A friction model of daily Bundesbank and Federal Reserve intervention

Almekinders, G.J.; Eijffinger, S.C.W.

Published in:
Journal of Banking and Finance

Publication date:
1996

ELSEVIER Journal of Banking & Finance 20 (1996) 1365–1380

Journal of BANKING & FINANCE

A friction model of daily Bundesbank and Federal Reserve intervention

Geert J. Almekinders [a], Sylvester C.W. Eijffinger [b,*]

[a] *International Monetary Fund, Washington, DC 20431, USA*

[b] *Department of Economics and CentER, Tilburg University, Tilburg, The Netherlands*

Received 15 November 1994; accepted 15 October 1995

Abstract

This paper takes a novel approach to derive a central bank intervention reaction function. A GARCH model for exchange rates is amended to allow interventions to have an effect on both the mean and the variance of exchange rate returns. An intervention reaction function is obtained by combining the model with a loss function for the central bank. Estimation results for the implied friction model reproduce the familiar 'leaning against the wind' policy by the Bundesbank and the Federal Reserve. Furthermore, the central banks appear to have reacted to increases in the conditional variance of daily DM/\$-returns.

JEL classification: F31

Keywords: Foreign exchange intervention; Exchange rates; GARCH models

1. Introduction

Since the breakdown of the Bretton Woods fixed exchange rate system in the early 1970s, the exchange value of the major currencies in the industrialized world is in principle determined by market forces. However, in the present system of managed floating the exchange rate is not the outcome of supply and demand by private market participants only. The monetary authorities of many countries have frequently tried to influence the relative value of their currency by exchange

* Corresponding author. Tilburg University, P.O. Box 90153, NL-5000 LE Tilburg, The Netherlands. Tel. +31-13-4662411; fax. +31-13-4663042.

PII S0378-4266(96)00002-7

market interventions. To comply with Article IV of the Articles of Agreement of the International Monetary Fund (IMF, 1993), central banks are obliged to promote a stable exchange rate system and hence to 'counter disorderly exchange market conditions'.

This paper reports on an empirical investigation into the objectives of foreign exchange market intervention by the Bundesbank and the Federal Reserve System in the Deutsche Mark–U.S. dollar market and the Japanese yen–U.S. dollar market. The sample period considered is the post-Louvre period February 23, 1987 to October 31, 1989. The paper takes a novel approach in the sense that the intervention reaction function is derived formally rather than in an ad hoc way. Furthermore, daily intervention data are used. Inspection of the data reveals that the central banks abstain from intervention on the majority of trading days in the sample. To accommodate this behavior, a friction model is employed to estimate the intervention reaction function consistently.

The majority of previous empirical investigations into the objectives of central bank intervention formulate the reaction function in an ad hoc manner (see, e.g. Almekinders and Eijffinger (1994). For a comprehensive survey see Almekinders and Eijffinger (1991) and Edison (1993)). This paper takes a novel approach. In Section 2 of this study the intervention reaction function is derived formally. First, we amend the popular GARCH model for the exchange rate to allow interventions to have an effect on both the mean and the variance of exchange rate returns. Second, a policy loss function for the central bank is combined with this exchange rate model to derive the intervention reaction function. Official purchases (sales) of foreign currency by the domestic central bank appear to depend on two variables. The model implies that they are positively related to the expected fall (rise) of the exchange rate below (above) the target level pursued by central banks and on the volatility of the exchange rate conditional on no intervention.

Section 3 describes the daily data on exchange rates and intervention we use to investigate the objectives of Bundesbank and Federal Reserve intervention. Furthermore, it introduces the explanatory variables used in the empirical implementation of the model in Section 4.

In practice, central banks are reluctant to intervene in the foreign exchange market. By abstaining from intervention in the face of small changes in the exchange rate and low levels of conditional volatility, central banks can be viewed as 'investing' in the potential effectiveness of interventions to be undertaken at times the foreign exchange market experiences some serious turbulence. This feature of intervention behaviour makes the standard linear regression model an inappropriate tool for estimating the derived reaction function.

To capture adequately this aspect of central banks' behaviour, we employ a friction model due to Rosett (1959) in which the dependent variable is zero as long as the independent variables remain 'close' to their desired levels. The central banks' tolerance threshold for deviations of the explanatory variables from their desired levels is one of the parameters in the model.

The estimation results reproduce the familiar 'leaning against the wind' policy by the Deutsche Bundesbank and the Federal Reserve. Furthermore, an increase in the conditional variance of daily DM/\$-returns is found to have led both central banks to increase the volume of intervention. Finally, the estimation results point to some interesting asymmetries in the intervention behaviour of the Bundesbank and the Federal Reserve.

2. The model

Neumann (1984) implements a flow market model for the determination of the exchange rate. He derives an intervention reaction function according to which the central bank of the home country supplies amounts of home currency to the foreign exchange market when the exchange rate of a foreign currency in terms of the home currency is lower than the target rate and ($S_t < S_t^T$) when an increase in the expected risk premium on assets denominated in the home currency raises speculative demand for that currency. [1] It should be noted that the serious measurement problems surrounding risk premiums are well established. More importantly, the flow market model and other structural models for exchange rate determination are rejected in empirical tests. [2] This has led many economists to adopt new research strategies in exploring the field of exchange rate economics.

By now, it is well established that a GARCH model offers a parsimonious description of the stochastic process of daily spot exchange rate returns (see, e.g. Baillie and Bollerslev, 1989). [3] This paper focusses on the motives for central bank intervention. Accordingly, it is assumed that interventions can alter both the mean and the conditional variance of daily exchange rate returns. Furthermore, the postulated stochastic process for the exchange rate allows for a GARCH-in-Mean effect:

$$\Delta s_t = a_0 + \delta_1 \, INV_t - \gamma \, DUM_t \, h_t + \epsilon_t, \quad \epsilon_t | \Omega_{t-1} \sim N(0, h_t), \tag{1a}$$

$$h_t = \pi - \delta_2 \, DUM_t \, INV_t + \alpha \epsilon_{t-1}^2 + \beta h_{t-1}, \tag{1b}$$

---

[1] Throughout the paper the exchange rate, S_t, is defined as the domestic currency price of one unit of foreign exchange. Subscript t denotes time and lower case letters refer to natural logarithms of variables. Greek letters denote positive constants.

[2] After surveying the empirical evidence on exchange rate models, MacDonald and Taylor (1992, p. 24) conclude that "...the asset approach models have performed well for some time periods, such as the interwar period, and, to some extent, for the first part of the recent floating experience (that is, 1973–1978); but they have provided largely inadequate explanations for the behavior of the major exchange rates during the latter part of the float".

[3] GARCH stands for Generalized Autoregressive Conditionally Heteroscedastic. The purport of the meanwhile extensive GARCH literature, surveyed in Bollerslev et al. (1992), is that volatility in daily returns is predictable in most financial markets. In several applications it has been shown that there is a considerable persistence in the effects of shocks in period t onto the conditional variance of exchange rates in consecutive periods.

$$DUM_t = 1(-1) \quad \text{if} \quad \Delta s_{t-1} < 0(\geq 0). \tag{1c}$$

All GARCH models in this paper are expressed in closing exchange rates (S^U). It follows that the dependent variable in (1a) is the exchange rate return over the 24 hours period from the closing of the foreign exchange market on day $t-1$ until day t's closing. Eq. (1a) characterizes the mean of the stochastic process which generates the exchange rate return series. a_0 denotes a constant rate of appreciation of foreign currency. INV_t is the volume of intervention defined as purchases of foreign currency by the domestic central bank. Interventions are effective if $\delta_1 > 0$ implying that purchases (sales) of foreign currency by the domestic central bank lead to a higher (lower) exchange value of foreign currency in terms of domestic currency. ϵ_t is the residual of the mean equation. It is indicated to have a conditional normal distribution with mean zero and variance h_t. The symbol Ω_{t-1} denotes the information available to exchange market participants at the beginning of the relevant interval for which the exchange rate return is calculated: at the closing of the foreign exchange market on day $t-1$. When measured over a sufficiently long period, the constant rate of appreciation of domestic currency a_0 may be approximately zero. Then, large drops in the exchange rate correspond with large negative realizations of ϵ_{t-1}, ϵ_{t-2}, etc. In case of bandwagon expectations among private exchange market participants, these may lead to a further decline of the exchange rate: the GARCH-in-Mean effect. When the exchange rate was falling (rising) in the previous period(s), a high conditional variance is likely to lead to a larger fall (rise) in the current period. Hence $DUM_t = 1$ ($DUM_t = -1$) in the case of a falling (rising) exchange rate. Eq. (1b) defines the variance equation (h_t). Due to the inclusion of the volume of intervention premultiplied by a dummy variable, this equation can capture the effect of both official sales and purchases of foreign currency. At first glance, less exchange rate volatility and uncertainty seems to be preferable for society as a whole.[4] Hence, interventions are effective if $\delta_2 > 0$. With the dummy variable defined as in Eq. (1c), this indicates that both purchases and sales of foreign currency lower the volatility of returns on the foreign exchange market. Presumably, the interventions work through the expectations channel. They may curb the bandwagon expectations and lead to a lowering of the conditional variance. In turn, the dampening effect of interventions on the conditional variance may lead to smaller daily returns on the foreign exchange market. This is the case if γ is significantly larger than zero.

[4] However, one can also think of situations in which central banks prefer a higher degree of uncertainty regarding the future course of currency movements. According to Blundell-Wignall and Masson (1985, p.156) "...it may be a deliberate part of an intervention strategy to change the degree of uncertainty concerning exchange rate fluctuations: either by limiting transitory fluctuations and hence providing a more stable planning environment, or by adding an erratic element to exchange rate movements, to discourage speculation".

The GARCH model in Eqs. (1a), (1b) and (1c) is not estimated directly in the present paper. The exchange rate return, which is the dependent variable in this model, is calculated from the closing of the Frankfurt or New York exchange on day $t-1$ onwards. However, day t's interventions of the Bundesbank or the Federal Reserve are mostly carried out during the last eight hours of the 24-hour period for which the exchange rate return is calculated. Consequently, the period for which the exchange rate return is calculated does not exactly match the period during which the central banks carry out interventions. Direct estimation results for the model in Eq. (1) are likely to suggest that central bank interventions have *reacted* to earlier exchange rate movements rather than to have *caused* them. [5]

Suppose the central bank wishes to limit deviations of the exchange rate from a target level (s_t^{T}). [6] Its expected policy loss increases more than proportionally with both positive and negative deviations from the target level:

$$\mathrm{E}_{t-1} L_t^{\mathrm{CB}} = \mathrm{E}_{t-1}\left(s_t - s_t^{\mathrm{T}}\right)^2. \tag{2}$$

To capture intervention carried out on account of a 'leaning against the wind' policy, the target level for the exchange rate can be thought of as representing past levels of the exchange rate. This follows immediately from the definition of smoothing exchange rate fluctuations: whether or not the exchange rate was considered to be at a desirable (or target) level in the previous period(s), deviations from this level will be countered.

Minimizing the loss function (2) by choosing INV_t subject to the constraints

[5] Baillie and Humpage (1992) estimate a model similar to Eq. (1). They find statistically significant *but systematically wrongly signed* coefficients for the intervention variables in both the conditional mean equations and the conditional variance equations. Perhaps a reasonable interpretation of Baillie and Humpage's estimation results is that central bank interventions have *reacted* to earlier exchange rate developments rather than *caused* them. This suggests that the exchange rate equation embodied in the GARCH model is a degenerated intervention reaction function. Indeed, when the estimated coefficients are viewed as coming from an intervention reaction function they are almost all statistically significant with the correct sign.Dominguez (1993) tries to infer the effectiveness of Bundesbank, Federal Reserve and Bank of Japan interventions from a similar GARCH model. She does not use matching exchange rate and intervention data either. Therefore, she also finds wrongly signed coefficients for the effect of intervention on the level of the exchange rate.

[6] Of course, the conduct of exchange rate policy is not the only issue of concern for a central bank. Neumann (1984) proposes a central bank policy loss function which accounts for a trade-off between controlling the monetary base on the one hand and the exchange rate on the other hand. However, in most large industrialized countries the monetary authorities give priority to domestic policy objectives and use instruments of monetary policy to attain these objectives. By definition, sterilized interventions lack a money market effect (cf. Pilbeam, 1991, p. 106). Therefore, it may be an appropriate simplification to focus on the motives for sterilized interventions in the spot market for foreign exchange.

implied by the stochastic process of the exchange rate described by (1a)–(1c) leads to the following intervention reaction function for the central bank: [7, 8]

$$INV_t = \frac{\delta_2 \phi_1^2}{2} DUM_t - \phi_1 (s_{t-1} + a_0 - s_t^{\mathrm{T}}) - \phi_1 \gamma \, DUM_t (\pi + \alpha \epsilon_{t-1}^2 + \beta h_{t-1}) \tag{3}$$

where

$$\phi_1 = 1/(\delta_1 + \gamma \delta_2)$$

and

$$DUM_t = 1 (-1) \quad \text{if} \quad \Delta s_{t-1} < 0 (\geq 0).$$

According to Eq. (3) the volume of intervention depends on a constant term which is positive (negative) when the exchange rate was falling (rising) in the previous period. Furthermore, official purchases (sales) of foreign currency by the domestic central bank depend positively on the fall (rise) of the exchange rate below (above) the target level, which is expected to occur during period t conditional on no intervention. Finally, an increase in the conditional variance of the exchange rate (again, conditional on no intervention) leads the domestic central bank ceteris paribus either to buy or sell more foreign currency depending on whether the course of the level of the exchange rate calls for purchases or sales of foreign currency.

3. The data

In this section we turn to an empirical study of the reaction function for daily interventions by the Deutsche Bundesbank in the spot Deutsche Mark–U.S. dollar exchange market and by the Federal Reserve System in the spot Deutsche Mark–U.S. dollar exchange market and the spot Japanese yen–U.S. dollar exchange market. [9] For that we must take account of the development of the respective exchange rates between successive days (interday), as well as in the course of these days (intraday). [10] In this study, when we look at the objectives of

[7] Appendix A.1 provides a convenient way to rewrite the loss function of the central bank.

[8] The second-order conditions for a minimum are met. Given the quadratic form of the loss function, the minimum is global.

[9] Unfortunately, we were not able to investigate empirically the reaction function for daily interventions by the Bank of Japan in the spot U.S. dollar–Japanese yen exchange market. The Japanese monetary authorities stick to a policy of strict confidentiality regarding intervention data.

[10] Goodhart and Hesse (1993) assess central bank foreign exchange market intervention virtually in continuous time. However, their investigations are based on *reported* intervention observations which appeared on Reuters screen information. This gives a far from exact representation of actual intervention operations (Klein, 1993; Osterberg and Wetmore Humes, 1993). Moreover, reported intervention observations do not contain information on the actual amount of intervention.

Bundesbank interventions the intraday development in the DM/$-market is approximated by three observations per day in the Frankfurt market:

1. the opening rate (primo) at 8.30 hours (Frankfurt time), $SFR_t^{8.30}$;
2. the fixing rate (official middle rate) at 13.00 hours (Frankfurt time) SFR_t^{13};
3. the closing rate (ultimo) at 16.30 hours (Frankfurt time), $SFR_t^{16.30}$.

Furthermore, the study makes use of daily observations for interventions by the Deutsche Bundesbank expressed in millions of U.S. dollars. [11] When we investigate the objectives of Federal Reserve intervention the intraday development in the DM/$-market and the yen/$-market are approximated by four observations per day in the New York market:

1. the opening rate at 9.00 hours (New York time), SNY_t^{9};
2. the first middle rate at 12.00 hours (New York time), SNY_t^{12};
3. the second middle rate at 14.00 hours (New York time), SNY_t^{14};
4. the closing rate at 16.00 hours (New York time), SNY_t^{16}.

Furthermore, the study makes use of daily observations for Federal Reserve interventions in the DM/$- and yen/$-exchange market expressed in millions of U.S. dollars.

In the model presented above a time subscript was attached to the symbol denoting the target exchange rate. This indicates that it is allowed to vary over time. Obviously, when the domestic central bank continues to direct intervention at a fixed target level for the exchange rate while the actual exchange rate is being driven up (i.e., the value of the domestic currency is being driven down) by a strong underlying market sentiment this intervention will in the end lead to a run on the (remaining) foreign exchange reserves of the domestic central bank. At the other extreme, when the central bank stubbornly tries to resist a persistent appreciation of the domestic currency (persistent decline of the exchange rate), it will encounter problems with sterilizing the money market effect of its increased foreign exchange reserves. Eventually, the central bank will have to tolerate an inflationary effect of the interventions. Thus, while it is assumed that the central bank wishes to limit deviations from a target level, a flexible formulation of the target level (S_t^{T}) is chosen which seems to be in accordance with the limited manageability of exchange rates in practice: for Bundesbank interventions

$$SFR_t^{\mathrm{MA}} = \frac{1}{21} \sum_{n=1}^{7} \left(SFR^{8.30} + SFR^{13} + SFR^{16.30} \right)_{t-n}^{\mathrm{DM/\$}},$$

for Federal Reserve intervention

$$SNY_t^{\mathrm{MA}} = \frac{1}{28} \sum_{n=1}^{7} \left(SNY^{9} + SNY^{12} + SNY^{14} + SNY^{16} \right)_{t-n}^{\mathrm{DM/\$,\ yen/\$}}.$$

[11] Originally, the Bundesbank intervention data are expressed in millions of Deutsche Marks. We computed their dollar value by dividing the DM value of day t's intervention by the opening rate of the U.S. dollar in Frankfurt on day t.

Table 1
Maximum likelihood estimates for the parameters of the standard GARCH model [a]

$100(\log S_t^U - \log S_{t-1}^U) = a_0 + \epsilon_t, \quad \epsilon_t \mid \Omega_{t-1} \sim N(0, h_t)$
$h_t = \pi + \alpha\epsilon_{t-1}^2 + \beta h_{t-1}$

	a_0	π	α	β	log L	$Q(12)$	$Q^2(12)$	m_3	m_4	LR(2)
DM/$-rate in	0.015	0.021	0.073	0.874	−649.34	10.29	20.63	0.04	4.29	35.68
Frankfurt	(0.65)	(2.77)	(4.47)	(31.51)						
DM/$-rate in	0.013	0.020	0.064	0.890	−684.79	7.47	6.88	−0.09	4.65	25.94
New York	(0.54)	(2.83)	(4.13)	(34.83)						
Yen/$-rate in	−0.006	0.043	0.083	0.834	−730.32	5.72	8.07	−0.13	5.21	42.41
New York	(−0.23)	(3.12)	(4.21)	(20.23)						

[a] t-statistics in parentheses. m_3 and m_4 give the sample skewness and kurtosis for the residuals, respectively. $Q(12)$ and $Q^2(12)$ refer to the Ljung–Box portmanteau test for up to 12th order serial correlation in the levels and the squares of the residuals respectively. The critical value for a 5%-level test is 21.0. LR(2) gives the value of the test statistic for the likelihood ratio test under the null hypothesis that the variance is conditional homoskedastic H_0: $\alpha = 0$, $\beta = 0$. As the alternative hypothesis is H_1: $\alpha \geq 0$, $\beta \geq 0$, the LR-statistic does not have a χ^2-distribution with two degrees of freedom. The tabulated critical value for a 5%-level test is 5.135 (Kodde and Palm, 1986).

The target level for the exchange rate is thought of as representing past levels of the exchange rate. This is not to say that the exchange rate was considered to be at a desirable level in previous days. It merely allows to test whether the central banks systematically 'leaned against the wind' and tried to smooth deviations from the seven-days moving average of the exchange rate. [12]

The reaction function in Eq. (3) proposes a second variable to explain the volume of intervention: the conditional variance of the respective exchange rate returns conditional on no intervention. Time series for the conditional variance of daily DM/$-returns (in the Frankfurt and New York market) and Yen/$-returns (in New York) are generated using the estimated parameter values of a standard GARCH model depicted in Table 1. For the time series $h_t^{FR,DM/\$}$, $h_t^{NY,DM/\$}$ and $h_t^{NY,YEN/\$}$, the unconditional or average variance of the return series for the sample considered in Table 1, σ^2, is used as a starting value. It is calculated as follows $\sigma^2 = \pi/(1 - \alpha - \beta)$.

The establishment of the February 22, 1987 Louvre Accord marks the beginning of a new exchange rate policy regime. Estimation results in Almekinders (1995) point to a marked change in the stochastic process generating the daily DM/$-return series as of that date. Furthermore, it appeared that the process remained relatively stable through to October 1989. Therefore, the sample period

[12] An alternative approach could be to have an auxiliary equation with 'fundamentals' (inflation, money growth, balance of payments accounts, etc.) determining the target exchange rate. However, given the monthly or quarterly base of the data on fundamentals this would lead to a rather sticky target rate in our daily model of exchange market intervention.

runs from February 23, 1987 through to October 31, 1989. This period comprises 677 observations for the Frankfurt market and 680 observations for the New York market. The estimated coefficients for the GARCH models shown in Table 1 are highly significant with the exception of the coefficient in the mean equation (a_0). The DM/$-rate and the yen/$-rate did not rise or decline uniformly across the sample. The value of the likelihood ratio (LR) test statistic in the last column of Table 1 indicates that the null hypothesis H_0: $\alpha = \beta = 0$ can be soundly rejected. This indicates that the random walk model with a GARCH error term fits the data better than the Gaussian random walk.

The variance of a variable is positive by definition. Yet, we would expect central banks to react differently to rises in the conditional variance of exchange rate returns depending on the level of the exchange rate, i.e. when the exchange rate is 'too high' ('too low') central banks are likely to respond to a rise in the conditional variance by selling (buying) foreign exchange. To facilitate a straightforward interpretation of the estimated coefficient for the conditional variance in the intervention reaction function we premultiplied the conditional variance h_t with a dummy variable which takes on a value 1 (-1) if the exchange rate is above (below) the Louvre-equilibrium level. The latter is approximated by the opening exchange rates in New York on February 23, 1987: \$ 1 = DM 1.8255 and \$ 1 = ¥ 153.4, respectively.

4. Estimation and results

The intervention reaction functions for the Bundesbank (DBB) and the Federal Reserve System (FED) implied by the model in Section 2 and the description of the data in Section 3 look as follows:

$$INV_t^{DBB} = b_0\, DUM_t + b_1\big(100 * \big(\log\big(SFR_t^{8.30}\big) - \log\big(SFR_t^{MA}\big)\big)\big) + b_2\, DL_t\, h_t^{FR} + \mu_t, \tag{4}$$

$$INV_t^{FED} = c_0\, DUM_t + c_1\big(100 * \big(\log\big(SNY_t^{9}\big) - \log\big(SNY_t^{MA}\big)\big)\big) + c_2\, DL_t\, h_t^{NY} + \mu_t, \tag{5}$$

where μ_t is a random disturbance term, $DUM_t = 1\ (-1)$ if $\Delta \log S_{t-1} < 0\ (\geq 0)$ and

$$\begin{aligned} DL_t &= 1 && \text{if} \quad S_t^{DM/\$} \geq S_{LOUVRE}^{DM/\$} \text{ or } S_t^{Yen/\$} \geq S_{LOUVRE}^{Yen/\$} \\ &= -1 && \text{if} \quad S_t^{DM/\$} < S_{LOUVRE}^{DM/\$} \text{ or } S_t^{Yen/\$} < S_{LOUVRE}^{Yen/\$}. \end{aligned}$$

In practice, central banks are rather reluctant to intervene in the foreign exchange market. Typical intervention efforts, which are of the order of \$ 100 or \$ 200 million, are very tiny compared to the average daily turnover on foreign exchange markets.[13] As a consequence of the relative negligibility of interventions, their impact on the course of exchange rate movements depends crucially on the strength of their announcement effect on the expectations of private exchange market participants. Hence, it seems reasonable to assume that the more frequent a central bank intervenes, the less attention will be paid to the message contained in the official foreign currency operations. It follows that the central bank is faced with a trade off. It can choose to intervene more frequently in the present with a (small) chance of driving the current spot rate closer to the target rate and/or limiting the volatility of the spot exchange rate. This will go at the cost of lowering the 'news'-content and thus the potential effectiveness of future interventions. Thus, by abstaining from intervention in the face of small changes in the exchange rate and low levels of conditional volatility the central banks can be viewed as 'investing' in the potential effectiveness of interventions to be undertaken at times the foreign exchange market experiences some serious turbulence.

The large proportion of zero observations for the dependent variable in the intervention reaction functions despite nonzero values of the explanatory variables is inconsistent with the continuous density specification of (4) and (5). Therefore, the use of ordinary least squares as an estimation technique would yield biased and inconsistent estimates. Rosett (1959) developed a friction model to suitably account for relationships in which the dependent variable is insensitive to small realizations of the explanatory variables.[14] In matrix notation:

$$\begin{aligned} INV &= (X\Omega + \mu) - \Theta^+ && \text{if} \quad (X\Omega + \mu) > \Theta^+, \\ INV &= 0 && \text{if} \quad \Theta^- \leq (X\Omega + \mu) \leq \Theta^+, \\ INV &= (X\Omega + \mu) - \Theta^- && \text{if} \quad (X\Omega + \mu) < \Theta^-, \end{aligned}$$

where INV is the dependent variable, X is the matrix of explanatory variables, $\mathbf{\Omega}$ is a vector of coefficients, $\boldsymbol{\mu}$ is a vector of normal, i.i.d. errors and $\Theta^+(>0)$ and $\Theta^-(<0)$ are the thresholds which must be exceeded before the central bank acts to buy or sell foreign currency, respectively. In the actual estimation of the friction model the thresholds replace the positive and negative constant terms in Eqs. (4) and (5).

---

[13] In April 1992 the daily average of global spot market turnover net of double-counting arising from both local and cross-border interbank operations was estimated to be $400 billion. This implies a 15 percent rise from the corresponding estimate of $350 billion for April 1989 (Bank for International Settlements, 1993).

[14] Rosett (1959, p. 263) mentions the example of small changes in yield not leading to changes in the holdings of a particular asset by a certain class of investors because of transaction costs. Forbes and Mayne (1989) estimate a friction model of the prime rate. The interest rates on bank loans under $1,000,000 to businesses are mostly tied to the prime rate which has a tendency to remain unchanged despite movements in for instance the secondary market rate on large, negotiable certificates of deposit. Feinman (1993) estimates a friction model for the volume of daily open market operations conducted by the Federal Reserve Open Market Desk. The Desk refrains from engaging in any transaction on roughly one day in four.

Maximizing the likelihood function of the friction model derived in Appendix A.2 provides estimates of the tolerance thresholds, the standard deviation of the disturbance term, σ, and the coefficient vector on the explanatory variables, $\mathbf{\Omega}$.

The maximum likelihood estimates for the parameters of the friction model for central bank intervention are reported in Table 2. The first two columns refer to Bundesbank intervention in the DM/$-market. The columns (3) and (4), and (5) and (6) refer to Federal Reserve intervention in the DM/$-market and the yen/$-market, respectively.

The columns (1), (3) and (5) assume symmetric leaning against the wind behaviour by both the Bundesbank and the Federal Reserve. Consistent with that, the first row of Table 2 depicts estimates for the coefficient b_1 and c_1 in Eqs. (4) and (5), respectively. The estimated coefficients have the expected negative sign indicating that increases (decreases) in the value of the U.S. dollar above (below) its seven-days moving average triggered sales (purchases) of U.S. dollars by the Bundesbank and the Federal Reserve. In fact, the estimated values of b_1 and c_1 imply that a one percentage point appreciation (depreciation) of the U.S. dollar vis-à-vis the Deutsche Mark above (below) its moving average on average led the Bundesbank to sell (buy) $ 79.77 million in the DM/$-market and the Federal Reserve to sell (buy) $ 106.91 million. The equivalent figure for Federal Reserve intervention in response to changes in the yen/$-rate is $ 99.25 million. [15]

The columns (2), (4) and (6) do not impose symmetric leaning against the wind behaviour. Rather, they allow to see whether the Bundesbank and the Federal Reserve tried to resist appreciations of the U.S. dollar (coefficient in the second row for 'positive deviations of the U.S. dollar's exchange rate from its moving average') as strongly as they tried to resist depreciations of the U.S. dollar (coefficient in the third row for 'negative deviations'). The estimates suggest that both central banks leaned against the wind rather selectively and tried to counteract appreciations of their own currency more strongly than depreciations.

Given that our focus is on a post-Louvre episode it is useful to keep in mind that the Louvre Agreement embodied a commitment to stabilize the value of the dollar at its then prevailing level and contain the steep decline induced by the Plaza Agreement of September 22, 1985. The Federal Reserve did indeed counter-

[15] At first sight, the 'leaning against the wind' coefficients reported in Table 2 seem to be more than three times as high as those reported in Dominguez and Frankel (1993). However, the intervention reaction function in the latter study has a different specification. The explanatory variables include three different 'leaning against the wind' variables: the contemporaneous change in the exchange rate, the lagged change in the exchange rate and the percentage deviation of the exchange rate from purchasing power parity. In addition, a lagged dependent variable is included in the model. After taking account of the difference in the specification of the reaction function, the results reported in Dominguez and Frankel are comparable with those reported in Table 2.

Table 2
Maximum likelihood estimates for the parameters of the Friction Model for central bank intervention [a]

Explanatory variables	Bundesbank intervention in DM/$-market		Federal Reserve intervention			
			in DM/$-market		in Yen/$-market	
	(1)	(2)	(3)	(4)	(5)	(6)
Deviations from moving average	−79.77		−106.91		−99.25	
	(−9.27)		(−8.76)		(−9.15)	
– Positive deviations		−55.07		−121.55		−138.80
		(−3.44)		(−6.07)		(−5.09)
– Negative deviations		−103.65		−92.75		−69.87
		(−6.56)		(−4.74)		(−4.80)
Conditional variance	−221.07	−224.96	−383.92	−381.99	−393.00	−383.17
	(−8.30)	(−8.27)	(−8.46)	(−8.37)	(−8.00)	(−8.16)
Positive threshold (Θ^+)	381.79	406.91	509.97	493.70	516.02	472.51
	(12.13)	(10.94)	(10.61)	(9.56)	(10.82)	(10.09)
Negative threshold (Θ^-)	−226.79	−205.32	−315.47	−327.10	−361.80	−394.28
	(−11.65)	(−8.99)	(−9.58)	(−9.00)	(−8.66)	(−8.47)
σ	196.32	195.69	218.51	217.77	220.53	216.21
	(18.65)	(18.72)	(14.51)	(14.39)	(17.64)	(18.25)
log L	−1300.18	−1298.70	−1168.40	−1168.03	−1037.70	−1034.89
LR(1) for equality		2.96		0.74		5.62

[a] t-statistics in parentheses. LR(1) gives the value of the test statistic for the likelihood ratio test under the null hypothesis that the coefficients for positive and negative deviations from the moving average are equal. The LR-statistic has a χ^2-distribution with one degree of freedom. The tabulated critical value for a 5% (10%)-level test is 3.84 (2.71).

act depreciations of the U.S. dollar vis-à-vis the German Mark and the Japanese Yen. This is witnessed by the significantly negative coefficient in the third row of Table 2 ('negative deviations from moving average'). However, the estimation results indicate that its intervention efforts in response to appreciations of the U.S. dollar in the DM/$- and ¥/$-market exceeded those in response to depreciations by 30 and 100 percent, respectively. The results of a likelihood ratio test depicted in the bottom row of Table 2 suggest that only the FED's intervention efforts in the ¥/$-market show a statistically significant asymmetry. For the Bundesbank it was relatively easy to hang on to its Louvre commitment. By supporting the value of the dollar it simultaneously prevented the international competitiveness of German industries from deteriorating.

The fourth row of Table 2 depicts estimates for the coefficient b_2 and c_2 in Eqs. (4) and (5), respectively. While the conditional variance term is multiplied by a dummy variable which takes on a value of 1 (-1) when the exchange rate is above (below) the Louvre equilibrium rate, the estimated coefficient is expected to have a negative sign: increases in the conditional variance will have led both central banks to sell more dollars when the exchange rate of the dollar was above its Louvre value and to buy more dollars when it was below the Louvre value.

The estimation results indicate that both central banks actively responded to increases in the anticipated volatility of the exchange market. In effect, the Federal Reserve's reaction to exchange rate uncertainty was considerably stronger than that of the Bundesbank. For example, given that the DM/$-rate was above the longer term target rate implied by the Louvre Agreement, an increase in the conditional variance of one point, say from 0.40 to 0.41, caused by a larger than average percentage change in the DM/$-rate during the previous days, on average induced the Bundesbank to sell $ 2.21 million, while it led the Federal Reserve to sell $ 3.84 million in the DM/$-market, ceteris paribus.

The estimation results confirm the seeming reluctance of central banks to intervene despite deviations of current exchange rates from their moving average and changes in the conditional variance of exchange rate returns. The tolerance thresholds for intervention (Θ^+ and Θ^-, for purchases and sales of U.S. dollars, respectively) of the Bundesbank and the Federal Reserve which replace the positive and negative constant terms b_0 and c_0 in Eqs. (4) and (5) are depicted in the fifth and sixth row of Table 2 and are all statistically significant. The thresholds for Bundesbank intervention are smaller than those for interventions by the Federal Reserve. This is not surprising since, on several trading days in the sample, the German central bank intervened at the fixing of the Frankfurt market for foreign exchange in small amounts (of the order of $3 to 5 million). These interventions have a technical character and are not always policy motivated. They do, however, lower the thresholds for Bundesbank intervention. The Fed's higher threshold, in absolute value, for purchases of U.S. dollars could be interpreted as evidence for its concern with the competitiveness of U.S. exporting firms. In addition, given the already high U.S. trade deficit, the Federal Reserve may have been relatively more opposed to an appreciation of the U.S. dollar vis-à-vis both the Deutsche Mark and the Japanese Yen.

5. Conclusions

We derived a central bank intervention reaction function by combining an amended GARCH model for the exchange rate with a loss function for the central bank. Consistent estimation results were obtained by implementing a friction model. Thus, we could cope with the fact that the Bundesbank and the Federal Reserve refrain from engaging in any transaction in the foreign exchange market on the majority of the trading days in the post-Louvre sample considered. Using daily exchange rate and intervention data we found that the German and U.S. central bank 'leaned against the wind' in the DM/$-market and the DM/$- and Yen/$-market respectively. We investigated whether the central banks take into account the well established empirical finding that exchange rate volatility is predictable to some extent. Both the Bundesbank and the Federal Reserve were found to have taken action to lower exchange market uncertainty.

In all, the estimation results suggest that during the post-Louvre period from February 23, 1987 to October 31, 1989 the Bundesbank and the Federal Reserve systematically tried to 'counter disorderly exchange market conditions' by carrying out foreign exchange market interventions. However, the estimation results presented in this paper do not allow one to determine whether the interventions were effective.

Acknowledgements

We are grateful to the Deutsche Bundesbank, Hauptabteilung Ausland for kindly providing the daily data on the official interventions of the Bundesbank on a confidential base and to the Board of Governors of the Federal Reserve System, Division of International Finance for kindly providing the daily data on the official interventions of the Federal Reserve System. Bertrand Melenberg has been extremely helpful to us in obtaining the estimation results reported in the paper. Furthermore, the paper benefitted from comments made by Frank de Jong, Bruce Mizrach and seminar participants at the Federal Reserve Bank of New York, the Division of International Finance of the Board of Governors of the Federal Reserve System, and at the Royal Economic Society Conference in Exeter, March 28–31, 1994. The second author is also a Professor of Monetary Economics at the College of Europe, Brugge, Belgium, and Stiftungsprofessor für Algemeine Wirtschaftspolitik at the Humboldt University of Berlin, Germany. The paper was written while the first author was with Tilburg University. The views expressed are personal and do not reflect any official position of the IMF.

Appendix A

A.1. Rewriting the loss function of the central bank

Given that the variance of a random variable X can be expressed as $\mathrm{Var}(X) = \mathrm{E}(X^2) - (\mathrm{E}X)^2$, the conditional expectation in Eq. (2) above can be rewritten as follows:

$$\begin{aligned}\mathrm{E}_{t-1}\left[\left(s_t - s_t^{\mathrm{T}}\right)^2\right] &= \left[\mathrm{E}_{t-1}\left(s_t - s_t^{\mathrm{T}}\right)\right]^2 + \mathrm{Var}_{t-1}\left(s_t - s_t^{\mathrm{T}}\right) \\ &= \left[s_{t-1} - s_t^{\mathrm{T}} + a_0 + \delta_1\, INV_t - \gamma\, DUM_t\, h_t\right]^2 + h_t. \end{aligned} \tag{A.1}$$

A.2. Derivation of the likelihood function

The likelihood function of the friction model consists of three components. For the observations for which INV is positive (first component) and the observations for which INV is negative (third component) an ordinary probability density function applies. For the observations with $INV = 0$ we know that $\Theta^- \leq (\boldsymbol{X\Omega} + \boldsymbol{\mu}) \leq \Theta^+$. Consequently,

$$\begin{aligned}\Pr\left[INV_t = 0\right] &= \Pr\left[\theta^- \leq X\Omega + \mu \leq \theta^+\right] \\ &= \Phi\left(\frac{\theta^+ - X\Omega}{\sigma}\right) - \Phi\left(\frac{\theta^- - X\Omega}{\sigma}\right)\end{aligned}$$

where Pr denotes the expected probability and Φ is the standard normal cumulative density function. The likelihood function can be written as follows:

$$\begin{aligned}L = \prod_{INV>0} \frac{1}{\sigma\sqrt{(2\pi)}}\, \mathrm{e}^{-(INV+\theta^+ - X\Omega)^2/2\sigma^2} * \prod_{INV=0} \left\{\Phi\left(\frac{\theta^+ - X\Omega}{\sigma}\right)\right. \\ \left. - \Phi\left(\frac{\theta^- - X\Omega}{\sigma}\right)\right\} * \prod_{INV<0} \frac{1}{\sigma\sqrt{(2\pi)}}\, \mathrm{e}^{-(INV+\theta^- - X\Omega)^{2}/2\sigma^2}.\end{aligned} \tag{A.2}$$

References

Almekinders, G.J., 1995, Exchange rate policy and the (un)conditional variance in the DM/$-rate, Jahrbücher für Nationalökonomie und Statistik.

Almekinders, G.J. and S.C.W. Eijffinger, 1991, Empirical evidence on foreign exchange market intervention: Where do we stand? Weltwirtschaftliches Archiv 127, 645–677.

Almekinders, G.J. and S.C.W. Eijffinger, 1994, Daily Bundesbank and Federal Reserve interventions: Are they a reaction to changes in the level and volatility of the DM/$-rate? Empirical Economics 19, 111–130.

Bank for International Settlements, 1993, Central bank survey of foreign exchange market activity in April 1992 (Monetary and Economic Department, Bank for International Settlements, Basle).
Baillie, R.T. and T. Bollerslev, 1989, The message in daily exchange rates: A conditional variance tale, Journal of Business and Economic Statistics 31, 297–305.
Baillie, R.T. and O.F. Humpage, 1992, Post-Louvre intervention: Did central banks stabilize the Dollar?, Working paper no. 9203 (Federal Reserve Bank of Cleveland, Cleveland, OH).
Blundell-Wignall, A. and P.R. Masson, 1985, Exchange rate dynamics and intervention rules, IMF Staff Papers 32, 132–159.
Bollerslev, T., R.Y. Chou and K.F. Kroner, 1992, ARCH modeling in finance: A review of the theory and empirical evidence, Journal of Econometrics 52, 5–59.
Dominguez, K.M., 1993, Does central bank intervention increase the volatility of foreign exchange rates?, Working paper no. 4532 (National Bureau of Economic Research, Cambridge, MA).
Dominguez, K.M. and J.A. Frankel, 1993, Does foreign exchange intervention work? (Institute for International Economics, Washington, DC).
Edison, H., 1993, The effectiveness of central bank intervention: A survey of the literature after 1982, Special Papers in International Economics (Princeton University, Princeton, NJ).
Feinman, J.A., 1993, Estimating the open market desk's daily reaction function, Journal of Money Credit and Banking 25, 231–247.
Forbes, S.M. and L.S. Mayne, 1989, A friction model of the prime, Journal of Banking and Finance 13, 127–135.
Goodhart, C. and T. Hesse, 1993, Central bank forex intervention assessed in continuous time, Journal of International Money and Finance 12, 368–389.
IMF (International Monetary Fund), 1993, Articles of agreement (IMF, Washington, DC).
Klein, M.W., 1993, The accuracy of reports of foreign exchange intervention, Journal of International Money and Finance 12, 644–653.
Kodde, D.A. and F.C. Palm, 1986, Wald criteria for jointly testing equality and inequality restrictions, Econometrica 54, 1243–1248.
MacDonald, R. and M.P. Taylor, 1992, Exchange rate economics: A survey, IMF Staff Papers 39, 1–57.
Neumann, M.J.M., 1984, Intervention in the Mark/Dollar market: The authorities' reaction function, Journal of International Money and Finance 3, 223–239.
Osterberg, W.P. and R. Wetmore Humes, 1993, The inaccuracy of newspaper reports of U.S. foreign exchange intervention, Federal Reserve Bank of Cleveland Economic Review 29, no. 4, 25–33.
Pilbeam, K., 1991, Exchange rate management: Theory and evidence (MacMillan, Basingstoke).
Rosett, R.N., 1959, A statistical model of friction in economics, Econometrica 26, 263–267.