

Döpke, Jörg; Pierdzioch, Christian

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## What can the ECB learn from Bundesbank interventions? Evidence on the link between exchange rate volatility and interventions

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# Kieler Arbeitspapiere

# Kiel Working Papers

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**What Can the ECB Learn from Bundesbank  
Interventions? — Evidence on the Link Between  
Exchange Rate Volatility and Interventions**

by

Jörg Döpke and Christian Pierdzioch



Institut für Weltwirtschaft an der Universität Kiel  
The Kiel Institute of World Economics

Kiel Institute of World Economics  
Düsternbrooker Weg 120, D-24105 Kiel

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Dr. Jörg Döpke  
Kiel Institute of World Economics  
Düsternbrooker Weg 120  
D- 24105 Kiel  
Phone: (0)49-431-8814-261  
Fax: (0)49-431-8814-525  
Email: j.doepke@ifw.uni-kiel.de

Christian Pierdzioch  
Kiel Institute of World Economics  
Düsternbrooker Weg 120  
D- 24105 Kiel  
Phone: (0)49-431-8814-269  
Fax: (0)49-431-8814-525  
Email: c.pierdzioch@ifw.uni-kiel.de

## **Abstract**

Using daily Bundesbank foreign exchange market intervention data, we employ a multinomial logit approach to estimate an intervention reaction function for the German Central Bank using options implied volatilities and the deviation of the exchange rate from its target level as explanatory variables. The empirical results underscore that distinguishing between positive and negative interventions improves the statistical properties of the Bundesbank reaction function. As the Bundesbank is often being seen as a paragon for the European Central Bank (ECB), we also discuss the implications of our results for the intervention policy of the ECB.

(94 words)

Keywords: Multinomial logit model; exchange rate volatility; central bank foreign exchange market interventions

JEL-classification: F31

# **What Can the ECB Learn from Bundesbank Interventions? — Evidence on the Link Between Exchange Rate Volatility and Interventions**

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# 1 Introduction\*

The introduction of a single European currency has changed conditions for exchange rate management. Because the volatility of nominal exchange rates might adversely effect the real sector of the economy (cf. e.g. Gros and Belke 1998), the question arises whether the European Central Bank (ECB) should intervene in the foreign exchange market to dampen the variability of this asset price. Since the ECB is often seen being in the tradition of the German central bank, the present paper takes up this issue by assessing the objectives of daily FX market interventions conducted by the Deutsche Bundesbank.

Our study provides new results concerning the objectives of daily Bundesbank foreign exchange market interventions and explores possible implications for inferences regarding the likely strategy of the ECB toward volatility in the foreign exchange market. The basic insight motivating our empirical analysis is that the relation between central bank foreign exchange market interventions and exchange rate volatility might be different in phases characterized by an appreciation of the domestic currency as compared to periods in which the foreign currency tends to strengthen relative to the domestic one. To take this hypothesis into account, we estimate a multinomial logit model of the type introduced into this strand of research by Lewis (1995). This type of model allows to discriminate between the impact of exchange rate volatility on sales and on purchases of foreign currency by central banks. Our results indicate that an asymmetric response of the Bundesbank to the variability of the DM/\$ spot rate has indeed taken place during some of the subsamples investigated in the present study.

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\* We thank Catherine Bonser-Neal and Glenn Tanner for generously sharing their implied volatility data with us. We also thank the Deutsche Bundesbank for providing the daily data on foreign exchange market interventions. Financial support from the Deutsche Forschungsgemeinschaft is gratefully acknowledged. C. Buch, J. Gottschalk, B. Kempa, C. Meier, J. Scheide, F. Schwenhold, G. Stadtmann and participants of a DFG-workshop have provided helpful comments on an earlier draft. The usual disclaimer applies.

In general, the stance of Bundesbank policy can serve as a blueprint for the ECB only if it is possible to unearth a typical reaction of the Bundesbank to conditions in the foreign exchange market. To accomplish this task, we estimate short-term reaction functions for the Bundesbank including indicator variables for both the level and the volatility of the exchange rate. Daily intervention data are utilized to explore the reaction function of the Bundesbank over various subsamples covering a period ranging from 1985 to 1997. Following Bonser-Neal and Tanner (1996) and Madura and Tucker (1991), daily implied volatility quotes estimated from Philadelphia Stock Exchange American style options are used to capture anticipated exchange rate volatility.

The remainder of the paper is organized as follows. Section 2 offers a brief review of related work. In section 3, we describe our daily Bundesbank DM/\$ intervention and implied volatility data. Section 4 is devoted to the estimation of Bundesbank reaction functions derived from implementing Probit models which serve to quantify the impact of both the level and of the volatility of the DM/\$ spot rate on the probability of an intervention. In Section 5, we formulate a multinomial logit model to capture the effects of these variables on the propensity of the Bundesbank to step into the DM/\$ market. In particular, the multinomial logit approach allows to disentangle the effect of changes in the regressands on sales and on purchases of US-Dollars by the Bundesbank. Section 6 sheds some light on the effectiveness of Bundesbank interventions and explores the implications of our empirical results for the conceivable exchange rate policy of the ECB. The final section offers some concluding remarks.

## 2 Evidence from Recent Studies

The evidence offered by previous work on the relation between central bank interventions and exchange rate volatility is mixed. Dominguez (1998) implements a general autoregressive conditional heteroskedasticity (GARCH) approach to model the impact of interventions over the period 1985–1991 on the volatility of the exchange rate. She concludes that interventions publicly known tend to decrease volatility while secret interventions generally increase exchange rate volatility. At the same time, it is reported that exchange rate volatility does not cause interventions. Baillie and Humpage (1992) present evidence that over the Post Louvre Accord period ranging from 1987 to 1990 the variability of the DM/\$ rate was positively affected by Bundesbank interventions. The same proposition is found to apply in the case of FED and Bank of Japan interventions on the volatility of the \$/Yen spot rate.

Focusing on the objectives of central bank intervention policy, Almekinders and Eijffinger (1994) integrate a conditional exchange rate variance derived from a GARCH framework into an intervention reaction function for the Bundesbank and for the FED. Using daily data for 1985–1989, they find that both central banks increase the volume of interventions when facing a rise in exchange rate volatility. Eijffinger and Gruijters (1991) confirm these results which are consistent with the so-called "leaning against the wind" hypothesis stating that central banks intend to smooth exchange rate fluctuations. The evidence presented in Neumann (1984), in contrast, indicates that the "leaning against the wind" strategy does not fit the data for the period 1974–1981. He points out that a rise in exchange rate uncertainty as measured by the monthly variance of daily changes in the DM/\$ spot rate induced the Bundesbank to control the money supply rather than the exchange rate. Taken together, the empirical evidence thus suggests that the Bundesbank's reaction function might not have been stable over time.



Using a Probit approach to estimate a reaction function for the Bundesbank, for the Bank of Japan, and for the US central bank, Baillie and Osterberg (1997a) document that both the deviation of the exchange rate from a target level and the gap between the conditional exchange rate volatility derived by estimating a GARCH model and its unconditional long-run value exert a significant impact on the propensity of the central banks to step into the Yen/\$ but not into the DM/\$ foreign exchange market. This result is confirmed by the findings of Baillie and Osterberg (1997b). Upon estimating separate Probit frameworks for sales and purchases of US Dollars, it is further found that an increase in the volatility of the Yen/\$ rate stimulated central banks to increase the supply of US-Dollars but did not significantly alter their propensity to intervene in favor of the Dollar. As concerns the variability of the DM/\$ spot rate, they report that exchange rate volatility did not trigger interventions.

While the studies mentioned so far rely on econometric models to quantify conditional exchange rate variability, Bonser-Neal and Tanner (1996) measure anticipated exchange fluctuations by the volatility implicit in option prices. Utilizing options implied volatilities to quantitatively substantiate the impact of central bank forex interventions on exchange rate variability has several advantages. For example, these data reflect market prices and embody market participants' expectations regarding the average volatility of the underlying exchange rate over the remaining time to expire of the derivative contract. Thus, in contrast to estimates of exchange rate variability obtained by using past data, options implied volatilities are forward looking variables by nature. Bonser-Neal and Tanner (1996) document that central bank interventions either do not affect or even raise expected exchange rate volatility. These findings are confirmed by Madura and Tucker (1991). Options implied volatilities are employed to measure anticipated exchange rate volatility during the Post Louvre period, it is revealed that the interventions carried out in the aftermath of the Accord were unsuccessful in reducing exchange rate volatility.

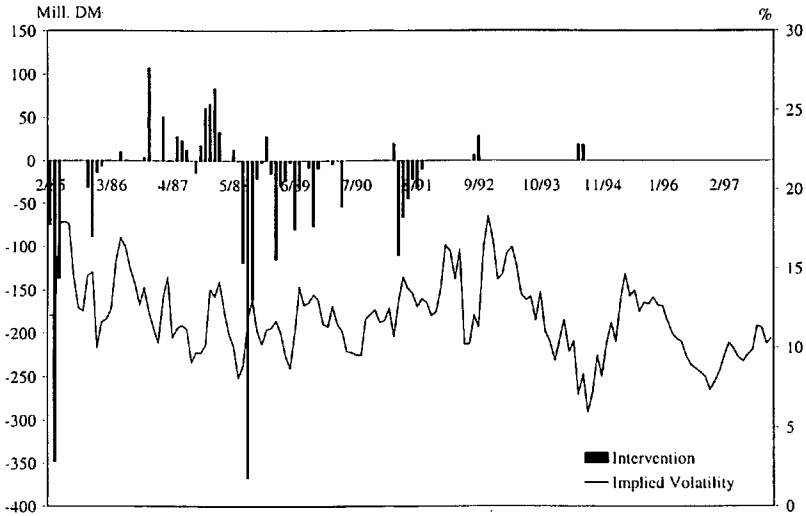
### 3 The Data

Daily Bundesbank intervention data are used to analyze the link between central bank interventions in the DM/\$ market and exchange rate volatility. Purchases (+) and sales (-) of US Dollars by the German central bank are measured in millions of DM. The time period under investigation ranges from January 1985 to December 1997. Following the literature (cf. e.g. Bonser-Neal and Tanner 1996), this period is subdivided into four main phases of intervention policy. The first subperiod ranges from 01/01/1985 – 02/20/1987 and represents the period between the Plaza Agreement and the Louvre Accord. The Plaza Communiqué was agreed upon by G-5 central bank governors and finance ministers on September 22, 1985 and aimed at bringing the then strong Dollar down. As can be seen in Figure 1, the Plaza Agreement was followed by pronounced sales of US Dollar by the Bundesbank. The exhibit further shows that even before the G-7 meeting held at the Louvre in Paris on February 22, 1987 the direction of foreign exchange market interventions changed its sign. The Louvre Accord was launched to stabilize the US Dollar at or around the then prevailing level (Funabashi 1988). The third subsample ranges from 01/02/1990 to 08/31/1992 and reflects the period following the breakdown of the Louvre Accord characterized by less systematic interventions of central banks. The final subperiod between 01/09/1992 and 12/31/1997 represents a phase characterized by only very few interventions. It is included for purposes of comparison of exchange rate volatility observed during periods of intensive central bank interventions and phases during which central banks are absent from the foreign exchange market.

Exchange rate volatility is measured in terms of annualized anticipated volatilities implicit in at-the-money DM/\$ Philadelphia Stock Exchange (PHLX) American style foreign currency options. As compared to conditional variances estimated from GARCH or related models, implied volatilities embody market participants expectations regarding perceived exchange rate variability over the remaining time to maturity of the option and are, therefore,

forward looking variables by nature. The DM/\$ implied volatilities used in the present study have been taken from three different sources. The first subset of data covering the period 1985–1991 is identical to the time-series utilized by Bonser–Neal and Tanner (1996).<sup>1</sup> Implied volatilities for the subsample 1992–1994 are based on own calculations using option market transaction data provided by the PHLX. Regarding the period from 1995 onwards, we use implied volatilities backed out of option price data by the PHLX.

*Figure 1 — Time Series Used in the Empirical Analyses*

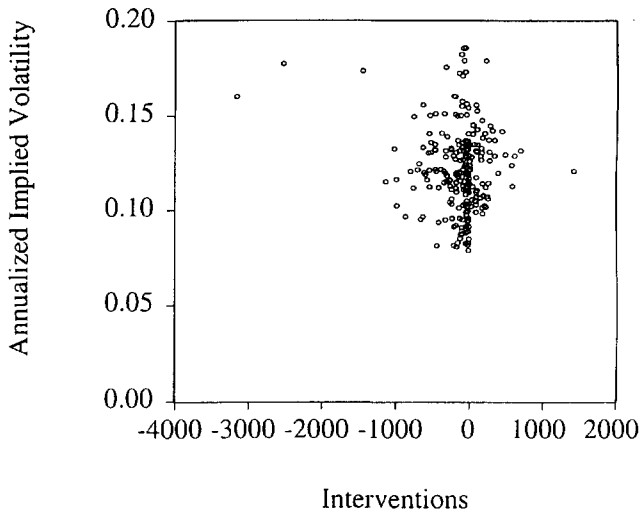


<sup>1</sup> We thank Catherine Bonser–Neal and Glenn Tanner for providing the implied volatility data to us. They have backed volatilities out of option prices by means of the Barone–Adesi and Whaley (1987) quadratic approximation technique. Implied volatilities are missing for the periods 01/25/1985 – 02/21/1985; 10/25/1985 – 11/28/1985; and 08/26/1985 – 09/29/1985. For the present study, we used conditional volatility forecasts derived from a GARCH model to close these gaps. A parsimonious GARCH(1,1) model based on  $t$ -distribution as suggested by Baillie and Bollerslev (1989) turned out to produce acceptable results as well as volatility forecasts which fitted well into the implied volatility time series. The estimation results are available from the authors upon request. For further details regarding the implied volatility series, cf. Bonser–Neal and Tanner (1996).

A detailed description of the data is delegated to the Appendix. Figure 1 depicts the time series used in the following econometric analyses. To alleviate the graphical exposition the series are plotted at a monthly frequency.

The scatter plot offered in figure 2 gives a first impression of the link between exchange rate volatility and interventions. The exhibit is constructed from data collected only from days on which an intervention took place and shows that there is a small yet significant negative correlation between the two time series. The figure takes into account the direction of the interventions and suggests that the Bundesbank tended to sell Dollars in times of high volatility. However, there are also days on which the Bundesbank intervened in favor of the US currency even though exchange rate volatility assumed a high value. Thus, though intuitively appealing, propositions regarding a possible causal relationship between exchange rate volatility and Bundesbank interventions should not be drawn from figure 2. A second aspect which should be taken into consideration when interpreting the figure is that the exhibit completely neglects the

*Figure 2 — Bundesbank Interventions vs. Implied Volatility (1985 – 1997)*



potential impact of the level of the exchange rate or of its deviation from some target level on the decision of the Bundesbank to intervene. Finally, conclusions from the figure would rest on the assumption that the link between exchange rate volatility and Bundesbank interventions was stable over time. Given the marked official policy changes which manifested themselves in the Plaza agreement and in the Louvre Accord, this proposition can hardly be justified.

Table 1 presents descriptive statistics concerning interventions as grouped by the value assumed by implied volatility. The data presented in the table reveal that the majority of interventions occur on days when volatility takes on a value close to its median. The strongest positive intervention also occurred at a "normal" volatility level. In contrast, the largest negative intervention corresponds to a very high volatility. The number of interventions which can be found in the groups representing either very high or very low volatility realizations are more or less equal. Thus, the relation between volatility and interventions is obviously non-monotonous. As was the problem with figure 2, however, the table does neither take into account the temporal ordering of the data nor the impact of the level of the exchange rate on the Bundesbank's intervention policy. To address these issues, the next sections of the paper are devoted to the estimation of Bundesbank reaction functions.

*Table 1* — Bundesbank Interventions Categorized by Implied Volatility (1985 – 1997)

Volatility	Mean	Median	Max	Min	Std. Dev.	Obs.
[0, 0.05)	11.83	0.00	414.00	0.00	69.98	35.00
[0.05, 0.1)	-5.13	0.00	402.00	-665.00	49.87	756.00
[0.1, 0.15)	-8.28	0.00	1426.00	-1140.00	97.04	2086.00
[0.15, 0.2)	-26.43	0.00	279.00	-3171.00	220.77	420.00
[0.2, 0.25)	0.00	0.00	0.00	0.00	0.00	19.00
All	-9.60	0.00	1426.00	-3171.00	112.88	3317.00

## 4 Bundesbank Intervention Functions

In this section, intervention reaction functions for the Deutsche Bundesbank are estimated. Within the related literature there are two contrasting approaches to specify such a relationship. The first group of equations models the time series of interventions directly by means of ordinary or two-stage least squares techniques. Examples for this approach can be found in Eijffinger and Grujters (1991) and Dominguez and Frankel (1993). The second strand of research relies on the estimation of univariate binary variables frameworks to describe the propensity of central banks to intervene in foreign exchange markets. In contrast to the first methodology, this implies an indirect representation of the underlying preferences of the central bank. Examples for this kind of analysis include Almekinders and Eijffinger (1994) and Baillie and Osterberg (1997a, 1997b). We now follow the latter strand of the literature and model Bundesbank intervention behavior by means of a Probit model.

The set of exogenous variables is composed of two time series: a five-day uncentered moving average of PHLX DM/\$ Dollar options implied volatilities and the deviation of the level of the DM/\$ spot rate from its five-day uncentered moving average. The latter variable is motivated by the presupposition that the Bundesbank had some kind of target level for the exchange rate. In order to check the robustness of the results we also tried alternative moving average specifications covering longer time windows. However, we found that the results do not vary very much.

Since the target value has hardly been stable during the entire prolonged investigation period, we approximate this target by a simple moving average as has also been suggested by Quirk (1977) and by Almekinders and Eijffingers (1994). The volatility time series is smoothed by a moving average as it is more reasonable to assume that the central bank reacts to enduring shifts in volatility which, in the case of our specification, last longer than a week rather than to

pronounced one-time volatility peaks. The equation representing the propensity of the Bundesbank to intervene ( $I^*$ ) is given by:

$$(1) \quad I_t^* = \beta_0 + \beta_1 \left( \text{US\$} - \frac{1}{5} \sum_{j=1}^5 \text{US\$}_{t-j} \right)_{t-1} + \beta_2 \left( \frac{1}{5} \sum_{j=1}^5 s_{t-j} \right)_{t-1} + u_t$$

where  $\sigma_t$  denotes the series of implied volatilities as described in section 1 and  $u_t$  represents a disturbance term. We now define an observable intervention indicator as follows:

$$(2) \quad I_t = \begin{cases} 1 & \text{if } I_t^* > 0 \\ 0 & \text{else} \end{cases}$$

In the Probit model the dependent is a dummy that takes the value 1 for an intervention day, and 0 otherwise. Hence, the intervention dummy is defined as below:

$$(3) \quad I_t = \begin{cases} 1 & \text{if an intervention occurs} \\ 0 & \text{else} \end{cases}$$

The goodness-of-fit of the models is evaluated by means of the Mc Fadden  $R^2$  (see Greene 1997: 898):

$$(4) \quad R^2 = 1 - (L_u / L_C)$$

In equation (4),  $L_C$  is the Log-Likelihood of a regression in which the intervention dummy is explained by a constant only.  $L_u$  is the log-likelihood of the unrestricted regression including a constant, the target variable, and options implied volatilities. The Mc Fadden  $R^2$  is bounded between 0 and 1 and can thus be interpreted in the same manner as the usual  $R^2$  in standard regressions. The significance of a regressor can be analyzed by using the standard normally

distributed ratio of the coefficient and its respective standard deviation ( $z$ -statistic).

Table 2 — Probit Models for Bundesbank Interventions in the DM/\$-Market

Time Period	$\beta_0$	$\beta_1$	$\beta_2$	$R^2$ (LR-Test)	% Correct Predictions <sup>a</sup>
01/01/1985 – 02/20/1987	-0.88 (-2.2)*	-3.88 (-0.8)	-2.64 (-1.1)	0.01 (2.78)	0.44 0.54
02/23/1987 – 12/31/1989	-1.80 (-5.1)***	7.05 (1.7)*	8.82 (2.8)***	0.03 (11.26)***	0.52 0.57
01/02/1990 – 08/31/1992	-1.53 (-3.5)***	17.6 (2.5)**	-1.74 (-0.5)	0.04 (6.49)***	0.53 0.66

<sup>a</sup>First number denotes correctly predicted non-interventions and the second figure gives the correctly predicted interventions. The cut-off rates has been set equal to the proportion of intervention days in the respective subsamples. These are: 11%, 23%, and 4%, respectively.  $z$ -statistics in parentheses. A \*(\*\*, \*\*\*) denotes rejection of the null hypothesis at the 10 (5,1) per cent level.

The estimates are given in table 2. It turns out that the results are not stable over the sub-samples. The most promising results are obtained for the subsample following the Louvre Accord. Only in this time period the coefficients are significantly different from zero. The impact of the difference between the exchange rate and its target is – as expected – negative. In contrast, the sign of the coefficient of the volatility series is positive. This implies that the more volatile the DM/\$ market the more likely is an intervention of the Bundesbank. However, this result does not hold for the other subsamples. Instead, the variable turns out to be insignificant during these phases. In the period between 1985 and 1987 the influence is even negative though not significant.

If the models are used to predict actual Bundesbank interventions it turns out that even if the cut-off probability is fixed at a rather low level equal to the per cent of interventions the overall forecasting performance of the univariate Probit models remains at about 50%. Nevertheless, for two out of the three



subsamples the exogenous variables have at least some explanatory power as indicated by the (Wald) LR-test.

All in all, the results suggest that the explanatory variables chosen in the present paper to construct the reaction functions are promising candidates to model Bundesbank intervention policy. At the same time, however, our findings indicate that the univariate binary dependent variable approach might be a too restrictive technique to describe central bank intervention behavior.

## **5 To Sell, To Buy, or to Do Nothing: A Multinomial Logit Approach**

Resorting to the baseline Probit framework to test for the impact of exchange rate volatility on the intervention policy of the Bundesbank neglects potentially useful information on the link between exchange rate variability and the *direction* of interventions. Therefore, a model which allows for three rather than only two possible outcomes of the dependent variable seems to be more appropriate to describe sales, purchases and no interventions of the Bundesbank.

A leading candidate for modeling central bank F/X market intervention behavior is a multinomial logit model. As compared to a simple univariate Probit set up, an advantage of the multinomial framework is that it also makes sense to estimate such a more complex model even when the sign of the interventions changes during the subsample under investigation. For this reason, we follow the approach suggested by Lewis (1995) and estimate a multinomial logit model to formally describe the intervention policy conducted by the German central bank. The main differences to the related work of Lewis (1995) are that she does not use exchange rate volatility as an explanatory variable and that her investigation rests on data on market rumors rather than on actual

interventions. Moreover, the time period considered in her contribution is restricted to the years 1985–1987.

We first define a new dependent series which takes on the value zero in case of no intervention, the value 1 if the central bank buys Dollars, and -1 whenever the central bank sells the foreign currency:

$$(4) \quad I_t = \begin{cases} 1 & \text{if a positive intervention is observed} \\ -1 & \text{if a negative intervention is observed} \\ 0 & \text{else} \end{cases}$$

Generally speaking, the aim in formulating a multinomial logit model is to estimate equations which provide a set of probabilities for the three possible intervention events. The multinomial logistic probability distribution can be expressed as follows (see e.g. Greene 1997: 913):

$$(5) \quad \text{Prob}(I_t = j) = \frac{\exp(b_j'x)}{1 + \sum_{j=1}^J \exp(b_j'x)} \quad ; J = -1, 1; \quad b_0 = 0$$

where  $b_j$  denote parameter vectors to be estimated and  $x$  a matrix that contains the set of explanatory variables. This can also be re-written in terms of the so-called logs-odds ratios given by (cf. e.g. Greene 1997: 915):

$$(6) \quad \ln \left\{ \frac{\text{Prob}(I_t = 1)}{\text{Prob}(I_t = 0)} \right\} = \gamma_0 + \gamma_1 \left( \text{US\$} - \frac{1}{5} \sum_{j=1}^5 \text{US\$}_{t-j} \right)_{t-1} + \gamma_2 \left( \frac{1}{5} \sum_{j=1}^5 s_{t-j} \right)_{t-1}$$

$$(7) \quad \ln \left\{ \frac{\text{Prob}(I_t = -1)}{\text{Prob}(I_t = 0)} \right\} = \varphi_0 + \varphi_1 \left( \text{US\$} - \frac{1}{5} \sum_{j=1}^5 \text{US\$}_{t-j} \right)_{t-1} + \varphi_2 \left( \frac{1}{5} \sum_{j=1}^5 s_{t-j} \right)_{t-1}$$

where the probability of no intervention has been utilized as "numeraire". The multinomial logit model can be estimated by maximum likelihood. See Greene (1997) and Maddala (1983) for further details.

The results of the estimation procedure are summarized in table 3. With regard to subsample one ranging from 01/01/1985 to 02/20/1987 and reflecting the Post-Plaza period, the figures presented in the table show that with respect to Dollar purchases of the Bundesbank none of the coefficients is significant. However, the coefficients in the equation modeling negative interventions, i.e. Dollar sales by the Bundesbank, are all significantly different from zero at least at the 5 per cent level. In the second subsample reflecting the Post-Louvre years, the equations for both purchases and sales of US Dollar contain non-zero coefficients. The only exception arises in the case of the impact of exchange rate volatility on negative interventions: the respective coefficient appears to be insignificantly different from zero. In the third subsample under investigation, the coefficient  $\gamma_1$  summarizing the influence of anticipated exchange rate volatility on Bundesbank's' intervention policy is significant in a broader sense

Table 3 — Estimation Results for the Multinomial Logit Model

Coefficient	01/01/1985 – 02/20/1987	02/23/1987 – 12/31/1989	01/02/1990 – 08/31/1992
$\gamma_0$	-1.32 (-0.7)	-6.85 (-4.9)***	2.13 (0.4)
$\gamma_1$	-18.41 (-1.3)	31.09 (3.8)***	-61.63 (-1.2)
$\gamma_2$	-22.11 (-0.7)	-63.17 (-4.9)***	-75.88 (-2.2)**
$\varphi_0$	-4.75 (-4.5)***	-2.41 (-3.5)***	-3.87 (-1.7)**
$\varphi_1$	13.50 (1.9)**	6.56 (1.1)	-1.87 (-0.1)
$\varphi_2$	-12.22 (-2.1)**	40.98 (5.8)***	91.95 (7.6)***
Log-Likelihood	-180.57	-456.80	-116.11
Schwarz Criterion	0.75	1.25	0.41
Wald LR-Test	12.96***	80.79***	74.01***
Pseudo-R <sup>2</sup>	0.02	0.05	0.15

A (\*\*, \*\*\*) denotes rejection of the null hypothesis at the 10 (5, 1) per cent level.

as its marginal probability level assumes a numerical value of 0.12. In contrast to the binomial Probit models the results of the Wald *LR*-tests indicate that the multinomial logit framework provides significant explanatory power with respect to the objectives of intervention policy in all three subsamples considered. Hence, distinguishing between sales and purchases of US Dollars by the German central bank improves the fit to the data and turns out to be an important modeling instrument in the discussion of the objectives of Bundesbank interventions.

The sign of the coefficients  $\gamma_1$  and  $\varphi_1$  can be utilized to further elaborate on the influence of exchange volatility on the direction of the intervention policy of the Bundesbank. As concerns the Post-Plaza Agreement period ranging from 01/01/1985 to 02/20/1987, the probability of Dollar purchases of the Bundesbank relative to the probability that no intervention occurs is an increasing function of turbulences in the FX markets. In addition, the log-odds ratio indicates that negative interventions become more unlikely as exchange rate volatility rises.

The situation is somewhat different in the Post Louvre subsample. Resorting once again to the respective log-odds ratio, it can be verified that relative to the basecase of no intervention a positive Bundesbank intervention becomes more likely as volatility increases. Thus, as compared to the first subsample, the probability of a positive intervention is an increasing function of volatility whereas in the Post Plaza period the propensity to purchase US Dollars declines as exchange rate variability rises.

While contrasting the finding obtained for the first subsample on first reading, the results turn out to be similar to each other if the ultimate aims of central bank intervention policy are taken into account. Given the extremely strong Dollar observed during the Post Plaza period, the aim of the Bundesbank was to strengthen the Deutsche Mark which required negative interventions, i.e. increases of the supply of Dollars by the Bundesbank. In the aftermath of the

Louvre Accord, the goal of the Bundesbank was quite different: the domestic currency had already sharply appreciated so that negative interventions were the appropriate policy instrument. Therefore, our results indicate a common picture for both subsamples as the probability of an intervention in the direction presumably preferred by the Bundesbank increased with exchange rate volatility. Obviously, the Bundesbank stood ready to defend its goals even in times of increased market turbulences.

The coefficients estimated for the final subsample show that the effect of exchange rate variability on both the propensity of the Bundesbank to sell and to purchase Dollars is insignificant. This result might be due to the rather small number of interventions observed during this period of time. Notwithstanding, this result might be interpreted as a further hint that the reaction function of the Bundesbank has changed over time.

## **6 Implications for the ECB**

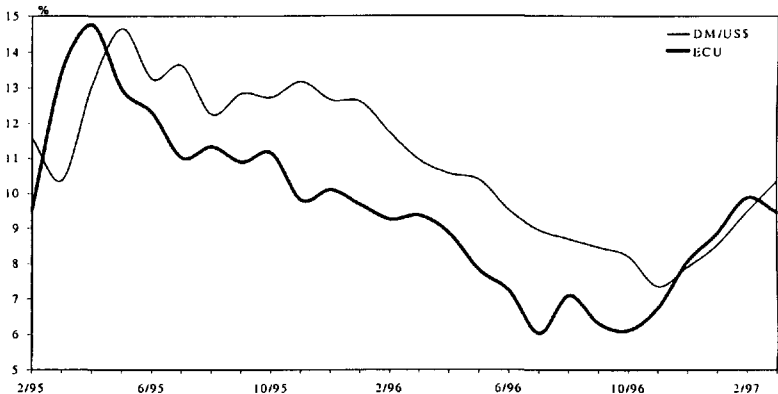
As the European Central Bank is often seen being in the tradition of the Bundesbank, the question arises whether the results of our analysis can also be employed to draw inferences regarding the conceivable stance of the ECB with respect to exchange rate volatility. However, it is only valid to extrapolate our results derived for the Bundesbank to describe the policy of the ECB toward turbulences in the foreign exchange market if the volatilities backed out of DM/\$ options are comparable in magnitude to volatilities implied on the Euro spot rate. To approximate the latter for a sufficiently long period of time, we resort to PHLX American style options on the European Currency Unit (ECU) since the Euro has been constructed by utilizing the basket weights which had formerly been employed to define the ECU.<sup>2</sup> Figure 5 confronts both implied volatility series for a sample period ranging from 07/95 to 02/97. It can be seen

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<sup>2</sup> A more detailed description of the data can be found in the Appendix.

that the overall pattern of the anticipated variabilities of both spot rates are similar to each other.

*Figure 5 — ECU vs. DM/\$ Annualized Implied Volatilities (1995 – 1997)*



Though the implied volatilities are similar to each other, the policy regime under which the ECB acts is quite different from the one of the Bundesbank. For example, no more or less official exchange rate target comparable to the ones agreed upon at the Plaza or at the Louvre does exist today. Moreover, the ECB has stated that exchange rate targets will not be taken into account in formulating monetary policy. Nevertheless, from a legal point of view, the ECB has the right to intervene in the foreign exchange market and has also developed the appropriate infrastructure to carry out such transactions (ECB 1999). Though interventions have actually not taken place yet, the ECB authorities might be confronted with situations in foreign exchange markets which will force them to initiate interventions. As the reaction of the Bundesbank to conditions in the foreign exchange market has been shown above to change over time, it is not possible to claim that the Bundesbank can serve as a blueprint for the ECB in such situations in general. However, given the lack of own experience with foreign exchange market interventions, the ECB might prefer to exploit the experience made by the Bundesbank and might therefore try to identify phases in which foreign exchange market interventions of the

German central bank were successful. In this context, two problems arise. First, in order to evaluate the effectiveness of interventions, it is necessary to define a success criterion. Second, given such a criterion it must be tested whether the intervention policy of the Bundesbank as described by one of the reaction functions derived above was in fact successful.

We define an intervention policy as being successful if either the volatility decreases in response to the central banks' actions in the foreign exchange spot market or the level of the exchange rate moves into the direction of the target variable which is defined as a 5-day moving average. To test this, we implement an event-study methodology similar to the one advanced by Bonser-Neal, Roley, and Sellon (1998). Specifically, the following equations are estimated:

$$(9) \quad (\bar{s}_t^+ - \bar{s}_t^-) = \alpha + \beta |\text{Intervention}|_t + \delta \bar{s}_t^- + u_t, \quad \bar{s}_t^\pm \equiv \frac{1}{5} \sum_{i=1}^5 s_{t\pm i}$$

$$(10) \quad |D_t^+ - D_t^-| = \alpha + \beta |\text{Intervention}|_t + \delta D_t^- + u_t, \\ D_t^\pm \equiv \frac{1}{5} \sum_{j=1}^5 \left| \text{US\$}_{t\pm j} - \frac{1}{5} \sum_{i=1}^5 \text{US\$}_{t\pm j-i} \right|$$

Equation (9) is used to assess whether Bundesbank interventions helped to reduce the average volatility of exchange rates computed over the five trading days following the intervention as compared to the average volatility prevailing during the five days preceding the central banks' step into the market. In this framework, an intervention is interpreted as being successful if volatility declines in response to the implementation of this policy measure. Hence, under the null hypothesis of an successful intervention the sign of the coefficient  $\beta$  is significantly negative. The level of the average volatility is included in the set of regressors to control for the causality running from exchange rate variability to interventions found in the multinomial logit analysis above. An alternative criterion to measure the effectiveness of central bank policy is given by the induced change in the absolute deviation of the exchange rate from its target

level. In equation (10), it is therefore tested whether an intervention helps to close the average gap between the actual exchange rate and its target observed in the five day window following the interventions as compared to the corresponding mean gap computed for the five days proceeding the intervention. In analogy to equations (9), a successful intervention policy is characterized by a significantly negative coefficient  $\beta$ . For the same reasoning as in equation (9), we enrich the set of explanatory variables by the average of the level of the deviation of the exchange from its target.

Table 4 — On the Effectiveness of Bundesbank Interventions

Subsample	Number of Interventions	$\alpha$	$\beta$	$\delta$	$R^2$
Equation (9)					
01/01/1985 – 02/20/1987	62	0.03 (2.39)***	$1.07 \times 10^{-5}$ (3.81)***	-0.27 (-2.74)***	0.18
02/23/1987 – 12/31/1989	162	0.02 (2.31)***	$1.09 \times 10^{-9}$ (3.53)***	-0.16 (-2.28)***	0.15
01/02/1990 – 08/31/1992	29	0.01 (0.53)***	$3.09 \times 10^{-6}$ (0.52)	-0.07 (-0.43)	0.01
Equation (10)					
01/01/1985 – 02/20/1987	61	0.02 (6.53)***	$8.06 \times 10^{-6}$ (1.60)	-0.28 (-1.8)*	0.19
02/23/1987 – 12/31/1989	162	0.01 (10.07)***	$8.60 \times 10^{-6}$ (2.42)**	-0.10 (-0.98)	0.06
01/02/1990 – 08/31/1992	29	0.01 (4.49)***	$-5.19 \times 10^{-7}$ (0.09)	-0.27 (0.96)	0.12

A \*\*\*,\*\*\*) denotes rejection of the null hypothesis at the 10 (5,1) per cent level. Standard errors are corrected for autocorrelation and heteroskedasticity using the procedure proposed by Newey and West (1987).

Table 4 reports the results of the estimations. It turns out that the intervention policy of the Bundesbank was not successful at all. As can be seen in the table, the coefficient measuring the success of central bank policy is either insignificant or has the wrong sign. While a positive change in volatility or an increase in the deviation from the target might be due to the influence of other exogenous factors omitted in the equations, a number of studies controlling for such variables document similar results. For example, Bonser-Neal and Tanner



(1996) control for the influence of macroeconomic variables and still find that the overall impact of Bundesbank interventions on the volatility of the DM/\$ spot rate was positive rather than negative. In a similar vein, Almekinders (1995) surveys the literature examining the potential impact of Bundesbank's interventions on the level of the exchange rate and resumes that, in general, such central bank actions were not successful. Therefore, our findings lead to us to reject the hypothesis that Bundesbank's foreign exchange market interventions have been successful during the period under investigation in the present study.

To further corroborate our results, we examine whether volatility has increased in the final subsample of our investigation period ranging from 1992 to 1997 during which the Bundesbank was absent from the foreign exchange market on almost all days. Of course, it is not possible to establish a formal Bundesbank reaction function for this period. However, a strictly non-interventionist stance of exchange rate policy can be interpreted as a special form of a reaction function itself. Hence, we have investigated whether exchange rate volatility during this policy regime was significantly different from the variability of the spot rate observed in earlier subsamples.

The results are given in table 5. The figures indicate that exchange rate volatility has decreased rather than increased in the no-intervention period. Although this can be due to favorable macroeconomic circumstances given the relatively long time period without any intervention, the test can be interpreted as *prima facie* evidence for the ineffectiveness of Bundesbank interventions. In other words, the policy of not intervening at all has not been followed by more pronounced turbulences in foreign exchange markets. All in all, these results suggest that, given our success criteria the ECB rather should refrain from using interventions as an instrument of exchange rate policy.

Table 5 — Effectiveness of Interventions as Measured by Implied Volatility

Time Period	Number / Mean Interventions	Mean of volatility	Median of Volatility	Test on equal mean <sup>1</sup>	Test on equal median <sup>2</sup>
2.1 1985 - 20.2.87	62/-19.6	0.137	0.135	(-)	(-)
23.2.86 - 31.12.89	162/-20.5	0.113	0.113	-37.3***	21.72***
2.01.90-31.8.92	29/-9.20	0.123	0.122	11.73***	9.89***
1.9.92 - 31.12.97	2/ 0.60	0.112	0.107	-12.01***	12.81***

1) t-test on equal mean as compared to the previous subsample. 2) Wilcoxon signed rank test on equal median as compared to the previous subsample. \*\*\* (\*\*,\*) denotes rejection of the null hypothesis at the 1(5,10) percent level.

## 7 Conclusions

The present study provides further insights regarding the objectives of daily Bundesbank foreign exchange market interventions. We show that, as compared to the univariate binary dependent variables model conventionally utilized in the literature, a multinomial logit model which has also been suggested by Lewis (1995) provides a more promising description of the intervention policy of the Bundesbank. In the reaction function estimated by means of the multinomial approach both the deviation of the exchange rate from its target and the variability of this asset price as measured by volatilities implicit in DM/\$ options turn out to significantly influence the propensity of the Bundesbank to intervene. Our results show that an asymmetric response of the German central bank to the volatility of the DM/\$ exchange rate can be established for two of the subsamples investigated in the present study. Moreover, the relative importance of the explanatory variables changes between the subsamples suggesting that the Bundesbank's reaction function was not stable over time. All in all, our empirical results demonstrate that distinguishing between positive and negative interventions of the German central bank improves the goodness-of-fit of the reaction function models.

To derive normative conclusions with respect to the exchange rate policy of the ECB, we have analyzed whether the F/X market interventions of the Bundes-

bank were successful in either bringing the level of the exchange rate closer to its target or in reducing exchange rate volatility. In line with the results documented in previous studies we reject these hypotheses.

## Appendix

The DM/\$ implied volatilities have been collected from three different sources. The first subset of data covering the period 1985–1991 has been provided to us by Bonser–Neal and Tanner (1996). They have used the Barone–Adesi and Whaley (1983) quadratic approximation algorithm to back volatilities out of American style PHLX options with moneyness being in the interval 0.98 and 1.02 averaged over traded maturities. For the period starting at 01/92 and ending at 12/94, the implied volatilities are own calculations. We have American style PHLX at-the-money options data taken from the transaction tape of the PHLX. Exploiting the fact that at-the-money options are approximately linear functions of volatility, we have used the results derived in Feinstein (1989) to speed up the computations involved when figuring out implied volatilities according to the Barone–Adesi and Whaley (1987) technique. Only highly traded options with a time to maturity of at least three months and at most six months have been used in the analysis. The DM/\$ implied volatilities for 1995 onwards as well as volatilities implicit in the European Currency Unit have been taken from the PHLX homepage. As in Bonser–Neal and Tanner (1996), implied volatilities have been averaged over the traded maturities. For some periods of time, implied volatilities were not available. In these cases, we used conditional volatility forecasts derived from a GARCH model. A parsimonious GARCH(1,1) based on  $t$ -distribution as suggested by Baillie and Bollerslev (1989) turned out to produce acceptable results and volatility forecasts which fitted well into the implied volatility time series. The estimated model takes the form:

$$\log(US\$_t / US\$_{t-1}) = 0.0000017 + \hat{\varepsilon}_t, \quad R^2 = 0.00058$$

(-1.39)

$$\sigma_{\varepsilon_t}^2 = 0.00001 + 0.0642 \hat{\varepsilon}_{t-1}^2 + 0.91692 \sigma_{\varepsilon_{t-1}}^2 + 4.9965D$$

(3.41)            (6.22)            (68.62)            (9.26)

The Kurtosis implied by a Student  $t$  distribution with 5 degrees of freedom is 9.0212. Ljung-Box test for serial fourth order correlation: 4.38. Test for remaining ARCH effects ARCH(4): 0.9381.

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