. The column variables are the first difference of monetary variables: MB = monetary base, NBR = non-borrowed reserves, FF = federal funds rate.

Table 2: Granger Causality Tests of Intervention on Interest Differentials

Frequency	Predicted Variables	
	$FF - R^{\text{Jpn}}$	$FF - R^{\text{Ger}}$
Daily	.472	.283
Weekly	.120	.581

Notes: Table reports marginal significance levels of the hypothesis that all lagged coefficients of intervention equal zero in a projection of the column variable on lagged own variables and intervention. Lag lengths were chosen by estimating a VAR with a maximum of ten lags and forming a Wald statistic that all lags greater than or equal to k are zero, for $k = 10, 9, \ldots$. The first lag that rejected this restriction was used as the lag length. Covariance matrix was corrected for conditional heteroskedasticity using Newey-West. These tests are reported in the appendix. The column variables are: FF = federal funds rate, R^{Jpn} is the Japanese call money rate and R^{Ger} is the German call money rate.

Table 3: Granger Causality Tests of U.S. Monetary Variables on Intervention

Frequency	"Causal" Variables			
	$\Delta M1$	ΔMB	ΔNBR	ΔFF
Daily	–	–	–	.113
Weekly	.093	–	–	.615
Bi-Weekly	.090	.635	.020	.027

Notes: Table reports marginal significance levels of the hypothesis that all coefficients on lags of the column variable equal zero in a projection of intervention on lagged intervention and lags of the column variable. Lag lengths were chosen by estimating a VAR with a maximum of ten lags and forming a Wald statistic that all lags greater than or equal to k are zero, for $k = 10, 9, \ldots$. The first lag that rejected this restriction was used as the lag length. Covariance matrix was corrected for conditional heteroskedasticity using Newey-West. These tests are reported in the appendix. The column variables are the first difference of monetary variables: MB = monetary base, NBR = non-borrowed reserves, FF = federal funds rate.

Table 4: Granger Causality Tests of Interest Differentials on Intervention

Frequency	"Causal" Variables	
	$FF - R^{\text{Jpn}}$	$FF - R^{\text{Ger}}$
Daily	.016	.077
Weekly	.283	.615

Notes: Table reports marginal significance levels of the hypothesis that all coefficients on lags of the column variable equal zero in a projection of intervention on lagged intervention and lags of the column variable. Lag lengths were chosen by estimating a VAR with a maximum of ten lags and forming a Wald statistic that all lags greater than or equal to k are zero, for $k = 10, 9, \ldots$. The first lag that rejected this restriction was used as the lag length. Covariance matrix was corrected for conditional heteroskedasticity using Newey-West. These tests are reported in the appendix. The column variables are: FF = federal funds rate, R^{Jpn} is the Japanese call money rate and R^{Ger} is the German call money rate.

Table 5: Logistic Probability Estimates of Intervention

$$\log\left[\mathrm{Prob}(I_t = -1)/\mathrm{Prob}(I_t = 1)\right] = c_0 + \sum_{\ell=1}^{k} c_\ell\,\Delta M(i)_{t-\ell}$$

$$\log\left[\mathrm{Prob}(I_t = -1)/\mathrm{Prob}(I_t = 0)\right] = g_0 + \sum_{\ell=1}^{k} g_\ell\,\Delta M(i)_{t-\ell}$$

$\Delta M(i)$	c_0	a_0	c_1	a_1	c_2	a_2	% Predicted
M1	$.734^a$ (.206)	1.320^a (.192)	$-.122^b$ (.073)	$-.152^b$ (.068)	—	—	52.3
MB	$.959^a$ (.334)	1.429^a (.319)	$-.249^b$ (.127)	$-.236^a$ (.120)	$-.175$ (.129)	$-.187$ (.122)	50.0
NBR	$.559^a$ (.247)	1.138^a (.226)	$.188$ (.382)	$.283$ (.351)	—	—	53.5
FF	$.456^a$ (.208)	1.534^a (.179)	$.073$ (.179)	$-.012$ (.160)	$.130$ (.191)	$.032$ (.153)	64.3

Notes: Standard errors are in parentheses. The frequencies of the estimates are: $M1$—weekly, MB— bi-weekly, NBR—bi-weekly, FF—weekly.

[a]Significantly different than zero at the 95% confidence level.

[b]Significantly different than zero at the 90% confidence level.

Table 6: Granger Causality Tests between U.S. Monetary Variables and Intervention Lagged One Period

A. Predicted Variables

Frequency	$\Delta M1$	ΔMB	ΔNBR	ΔFF
Weekly	.424	–	–	.006
Bi-Weekly	.893	.084	.708	.128

B. "Causal" Variables

Frequency	$\Delta M1$	ΔMB	ΔNBR	ΔFF
Weekly	.255	–	–	.615
Bi-Weekly	.893	.707	.341	.367

Notes: Table reports marginal significance levels for the hypothesis that lagged coefficients of intervention are zero in a projection of the column variable for Panel A, and for the hypothesis that lagged coefficients of the column variable are zero in a projection of intervention for Panel B. See notes in Tables 1 and 3 concerning lag lengths.

Table A: Lag Length Tests for VARs of
U.S. Monetary Variables and Intervention

Frequency	$\Delta M1$	ΔMB	ΔNBR	ΔFF
Daily	–	–	–	9 (.022)
Weekly	1 (<.001)	–	–	2 (.006)
Bi-Weekly	1 (<.001)	2 (.017)	1 (<.001)	1 (<.001)

Notes: Table reports the first lag at which the hypothesis that all coefficients on lags greater than or equal to this number is equal to zero in at least one equation. The marginal significance levels are in parentheses and are corrected for conditional heteroskedasticity with Newey-West (1987). The maximum lag for the daily data is 10; while for the weekly and bi-weekly it is 3. These systems correspond to the systems in Tables 1 and 3.

Table B: Lag Length Tests for VARs of
Interest Differentials and Intervention

Frequency	$FF - R^{Jpn}$	$FF - R^{Ger}$
Daily	9 ($<.001$)	9 ($.004$)
Weekly	2 ($.031$)	3 ($.007$)

Notes: Table reports the first lag at which the hypothesis that all coefficients on lags greater than or equal to this number is equal to zero in at least one equation. The marginal significance levels are in parentheses and are corrected for conditional heteroskedasticity with Newey-West (1987). The maximum lag for the daily data is 10; while for the weekly and bi-weekly it is 3. These systems correspond to the systems in Tables 2 and 4.

Table C: Lag Length Tests for VAR Systems

A. Bivariate $(\log X_t, \log Y_t)$

Y_t	X_t			
	$M1$	NBR	MB	FF
DM	9 (.0405)	5 (.0395)	2 (5.34E-09)	4 (.0008)
Yen	9 (.0032)	10 (.0393)	2 (2.60E-06)	4 (.0002)

B. Trivariate $(\log X_t, \log R_t^*, \log Y_t)$

Y_t, R_t^*	X_t			
	$M1$	NBR	MB	FF
DM, R_t^{Ger}	8 (.0315)	8 (.0389)	8 (.0338)	4 (.0361)
Yen, R_t^{Jpn}	10 (.0365)	10 (.0472)	10 (.0118)	7 (.0133)

Notes: Table reports the first lag at which the hypothesis that all coefficients on lags greater than or equal to this number are equal to zero in at least one equation. The marginal significance levels are in parentheses. These systems correspond to the impulse response functions in Figures 2 to 5.