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Does foreign exchange intervention signal future monetary policy?

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Abstract

A frequently cited explanation for why foreign exchange interventions affect the exchange rate is that these interventions signal future monetary policy intentions. This explanation says that central banks signal a more contractionary monetary policy in the future by buying domestic currency today. Therefore, the expectations of future tighter monetary policy make the domestic currency appreciate, even though the current monetary effects of the intervention are typically offset by central banks. Of course, this explanation presumes that central banks in fact back up interventions with subsequent changes in monetary policy. In this paper, we empirically examine this presumption.

Key words: Monetary policy; Foreign exchange intervention

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1. Introduction

The potential effects of foreign exchange intervention upon exchange rate behavior has been an important issue of debate in both academic and policy-making circles since the end of the Bretton Woods system. Much of the debate has centered on a puzzle derived from the practice of 'sterilization' by the major central banks, such as the Federal Reserve. According to this practice, interventions to, say, buy domestic currency and sell foreign currency are accompanied by offsetting open market operations that increase the domestic money supply back to its level before the intervention. Since these 'sterilized' interventions do not affect relative money supplies, it is unclear how interventions could potentially affect their relative price, the exchange rate.

To this puzzle, Mussa (1981) proposed the following expectations-based explanation. The exchange rate depends upon current and future variables including monetary policy. While current sterilized intervention to buy domestic currency does not affect current money supply, it reflects greater concern by the monetary authorities about the weakness of the domestic currency. As a result, dollar-purchasing interventions are likely to be correlated with tighter future monetary policy. Market participants recognize this correlation, anticipate tighter future monetary policy, and the domestic currency appreciates immediately. This story has been called the 'signalling hypothesis' and has been cited in a number of contexts in both academic and policy-making circles.[1]

In this paper, we empirically examine this signalling story using data on market observations of U.S. intervention together with U.S. monetary policy variables from 1985 to 1990. We test whether current interventions by the Federal Reserve imply changes in monetary policy in the future.[2] Interestingly, we strongly reject the hypothesis that intervention provides no information about future monetary policy. More importantly, we also find that the information is typically of the *opposite* sign from the predictions of the simple signalling story. It therefore appears unlikely that the monetary authorities are intentionally trying to convey information with intervention. Indeed, assessing our results using accounts of deliberations at the Federal Open Market Committee (FOMC) meetings suggests that the relationships between intervention and monetary policy arose from 'leaning against the wind' behavior.

[1]For empirical studies discussing the signalling story, see Dominguez (1990, 1992) as well as other references in the survey by Edison (1993). Signalling has been noted as a reason for intervening in the Federal Reserve Bank of New York Quarterly (1991) and has been used as a reason against intervention at Federal Open Market Committee meetings (Board of Governors of the Federal Reserve System Annual Report, 1989; e.g., Record of Policy Actions of the FOMC, August 1989).

[2]Klein and Rosengren (1992) also examine this question by looking at the relationship between intervention and discount rate changes across the Group of Three countries.

Table 1
Foreign exchange intervention and exchange rates

		Reaction of exchange rates to intervention			
		Selling dollars intervention		Buying dollars intervention	
Period	Currency	Mean	*t*-stat.	Mean	*t*-stat.
09/23/85–12/31/85	DM	– 0.264	– 0.974		
	JY	– 0.282	– 1.099		
01/01/87–12/31/87	DM	0.306	1.292	– 0.433	– 3.532
	JY	0.197	1.250	– 0.639	– 4.040
01/01/88–12/31/88	DM	0.376	2.217	– 0.080	– 0.486
	JY	0.260	2.170	– 0.044	– 0.249
01/01/89–02/02/90	DM	0.201	2.659		
	JY	0.238	2.917		

Reaction: percentage change in the exchange rate on the day of the intervention relative to the exchange rate on the previous day. Rates are quoted at 12 noon New York market.

DM: Deutsche mark/dollar rate, JY: Japanese yen/dollar rate.

We also re-examine the effects of intervention on the exchange rate in this paper. The empirical literature on this question has found quite mixed results.[3] Furthermore, the strength of the effects of intervention have depended upon the sample period examined. The mixed and sample-dependent nature of the results are found in Loopesko (1984), Humpage and Osterberg (1992), and Dominguez and Frankel (1992). This last study examines exchange rate movements following intervention and finds that intervention appears to affect the exchange rate over some periods but not others. Dominguez (1990) examines how the foreign exchange risk-premium responds to interventions, again finding inconclusive results.

To illustrate the sample-dependent nature of the intervention and exchange rate relationship, Table 1 shows the mean change in the foreign currency price of dollars and its *t*-statistic for the day following interventions, broken down by year.[4] The days are decomposed into those following dollar sales when interventions should push the price of dollars down, and those following dollar purchases when the intervention should raise the dollar value. Although potentially plagued by simultaneity, the statistics suggest that interventions are not particularly successful. Interventions either had no significant effect or else moved the

[3]For a survey of this literature including the related portfolio balance literature, see Edison (1993).

[4]The year 1986 is not included since the Federal Reserve did not intervene over this period and the sample ends in February 1990 so that these observations are included with 1989.

currency significantly in the wrong direction. For example, during 1988 and 1989, dollar sales led to an appreciation in the dollar.

In this paper, we analyze these relationships using our information about whether interventions are followed by systematic movements in monetary policy. We find that for days when interventions are backed up by movements in monetary policy in the direction consistent with the intervention, exchange rates tend to move significantly in the direction implied by the intervention. On the other hand, when interventions are followed by movements in monetary policy in the opposite direction, exchange rates also tend to move in the opposite direction. Though suggestive, this evidence is consistent with the view that interventions have no independent effect upon exchange rates. Only the market's perceptions of how these interventions relate to future monetary policy appear to affect exchange rates. Since interventions did not lead to consistent movements in the direction of monetary policy, these interventions also did not lead to consistent movements in the exchange rate.

The rest of this paper is organized as follows. Section 2 briefly describes the standard signalling story of intervention and the general behavior of U.S. monetary and intervention policies from 1985 to 1990. Section 3 estimates a benchmark case – a regime-switching process for three indicators of monetary policy without allowing traders to incorporate intervention as a signal. Section 4 develops a regime-switching process for monetary policy where traders can use intervention as a signal. Section 5 examines the reaction of exchange rates to intervention. Section 6 presents concluding remarks.

2. The signalling hypothesis, monetary, and intervention policy

2.1. The exchange rate and the signalling story

The Mussa (1981) signalling story is very intuitive.[5] According to standard models, the exchange rate depends upon the relative supplies of domestic and foreign monies. If traders in the market are forward-looking, then the exchange rate depends upon the relative money supplies expected in the future as well. The signalling story says that even though a sterilized intervention to buy domestic currency does not affect current monetary policy, it leads traders to expect tighter monetary policy in the future. Therefore, the exchange rate appreciates today.

The signalling story presumes that an intervention at time t will be followed by a future change in monetary policy relative to previous expectations. If traders use information efficiently, they will not interpret intervention as a signal unless monetary policy indeed changes in a systematic way following

[5] Lewis (1995) provides a simple model to illustrate this story.

intervention. We examine this hypothesis below using data on market observations of foreign exchange market intervention by the Federal Reserve together with measures of monetary policy from September 1985 until February 1990.

2.2. *Measuring monetary policy*

In order to test the signalling hypothesis, we require a measure of monetary policy over the period of Federal Reserve intervention in the 1980s. The Federal Reserve resumed intervention in 1985 after a long hiatus during the first Reagan administration. The impetus for an intervention policy came after the Plaza Meeting in September 1985 when the central banks of the Group of Three countries agreed to intervene more heavily to push down the value of the dollar. We therefore begin our sample at this time. On the other hand, a conflict between the Federal Reserve and the Treasury on the issue of intervention led the Fed to quit intervening on its own account during 1990. Rather than intervening on the accounts of both the Treasury and the Fed, as is normal practice, future interventions during that year were carried out only on the account of the Treasury. Since the Fed was clearly an unwilling participant in the operation, intervention could not have been signalling monetary policy. For this reason, our study ends in February 1990.

The ideal approach to evaluating monetary policy would be to estimate a reaction function that depends upon key economic variables of importance to the monetary authorities and then consider policy based upon this function. However, since our sample is short, we cannot estimate a reaction function that would depend upon standard macroeconomic variables available only at a quarterly or even monthly frequency. Instead, we focus upon higher frequency weekly and bi-weekly data.

In particular, we use monetary policy variables. To check whether our results are robust to different measures of monetary policy, we test the signalling story using very different measures of monetary policy. The specific series we study are the Federal Funds rate, M1, and nonborrowed reserves (NBR), all obtained from the Federal Reserve Board data bank.[6,7]

[6]Various measures of monetary policy have been used and advocated in the literature. For example, Mishkin (1981) and Cochrane (1989) use M1, while Melvin (1983) uses M2 and Reichenstein (1987) uses both M1 and M2. However, some authors, such as Christiano and Eichenbaum (1992a, 1992b) and Strongin (1992), have argued that movements in broad monetary aggregates can be misleading measures of monetary policy since they confound money demand shocks with money supply shocks and have suggested using nonborrowed reserves as the indicator of monetary policy. Still others, such as Bernanke and Blinder (1992) and Goodfriend (1992), have argued for the Federal Funds rate as the monetary indicator.

[7]The Federal Funds rate is the weekly average of the daily rate. M1 is the average stock of money for the week ending on Mondays. NBR is the seasonally adjusted average of the two-week reserve maintenance period ending on Wednesdays.

Clearly, it is important to examine whether the behavior of monetary policy indicators during this period was consistent with other accounts of U.S. monetary policy. For this reason, we next provide a brief description of monetary policy behavior and its relationship with monetary indicators. Later, in Section 4, we show that our monetary policy variables are consistent with qualitative measures of policy such as discussions in the press and in the FOMC.

2.3. Monetary aggregates during the late 1980s

U.S. monetary policy changed significantly over the 1980s. For most of the early 1980s, monetary policy was considered quite contractionary as U.S. interest rates hit historic peaks. However, by the beginning of our sample in 1985, U.S. monetary policy had become relatively expansionary.

Fig. 1 shows some measures of monetary policy. The top panel plots weekly observations of M1 and M2 together with bi-weekly observations of nonborrowed reserves, while the middle panel shows the Fed Funds rate and the discount rate. As the picture illustrates, the growth rate of M1 accelerated during 1985 and 1986. At the same time, the Federal 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 and many short-term interest rates were essentially cut in half. These downward movements were accommodated by two discount rate cuts in April and August of 1986. As Fig. 1 shows, the Federal Funds rate reached a trough in late 1986 to early 1987, around the same time that the rate of increase of M1, M2, and nonborrowed reserves began to level off.

Monetary policy was quite different during the following period from roughly 1987 through late 1989. Largely in response to an increase in inflation, the Federal Reserve began tightening reserves in the second quarter of 1987.[8] The top panel of Fig. 1 shows the sharp deceleration in the growth rates in M1 and NBR. At the same time, the Federal Funds rate began an upward trend that would continue into 1989. This tightening of monetary policy was accentuated with discount rate increases in October 1987, August 1988, and February 1989.

It was not until the second half of 1989 that monetary policy may have eased slightly. Concerned about the sluggish growth of the economy while remaining cautious about inflation, the Federal Reserve began to increase the availability of reserves to depositing institutions and the Federal Funds rate fell more than $1\frac{1}{2}$ percentage points by early January 1990.[9] However, popular press accounts

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[8]See the *Economic Report of the President* (1988, p. 37).

[9]See 'Monetary Policy and Open Market Operations during 1989' in the *Federal Reserve Bank of New York Quarterly Review*, Spring 1990, Vol. 15, pp. 43–65.

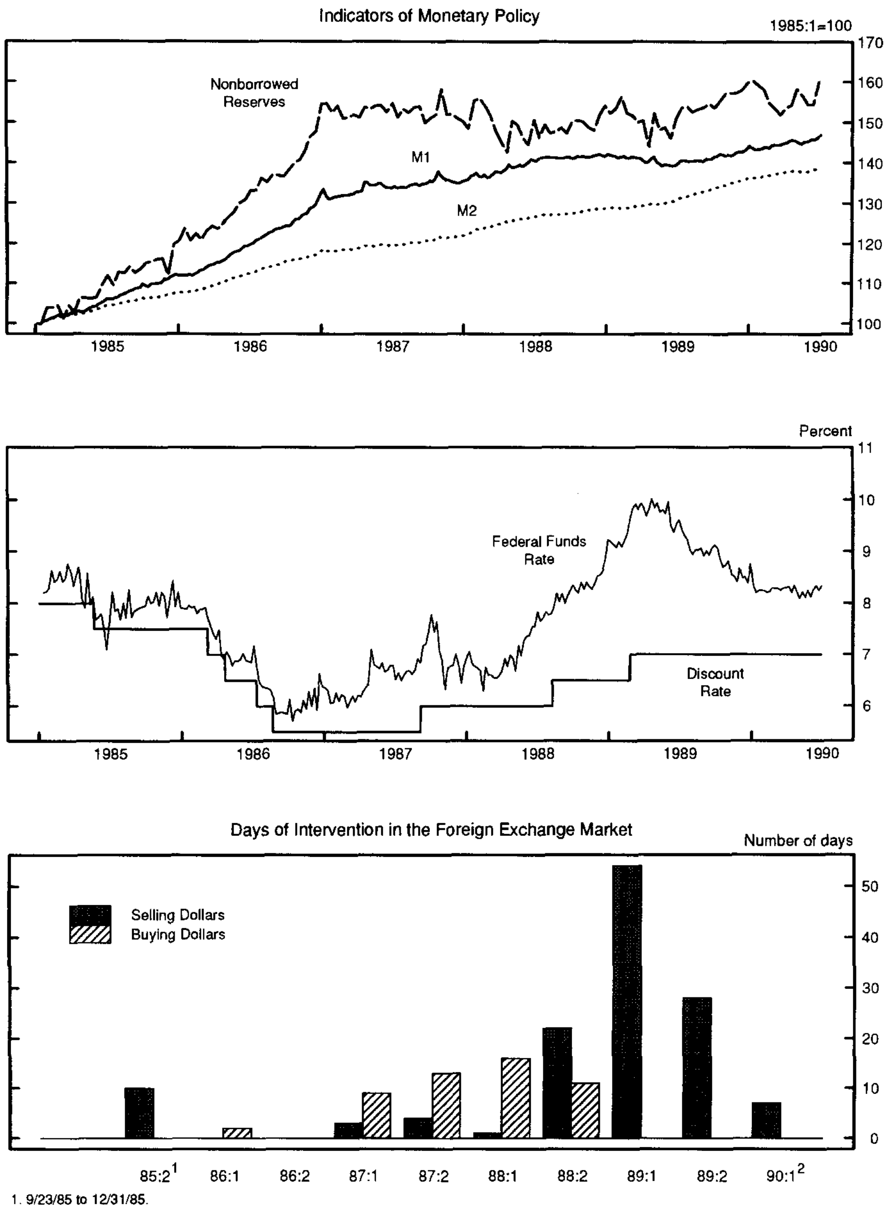

Fig. 1. Monetary and intervention policies.

appeared quite divided over whether monetary policy was in fact easing during late 1989. This inconsistency was due in part to differences in behavior among the monetary variables, a feature we also find below.

2.4. *Intervention and monetary policy*

The U.S. followed an active intervention policy during much of the late 1980s, as shown by the bottom panel of Fig. 1. The figure shows days of intervention based upon reports by traders.[10] These data were collected from accounts in the *Wall Street Journal*, the *New York Times*, and the *Financial Times*. The series consist of days in which the Federal Reserve was observed intervening by traders. These days are further decomposed into days when the Fed either bought or sold dollars. We focus upon this series to test the signalling hypothesis because these interventions are observed by traders, while actual interventions are observed with at least a year lag. As the figure shows, the Fed was active on both the buying and selling side of the foreign exchange market, particularly over the early part of the period.

3. A Markov-switching model for monetary policy without intervention as a signal

Monetary policy in the United States during the late 1980s appeared to alternate between relatively expansionary and contractionary regimes as measured by the monetary indicators. To evaluate whether intervention provided a significant signal about this policy change, we first consider how expectations of this monetary change would have evolved if market participants did not use intervention as a signal. This benchmark model allows us to ask in the next section whether intervention provides additional information to the monetary variable alone.

To capture the changes in monetary policy behavior, we estimate a univariate process for the monetary indicators allowing their evolution to follow two regimes, $R_t = i$, for $i = 0, 1$. Conditional upon each of these regimes, the process is autoregressive of order l in first differences:

$$\Delta x_t = \delta_0^i + \sum_{j=1}^{l} \delta_j^i \Delta x_{t-j} + \varepsilon_t, \qquad \varepsilon_t \sim \mathrm{N}(0, \sigma^2), \tag{1}$$

[10]Using the same data set, Klein (1993) finds that newspaper accounts are mostly accurate in picking up days of actual intervention during this period. The newspaper accounts tend to understate the number of days of intervention, since central banks occasionally try to conceal interventions. This under-reporting suits our purposes since concealed interventions are clearly not intended to signal anything. Reports of intervention when there was no intervention are rare, although in 1986 intervention was twice reported by traders when there was no actual intervention.

where x_t is either the logarithm of M1, the Federal Funds rate, or the logarithm of NBR. Also, δ_0^i is the drift of the monetary indicator in regime i, δ_j^i are the parameters of the AR process for Δx, and ε_t is the innovation in monetary policy. The innovations are assumed iid and normally distributed with variance σ^2 in both regimes. For expositional purposes, we define Regime 1 as the relatively expansionary monetary regime. Using a likelihood ratio test, we identify the maximum lag length, l, as zero for M1 and one for both the Fed Funds rate and NBR. Hence, if M1 is the monetary indicator we normalize $\delta_0^1 > \delta_0^0$, while for the Federal Funds rate we choose regimes such that the long-run mean is lower, $\delta_0^1/(1-\delta_1^1) < \delta_0^0/(1-\delta_1^0)$. By contrast, for NBR, we choose the regime with the higher unconditional growth rate, $\delta_0^1/(1-\delta_1^1) > \delta_0^0/(1-\delta_1^0)$.

The probability of switching between these two regimes is governed by the following stationary probability matrix:[11]

	$R_{t-1}=1$	$R_{t-1}=0$
$R_t=1$	$(1-\lambda)$	λ
$R_t=0$	λ	$(1-\lambda)$

(2)

Traders do not observe these regimes, R_t, directly but must infer them from the current information set. For this benchmark model without intervention as a signal, we simply assume that the traders' information set is confined to current and past observations on the monetary indicator. This information set is given by $\phi_t = \{\Delta x_t, \Delta x_{t-1}, \ldots, \Delta x_1\}$ for alternatively, $x = \log(\mathrm{M1})$, the Federal Funds rate, or log(NBR). For this benchmark model, we use Hamilton's (1988) nonlinear filter to estimate the process in Eqs. (1) and (2) for the period September 23, 1985 to February 2, 1990. Details of this procedure are provided in the Appendix to Kaminsky and Lewis (1993).

Table 2, panel A reports the results of this estimation. We report the results using M1, the Federal Funds rate, and NBR as policy variables. Interestingly, the model indeed captures an expansionary and a contractionary monetary regime for all three indicator variables. During the expansionary monetary regime, M1 grows at 0.33 percent per week while in the contractionary monetary regime money supply grows at only 0.048 percent per week. The drift is positive in the expansionary Regime 1 for NBR and the contractionary Regime 0 for Fed Funds, while the drift is smaller for NBR and even negative for Fed Funds in the opposite regime.

[11]We also estimated a more general version of the model where the variances and the transition probabilities were state-dependent. Likelihood ratio tests could not reject the hypothesis that the variances and the probabilities were the same, and we therefore present only this more parsimonious specification in the text.

Table 2
Estimates of the regime-switching model for different indicators of monetary policy

Parameter	δ_0^0	δ_1^0	δ_0^1	δ_1^1	λ	p	q	σ
Panel A: Model without intervention signals								
M1								
Estimate	0.048		0.332		0.943			0.329
t-stat.	1.809		4.469		1.118			20.325
Federal Funds rate								
Estimate	0.035	− 0.260	− 0.044	− 0.480	1.293			0.185
t-stat.	1.389	− 2.297	− 2.095	− 4.568	1.040			1.040
Nonborrowed reserves								
Estimate	0.076	− 0.348	1.039	− 0.369	1.437			1.745
t-stat.	0.341	− 3.192	2.192	− 2.013	0.827			14.416
Panel B: Signalling model								
M1 LRT = 64.329, (a): 0.000								
Estimate	0.058		0.373		0.570	2.139	42.315	0.329
t-stat.	2.334		8.377		1.317	1.210	5.021	21.541
Federal Funds rate LRT = 67.871, (a): 0.000								
Estimate	0.017	− 0.203	− 0.023	− 0.497	0.423	0.000	30.216	0.187
t-stat.	1.035	− 2.349	− 1.288	− 5.749	1.086	0.000	3.851	21.244
Nonborrowed reserves LRT = 44.643, (a): 0.000								
Estimate	0.087	− 0.343	1.073	− 0.379	0.713	0.000	48.000	1.745
t-stat.	0.395	− 3.255	3.622	− 2.225	0.931	0.000	5.124	14.793

λ, p and q are in percent. When the monetary indicator is money supply, δ_0^0 and δ_1^1 are also in percent.

LRT is the likelihood ratio test of the null hypothesis that intervention does not convey any information about monetary policy. (a) Marginal significance level.

Another feature of the model is that the transition probabilities, λ, are very small at between about 1 to $1\frac{1}{2}$ percent for all three measures of monetary policy, indicating that both regimes display considerable persistence. In fact, the estimated probability implies that the expected duration of the monetary regimes is approximately 106 weeks for M1, 77 weeks for Federal Funds, and 139 weeks for NBR.

Using our estimates as well as the evolution of the monetary indicator variables, we generate the traders' assessed probabilities of being in an expansionary monetary regime. These probabilities are depicted in Fig. 2.[12] The figure shows the probability of being in an expansionary monetary regime using M1, the Fed Funds rate, and NBR as the monetary policy indicators in the top, middle, and bottom panels, respectively.[13] Strikingly, the predictions of the model with all three indicators are roughly consistent with the stylized evidence of monetary policy discussed above. In particular, the probability of an expansionary regime is quite high through much of 1986, but then drops to below 50 percent during 1987. Most of the latter part of the sample is characterized by a fairly low probability of the expansionary regime. If we use the criterion of assigning observation t to Regime 1 if the conditional probability is larger than $\frac{1}{2}$, then these probabilities classify the following observations as belonging to the expansionary monetary regime:[14]

Expansionary monetary regime episodes

Money supply (M1)	Federal funds rate	Nonborrowed reserves
	1985:41–1985:43	
1986:14–1987:02	1985:45–1985:49	1985:45–1985:47
1987:17–1987:18	1985:51–1987:18	1986:01–1987:29
	1989:31–1989:39	
	1989:42–1990:05	

Clearly, while all three measures indicate a fairly expansionary policy over the first part of the sample, the Fed Funds rate suggests that the probability of an expansionary regime was higher in late 1989. However, these estimates are based

[12]The reported probabilities are the posterior probabilities based upon the traders observing the current monetary indicator. In Kaminsky and Lewis (1993), we also report the prior probabilities.

[13]The relative smoothness of the probability based upon nonborrowed reserves arises from the lower frequency relative to the other indicators, i.e., bi-weekly as opposed to weekly.

[14]To minimize noise, we require the probability to stay above 0.5 more than one period to be classified as a regime.

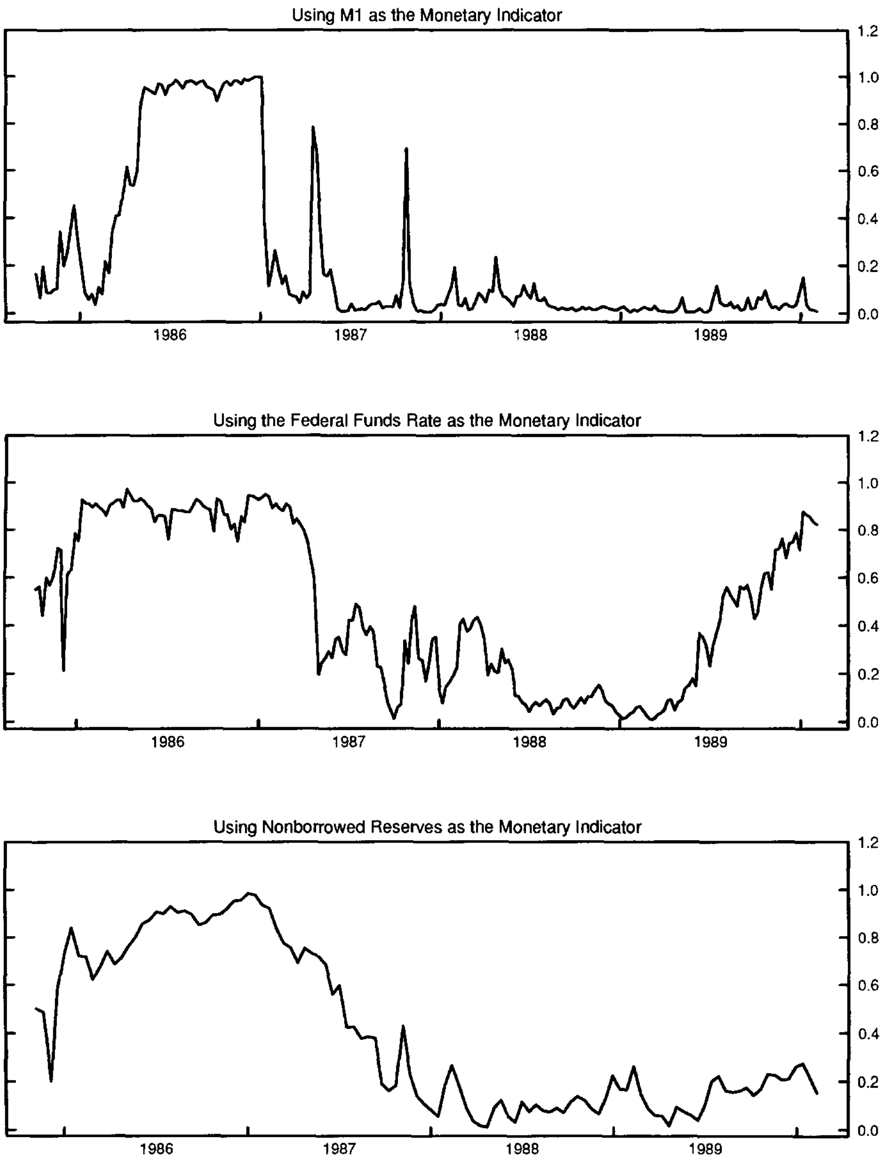

Fig. 2. Posterior probabilities of an expansionary monetary regime (without using intervention signals).

solely upon the univariate behavior of the monetary indicator variables. An interesting feature of incorporating intervention into traders' information sets below is that these differences largely disappear.[15]

4. Does intervention provide information about future shifts in monetary policy?

In this section we ask whether intervention provides a significant signal of the shift in policy noted above. We begin by describing the evolution of expected future monetary policy with intervention as a signal, before turning to the empirical results.

4.1. Expected future monetary policy with intervention as a signal

We address the question of whether intervention provides information about future monetary policy in two different ways. First, does intervention provide information about future monetary policy at all? If intervention has nothing to do with future monetary policy, then traders disregard information about intervention when forming forecasts. To test this hypothesis, we examine whether intervention at some lag k is useful for predicting the current monetary regime, R_t. Before describing more precisely what we mean by the past intervention, we simply define the event of this past intervention at $t-k$ as $S_t = 1$ and the event of no intervention at $t-k$ as $S_t = 0$. Thus, we first ask whether S_t helps predict R_t.

A second way we ask the question is: if intervention *does* provide information about future monetary policy, are interventions correlated with future monetary policy in the same direction as suggested by the signalling story? For example, interventions to buy dollars would suggest that the Federal Reserve is more concerned about the value of the U.S. dollar and might reflect an intention to pursue more contractionary monetary policy in the future. We refer to this type of relationship between intervention and monetary policy as 'Consistent Policies'. On the other hand, an intervention to buy dollars may also be an attempt to bolster the value of the dollar when monetary policy is actually expansionary in the future. We call this relationship between intervention and

[15]Interestingly, the different classifications of monetary policy in the last semester of 1989 by the Fed Funds rate also corresponds to confusion over policy in the popular press, as documented by Kaminsky and Lewis (1993). However, the perception that monetary policy remained contractionary even in the fall of 1989 was reinforced by Chairman Greenspan's statements in congressional testimony. The London *Financial Times* stated: 'Mr. Greenspan's [...] comments were seen by observers as highlighting the Fed's current caution about any early substantial easing of U.S. monetary policy and of interest rates' ('Greenspan Warns That U.S. Inflation Rate Is Too High', London *Financial Times*, October 26, 1989).

monetary policy 'Inconsistent Policies'. Even though these interventions predict that future monetary policy will move in the opposite direction, systematic intervention of this type can be useful to traders in assessing the course of future policy.[16]

This discussion leads to three possible results in our investigation. First, the signalling story may be true. In this case, *consistent* policies will hold most of the time in our sample. Second, the signalling story may be false yet intervention may convey information about future monetary policy if intervention is systematically related to future monetary policy through *inconsistent* policies. Third, the signalling story may be false because intervention provides no information about future monetary policy. If intervention conveys no information about future monetary policy, it must be true that market participants observing current intervention consider *consistent* and *inconsistent* policies as equally likely. We test this hypothesis below.

In order to test this hypothesis, we allow the perceived probabilities of *consistent* policies and *inconsistent* policies to vary over time.[17] Specifically, the market views the relationship between intervention and monetary policy as following a process that may shift between the *consistent* policy regime, denoted C, and the *inconsistent* policy regime, denoted N. To see how these regimes evolve, suppose first that the monetary authority intervenes every period ($S_t = 1$ for all t). At the time of intervention, $t - k$, the authorities may have been following a 'consistent' policy defined by the regime C_t or an 'inconsistent' policy defined by the regime N_t. In keeping with the Markov switching process for monetary policy above, we allow these states to evolve according to the transition probability matrix:

	C_{t-1}	N_{t-1}
C_t	$(1-p)$	p
N_t	p	$(1-p)$

(3)

Eq. (3) describes the transition probability between consistent and inconsistent policy regimes under the assumption that the monetary authority intervenes every period. However, we have seen in Fig. 1 that the Fed chose not to intervene (i.e., $S_t = 0$) for long stretches of time during the period under study. For example, there was essentially no intervention by the Fed during 1986. If

[16]Of course, a recognition by the market that interventions are in the opposite direction of future monetary policy would be detrimental to the usefulness of intervention on the part of central bank. An example of this behavior during the sample will be discussed below.

[17]The model described below is a generalization of the model developed in Kaminsky (1993).

periods with and without signalling alternate, it is necessary to specify the dynamics across these states too. It seems implausible that traders who do not observe intervention for such a long period of time simply update the probability of the consistency between intervention and monetary policy according to Eq. (3).

It appears more reasonable to suppose that when intervention does not occur for some time traders view differently the probability of consistent intervention and monetary policies. We therefore treat the probability of the consistency of policies if intervention occurs after a period of no intervention as

$$\begin{aligned} &\text{Prob}(C_t | S_t = 1, S_{t-1} = 0) = q, \\ &\text{Prob}(W_t | S_t = 1, S_{t-1} = 0) = 1 - q. \end{aligned} \tag{4}$$

In other words, if traders observe intervention potentially useful for understanding the current regime, $S_t = 1$ after no intervention in the previous period, $S_{t-1} = 0$, they believe that the policies will be consistent with probability q but inconsistent with probability $(1 - q)$.

We now combine both the processes in (3) and (4) to provide a full transition process of the relationship between intervention and monetary policy. This process is given by[18]

		$S_{t-1} = 1$		$S_{t-1} = 0$
		C_{t-1}	N_{t-1}	
$S_t = 1$	C_t	$(1 - p)$	p	q
	W_t	p	$(1 - p)$	$(1 - q)$

(5)

Hence, the complete process consists of Eqs. (1), (2), and (5).

To specify the link between the potential evolution of policy combinations in (5) and the process for the monetary indicators in (1) and (2), we need to incorporate one last piece of information: whether the intervention k periods ago was a dollar sale or purchase. For this purpose, define an observation of intervention at time $t - k$ as $I_{t-k} = 1$ if the Federal Reserve intervened by selling dollars or $I_{t-k} = 0$ if it intervened by buying dollars. A 'consistent' policy, C_t, between intervention at time $t - k$ and the monetary regime at time t implies

[18]Note that S_t is lagged intervention and is therefore known at time t, the transition probability between S_t and S_{t-1} does not need to be specified. It is always zero or one.

a positive relationship between $I_{t-k} = 1$ and $R_t = 1$, or more generally, between $I_{t-k} = i$ and $R_t = i$. On the other hand, an 'inconsistent' policy state N_t implies a correspondence between $I_{t-k} = i$ and $R_t = j$, where $j \neq i$. More formally, $C_t = \{I_{t-k} = i | R_t = i; i = 0, 1\}$ and $N_t = \{I_{t-k} = i | R_t = j, i \neq j, i, j = 0, 1\}$. Note that the full information set of traders now also includes the occurrence of intervention and its direction, i.e., $\Omega_t = \{\Delta x_t, S_t, I_{t-k}, \ldots, \Delta x_1, S_1, I_{1-k}\}$.

The evolution of intervention together with the monetary regime determine expected future monetary policy. For example, note that the monetary regime affects expectations of monetary policy since by (1) and (2) the expected monetary policy next period is given by

$$\mathrm{E}_t \Delta x_{t+1} = \left(\delta_0^0 + \sum_{j=0}^{l} \delta_j^0 \Delta x_{t-j}\right) [1 - \mathrm{Prior}(R_{t+1} = 1)] + \left(\delta_0^1 + \sum_{j=0}^{l} \delta_j^1 \Delta x_{t-j}\right) \mathrm{Prior}(R_{t+1} = 1). \tag{6}$$

These priors are in turn transition probability-weighted averages of the posterior probabilities of each regime based upon information at time t. This information includes the intervention signal, S_t, the direction of the intervention, I_t, and the monetary indicator, x_t. In the Appendix to Kaminsky and Lewis (1993), we give details about the full evolution of the joint system of intervention, monetary indicators, and the consistency between the two policies.

4.2. *Empirical results*

We now describe the estimation of the system. Using Eqs. (1) and (5), we construct the joint likelihood function of current indicators of monetary policy and lagged intervention. Specific information about the construction of this function is provided in the Appendix to Kaminsky and Lewis (1993). We then estimate the model by maximizing this function numerically with respect to the unknown parameters: δ_0^0, δ_0^1, δ_j^0, δ_j^1, σ^2, λ, p, and q. For the initial period, we assume a diffuse prior on both the monetary regime and the nature of the relationship between intervention and future monetary policy. That is, we set the initial priors equal to 0.5.

We also make an identifying assumption about the lag at which past intervention is useful for predicting the current monetary regime. For intervention to provide valuable information to traders, as supposed by the signalling story, it must precede monetary policy changes in a proximate and consistent manner. Since the Fed can provide information to the public about monetary policy intentions through other methods such as statements in the Record of Policy Actions of the FOMC published approximately every six weeks, it seems unlikely that the lag of this signal can be very long. We therefore experimented with different small values of k. In particular, we estimated the model with $k = 1$

week and $k = 3$ weeks. Since the results are essentially the same, we report the results with $k = 1$ alone.[19]

Table 2, panel B reports the estimation results. Consistent with our findings for the model without intervention as a signal, the growth rate of M1 in the expansionary regime is significantly higher than the growth rate in the contractionary regime. In particular, δ_0^1 is about 0.37 percent weekly or about 19 percent annualized, while δ_0^0, its counterpart in the contractionary regime, is only about 0.06 percent weekly or 3 percent annualized. The results using the Federal Funds rate and NBR also support the hypothesis of a switch in monetary regime. In Regime 1, the unconditional mean growth rate, $\delta_0^1/(1 - \delta_1^1)$, is negative and equal to -0.03% or -1.5% annualized for Fed Funds and 0.76% or 19.7% annualized for NBR. In the contractionary Regime 0, the unconditional mean growth rate of Fed Funds is equal to 0.04% or 1.5% annualized, while for NBR it is 0.06% or 1.5% annualized. For these indicator variables, the drift terms in the contractionary regime are insignificantly different from zero. As before, the transition probability of the monetary regime, λ, is quite small. These probabilities imply mean regime durations of 175 weeks for M1, 236 weeks for Fed Funds, and 280 weeks for nonborrowed reserves.

The policy consistency process provides two new parameters: the transition probability between the 'consistent' and 'inconsistent' regimes, p, and the probability of a 'consistent' policy regime given no recent interventions, q. As panel B of Table 2 shows, the transition probability p is close to zero. The probability of a 'consistent' regime given no past intervention, q, is less than 0.5.

We test the signalling story in a straightforward and intuitive way using this framework. Specifically, if the authorities appear to switch between consistent and inconsistent regimes with even odds, then observations of intervention convey no meaningful information about future monetary policy. Formally, this behavior is identical to a value of p, the transition probability between the 'consistent' and 'inconsistent' states, equal to $\frac{1}{2}$. Also, when interventions have not occurred recently, a new intervention does not convey any information if the probability of consistent policy is also $\frac{1}{2}$. Thus, a test of the null hypothesis that intervention provides no information about policy is a test of the constraint $p = q = \frac{1}{2}$.

In this case, the joint density function for Δx_t, S_t, and I_{t-k} is just a function of the marginal density function for the monetary indicator alone. If we define the likelihood function of any variable Z given another variable Y as $f(Z \mid Y)$, then

[19] Of course, if intervention provides information about monetary policy at a one-week horizon, by iterating the Markov process forward, it also provides forecasts of monetary policy regimes in any future period.

this restriction can be written:

$$f(\Delta x_t, S_t, I_{t-k} | \Delta x_{t-1}, S_{t-1}, I_{t-k-1}, \ldots, \Delta x_1, S_1, I_{1-k})$$
$$= 0.5 f(\Delta x_t | \Delta x_{t-1}, \ldots, \Delta x_1). \tag{7}$$

Since the conditional probabilities of monetary regimes depend only upon past values of the monetary indicator, we construct the likelihood ratio test of the constrained and unconstrained models as

$$LRT = 2\,\{\ln(f(\Delta x_t, S_t, I_{t-k}, \ldots, \Delta x_1, S_1, I_{1-k}))$$
$$- [\ln(f(\Delta x_t, \ldots, \Delta x_1)) + n\ln(\tfrac{1}{2})]\}, \tag{8}$$

where n is the number of intervention events in the sample (i.e., $n = \sum_{t=1}^{T} S_t$). Since the difference between the two models involves two constraints ($p = \frac{1}{2}$ and $q = \frac{1}{2}$), the likelihood ratio test is distributed as χ^2 with two degrees of freedom.

Table 2, panel B reports this test statistic under the monetary variable headings along with its marginal significance level in parentheses. As the table shows, the likelihood ratio test is quite large and the null hypothesis is strongly rejected at standard significance levels for all three monetary indicators. Thus, intervention provides significant information about future changes in monetary policy.[20]

4.3. The evolution of the monetary regimes and perceptions of policy intentions

The estimates provide probabilities of the expansionary monetary regime as well as of the consistency between intervention and monetary policy conditional on the time period. Fig. 3 depicts the probabilities of the expansionary regime based upon lagged intervention and the current period's monetary indicator (M1, the Federal Funds rate, and NBR in the top, middle, and bottom panels, respectively). These series are plotted along with the probabilities of the consistency between policies. In this figure, we plot the posterior probabilities, that is, the probabilities assessed by traders based upon observing intervention and monetary policy over the current period. The prior probabilities are depicted in Kaminsky and Lewis (1993).

The probabilities of the expansionary monetary regime follow a similar pattern for all three measures of policy. For all three, the probability of expansion is high during the first part of the sample with some variability during

[20] We also tested the constraint that the probability of a consistent regime given no past intervention, q, is equal to the probability of a consistent regime conditional on past intervention, $1 - p$. The t-tests for this hypothesis were 6.6 for M1, 8.9 for Fed Funds, and 5.5 for NBR. Thus, the hypothesis was strongly rejected at standard significance levels.

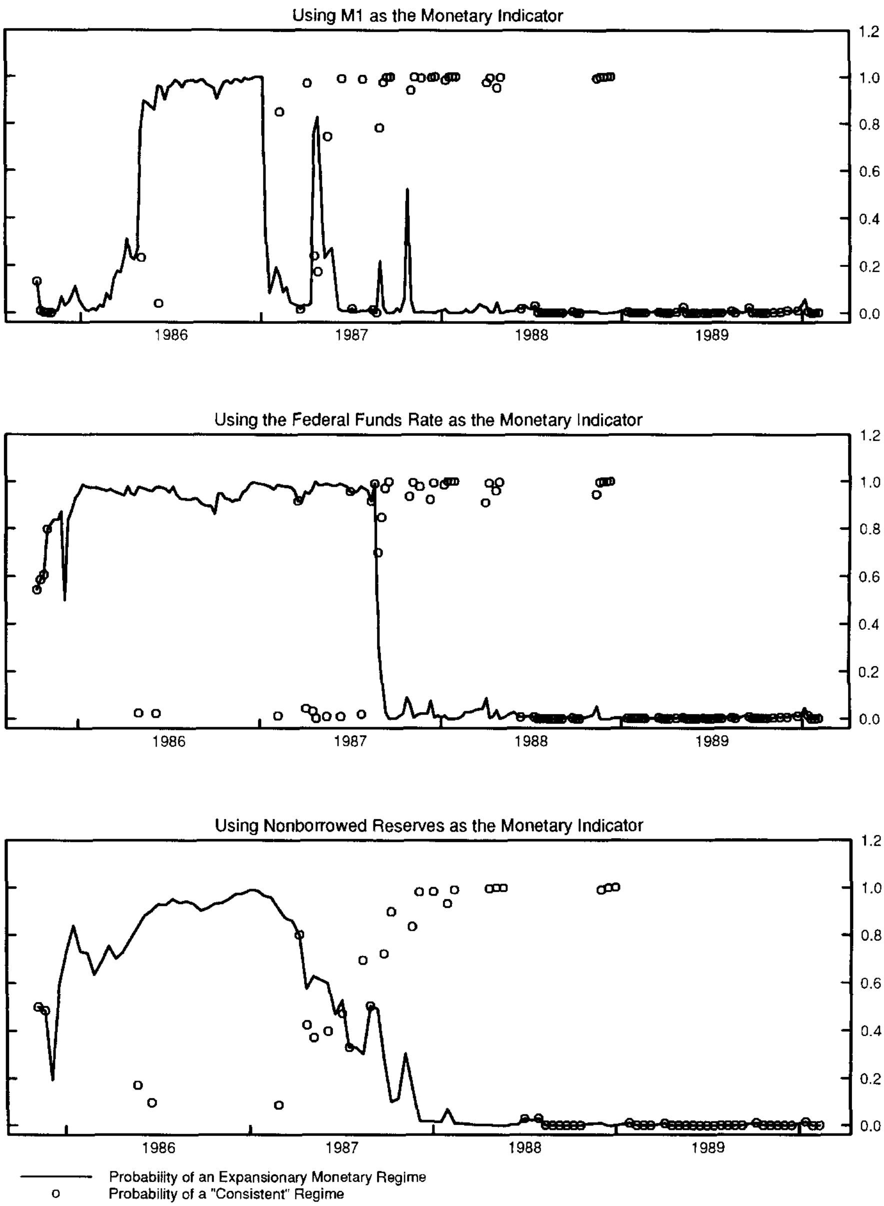

Fig. 3. Posterior probabilities implied by the signalling model.

late 1985. Also, the monetary regime appears to switch into a contractionary policy during 1987 for all the measures, though the exact timing differs somewhat. The results in panel B of Table 2 indicate that these differences do not matter for the overall conclusion, however. The hypothesis that intervention conveys no information about monetary policy is strongly rejected in all cases.

Using the criterion described above, the probabilities of being in an expansionary monetary regime classify the observations as follows:

Expansionary monetary regime episodes

Money supply (M1)	Federal funds rate	Nonborrowed reserves
1986:19–1987:02	1985:41–1985:48	1985:45–1985:47
1987:17–1987:19	1985:50–1987:35	1986:01–1987:25

These classifications correspond to greater conformity across monetary indicators than the classifications that ignore intervention as a signal. Also, this regime classification roughly matches a measure of monetary policy stance developed by Boschen and Mills (1991) (BM). With the exception of the increase in liquidity following the October 1987 stock market crash, our regimes classification is similar to theirs. We note more details about their description of Fed policy below.

Fig. 3 also plots the probability of a 'consistent' state as circles. Since intervention can provide information only after intervention occurs, this series is not continuous. Interestingly, periods of concentrated intervention generally show the persistence of 'consistent' or 'inconsistent' states captured by the estimation. The probabilities of consistent and inconsistent intervention regimes are near zero and one, in part because the estimates are based upon observing monetary policy and intervention over the period. The prior probabilities show somewhat more uncertainty.

Most of the intervention took place when monetary policy was contractionary. During some of these intervention episodes, such as the one after the Louvre Accord, the Fed intervened to support the dollar. According to the signalling story, these dollar purchases should herald a contractionary monetary stance. It is these episodes of intervention that the model classifies as belonging to the 'consistent' regime.

But intervention policy was not usually consistent with the monetary policy regime. To understand this inconsistent behavior, it is useful to understand more about monetary policy, particularly over the later part of the sample. As monetary policy became more contractionary and remained so well into 1989, this tightening led to a relative strengthening of the dollar. Due to concerns by the Treasury about this strengthening, the U.S. intervened heavily to sell dollars for much of this period. Starting on June 27, 1988 the U.S. 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. Since monetary policy remained relatively tight for this period, interventions were systematically in the opposite direction of the signalling story. This pattern shows up as 'inconsistent' regimes in our estimates.

In sum, the probabilities of a consistent relationship between intervention and subsequent monetary policy show that this relationship conflicts with the standard signalling story. Intervention provides significant information about future monetary policy. However, most of the information comes from interventions to sell dollars, followed by tight monetary policy. In the next subsection, we discuss how these findings are consistent with qualitative evidence such as Federal Reserve documents and press accounts of the period.

4.4. The estimates in light of other measures of Federal Reserve policy

Documents of the Federal Reserve also imply the pattern of signalling we found above.[21] We determined this pattern by examining Federal Reserve publications such as the Annual Report and then comparing our own reading with the documentation by Boschen and Mills (BM) (1991).

From 1985 through 1987, there was little discussion in the FOMC concerning intervention. The dollar selling interventions following the Plaza Meeting in September 1985 and the lack of interventions in 1986 were consistent with the relatively expansionary monetary policy stance. For example, BM provide as a typical quote from the Record of Policy Actions of the FOMC over this period: 'decrease somewhat the existing degree of pressure on reserve positions ... ' (July 8, 1986).

In the March 1987 meeting of the FOMC, the participants noted in passing that recent interventions following the Louvre had seemed to help stabilize the exchange rates. While the primary emphasis appeared to be on domestic inflation and credit markets, attention was paid to foreign exchange markets. BM quote from the March 31, 1987 meeting that the Fed intended to 'maintain the existing degree of pressure on reserve positions; somewhat greater reserve restraint might be acceptable depending on developments in foreign exchange markets ... the strength of the business expansion, progress against inflation and conditions in credit markets'.

However, most of the meetings during 1987 focused upon more pressing domestic issues, particularly following the October 1987 stock market crash. As

[21]The following analysis was based upon reading the summary of FOMC meetings given by the 'Record of Policy Actions by the Federal Open Market Committee' for each committee meeting during our sample. For a more detailed account, see these records in the Board of Governors of the Federal Reserve System Annual Report (1985–1990).

BM quote from the October 1987 meetings, the Fed recognized the 'need for special flexibility in open market operations for meeting the liquidity requirements of the economic and financial system'.

In early 1989, debate increased among the governors on the Federal Reserve Board concerning intervention and the appropriateness of its signal toward monetary policy. By the FOMC meeting on May 16, 1989, intervention had become an important issue of discussion as the large purchases of foreign currency assets by the New York Federal Reserve Bank had increased holdings of these assets beyond the internal Federal Reserve limit. Since this limit is placed upon the Federal Reserve by itself, exceeding the limit suggested that actual interventions to weaken the dollar had surpassed the magnitudes previously expected by the FOMC. Governor LaWare dissented in a vote to extend the limit on foreign currency holdings to 'convey skepticism about intervention'. The continued dollar sales meant that intervention was again an issue at the June 14 FOMC meeting, when the limit on foreign currency holdings had to be increased again. By the August 22 FOMC meeting more 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'.

Due to this controversy, most of the interventions by the end of 1989 were no longer conducted on the Federal Reserve's account, but rather on the Treasury's account. From the total amount of dollar-selling intervention in the first four months of 1990 of 2.4 billion dollars, only 675 million dollars were on the Federal Reserve's own account. With growing concern among FOMC members about conflicting signals sent to the market through intervention, from March 5, 1990 through the rest of the year all interventions were on the Treasury's account alone.

This period of conflict between the Treasury and the Fed did not go unnoticed by the markets or the popular press. In mid-October 1989, a newspaper reported that Treasury Secretary Nicholas Brady 'conceded the existence of differences over interest rate and dollar policy between the administration and Federal Reserve'.[22] The potential impact of these differences also arose in the late October congressional testimony of Chairman Greenspan. Following reports of disputes among policymakers, including public dissent by two Fed governors, he pointed to the limits on how far intervention in the foreign exchange market could influence the level of the dollar.[23]

Notably, this account of the Federal Reserve's concern about 'inconsistent' policies accords with our estimates above. This account and our estimates

[22] 'Brady Plays Down Policy Rift', London *Financial Times*, October 23, 1989.

[23] 'Greenspan Warns That U.S. Inflation Is Too High', London *Financial Times*, October 26, 1989.

indicate the Federal Reserve was not intentionally signalling future monetary policy changes. Rather, it appears more likely that interventions were a reaction by the Treasury to the strengthening of the dollar, as the Fed continued maintaining a contractionary monetary policy. If so, then the 'signal' of intervention in the opposite direction from actual future monetary policy was unintentional.

We have shown, however, that intervention provided statistically significant information about the course of future monetary policy. It therefore seems likely that market participants incorporated this information about whether the intervention was based upon 'consistent' or 'inconsistent' policy states into their expectations. In the next section, we provide suggestive evidence that foreign exchange traders were informed about the potential, though unintentional, signal in intervention.

5. Reaction of exchange rates to intervention: Some suggestive evidence

According to standard models, the exchange rate depends upon current and expected future changes in monetary policy as well as other fundamental variables not controlled by the central bank. According to these models, an intervention of dollar sales based upon 'consistent' policies leads to a looser expected future monetary policy relative to no intervention. Of course, since the exchange rate depends upon the current and expected future levels of other variables as well as current monetary policy and central banks may intervene in response to these variables, intervention may not necessarily move the exchange rate at all. However, to the extent that 'consistent' interventions do move the exchange rate, rational trading should depreciate the value of the dollar following dollar sales. Thus, looking at movements in the exchange rate on the day following 'consistent' intervention, we expect to find either no significant effect or else a significant movement in the direction intended by the intervention (i.e., appreciation if dollar purchases, depreciation if dollar sales).

On the other hand, if interventions are perceived as conveying information that future monetary policy will move in the opposite direction, then the same logic applies in the reverse. Dollar sale interventions then lead traders to expect tight monetary policy in the future. This new information will either not be sufficiently significant to move the dollar or else will significantly push the dollar value up.

Thus, the predicted exchange rate movement depends upon whether the information is perceived as accompanied by 'consistent' or 'inconsistent' policies. Generally, exchange rates following 'consistent' interventions should tend to move in the direction implied by the operation if at all. On the other hand, 'inconsistent' interventions should generally move exchange rates in the opposite direction, if at all.

To consider this relationship, we examine the response to intervention news of the Deutsche mark/dollar and the Japanese yen/dollar rate. We use daily data on intervention and exchange rates. Exchange rates are quoted at noon in the New York market.[24] The reaction is measured as the change in the exchange rate on the day of the intervention, as shown in Table 1. According to the discussion above, the exchange rates should react differently depending on the information state. We therefore further divide the sample between episodes with consistent and inconsistent policies as indicated by the prior probabilities of the Federal Funds rate model (the results based upon M1 and NBR are similar).

Table 3 reports the results decomposed according to dollar selling and dollar buying interventions. The evidence is remarkably consistent with the story told above. For 'Days of Selling Dollars Intervention' under 'Consistent Policies', the dollar either depreciated significantly as in 1985, or else was not significantly changed. By sharp contrast, when these same dollar sale interventions were perceived as 'Inconsistent Policies' (under the third and fourth columns), the exchange rate significantly appreciated in every year except 1985 when the effect was insignificant.

The dollar purchases interventions summarized in the last four columns of Table 3 provide further evidence of this phenomenon. When the signal is viewed as 'consistent', the intervention led to a significant appreciation in the dollar relative to the yen in 1988 as would be predicted by the signalling story. In all other cases, the relationship is insignificant. On the other hand, when the intervention is viewed as inconsistent with future monetary policy, dollar buying interventions led to significant dollar depreciation against both currencies in 1987 and insignificant depreciation in 1988.

In all of these cases, significant movements in the exchange rates following interventions depend crucially upon whether the interventions are viewed as consistent with future monetary policy. This evidence suggests an interpretation of the typical finding in the literature that the effectiveness of intervention appears to depend upon the sample period. During periods when intervention is viewed as consistent with the direction of future monetary policy, the regression of exchange rate changes on intervention may provide statistically significant coefficients in the direction suggested by effective intervention policy. However, for other periods, the evidence may be insignificant or even in the wrong direction. The evidence in this paper suggests that the sample dependent nature of this evidence may come from the sample dependent nature of monetary and intervention policy.

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[24]We use rates corresponding to this timing since most U.S. interventions take place in the morning during the overlap period when European markets are still open. Conducting the same analysis using rates at the close in New York or later in the evening therefore tend to dissipate the effects from the intervention. In this case, the effects upon the exchange rates to be reported below are less precise. We thank Kathryn Dominguez for pointing out this time of day relationship to us.

Table 3
Foreign exchange intervention and exchange rates

		Reaction of exchange rates to intervention							
		Selling dollars intervention				Buying dollars intervention			
		Consistent signals		Inconsistent signals		Consistent signals		Inconsistent signals	
Period	Currency	Mean	*t*-stat.	Mean	*t*-stat.	Mean	*t*-stat.	Mean	*t*-stat.
09/23/85–12/31/85	DM	− 1.097	− 4.968	0.152	0.584				
	JY	− 1.058	− 11.231	0.106	0.400				
01/01/87–12/31/87	DM	0.001	0.006	0.534	1.557	− 0.173	− 1.585	− 0.510	− 3.384
	JY	− 0.114	− 1.209	0.430	2.127	− 0.220	− 1.331	− 0.744	− 3.985
01/01/88–12/31/88	DM			0.376	2.217	0.111	0.443	− 0.272	− 1.343
	JY			0.260	2.170	0.259	2.170	− 0.190	− 1.343
01/01/89–02/02/90	DM			0.201	2.659				
	JY			0.238	2.917				

Reaction: percentage change in the exchange rate on the day of the intervention relative to the exchange rate on the previous day. Rates are quoted at 12 noon New York market.

DM: Deutsche mark/dollar rate, JY: Japanese yen/dollar rate.

The 'consistent' and 'inconsistent' episodes are obtained from the signalling model using the Federal Funds rate as the monetary indicator.

6. Concluding remarks

This paper investigated whether U.S. foreign exchange interventions during the late 1980s signalled a change in monetary policy. To address this question, we developed a methodology allowing intervention to signal shifts in monetary policy regimes. We tested and rejected the hypothesis that intervention provides no signal of future monetary policy. Thus intervention was informative about future monetary policy over the period.

We showed that this evidence cannot be used to argue the intervention policy is effective, however. Indeed, the estimates indicate that interventions signalled future monetary policy in the *opposite* direction from the signalling hypothesis for much of the period. For example, dollar sales in the foreign exchange market were frequently followed by contractionary monetary policies. Furthermore, if interventions did not occur for some period of time, a new episode of intervention was viewed as only 30 to 48 percent likely to provide information about future monetary policy consistent with the signalling story.

When traders view intervention as signalling monetary policy changes in the opposite direction, these interventions are useful for predicting the future. However, the implied movements in the exchange rate also tend to move perversely. For example, on the days following interventions viewed as conveying incorrect signals, all significant movements in the exchange rate were in the opposite direction intended by the intervention. These types of interventions can be very costly in terms of the required intervention volume. This problem was evident during 1989 and 1990 when dollar sales intervention in the face of continued tight monetary policy forced the Fed to acquire foreign currency holding beyond its internal limit.

The approach taken in this paper suggests several directions for future research. First, we assumed that if the Fed has not intervened for a period of time, traders do not use past information about the credibility of intervention as a signal. However, past information about whether central banks signalled correctly may potentially be important. Second, we treat monetary policy and the consistency of intervention with monetary policy as two processes and test for their independence. In a comment, Faust and Henderson (1994) suggest a different approach to examining this issue by treating intervention and monetary policy as the two potentially independent processes. This approach may be an interesting model to examine in future work. Third, we have assumed that the transition probabilities of changes in the credibility of the signals are constant over time. In reality, these probabilities are likely to be functions of variables such as the state of the economy. Finally, our short sample period precludes considering a reaction function that depends upon real variables that are only available at longer time intervals, though including such variables with a longer data set may provide important additional information. Despite these important modifications, this paper represents an important first attempt at testing whether and how intervention interacts with future shifts in money supply.

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