Central Bank Intervention and Exchange Rate Expectations – Evidence from the Daily DM/US-Dollar Exchange Rate

Stefan Reitz
(Justus-Liebig-University Giessen)

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Deutsche Bundesbank, Wilhelm-Epstein-Strasse 14, 60431 Frankfurt am Main,
Postfach 10 06 02, 60006 Frankfurt am Main

Tel +49 69 95 66-1
Telex within Germany 4 1 227, telex from abroad 4 14 431, fax +49 69 5 60 10 71

Please address all orders in writing to: Deutsche Bundesbank,
Press and Public Relations Division, at the above address or via fax No. +49 69 95 66-30 77

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Abstract

In this paper we propose a generalisation of the noise trader transmission mechanism to examine the impact of central bank intervention on exchange rates. Within a heterogeneous expectations exchange rate model intervention operations are supposed to provide support to either chartist or fundamentalist forecasts, which forces portfolio managers to adjust their foreign currency positions. The empirical examination of the hypothesis is done by applying a markov regime-switching approach to daily US-dollar/DEM forward rates and intervention data of the Deutsche Bundesbank and the Federal Reserve from 1979 to 1992. It is shown that the performance of simple chartist trading rules was strong whenever these central banks intervened on the foreign exchange market. A similar coincidence cannot be found within the more sophisticated fundamentalist approach.

JEL classification: F31, C32, E58, G15

Keywords: exchange rates, intervention, regime-switching

Zusammenfassung

Die vorliegende Arbeit schlägt eine Verallgemeinerung des Noise-Trader-Transmissionsmechanismus vor. Damit sollen die Auswirkungen von Zentralbankinterventionen auf die Wechselkurse untersucht werden. Im Rahmen eines Wechselkursmodells mit heterogenen Erwartungen dürften Interventionen Prognosen stützen, die entweder auf der Chartanalyse oder der Analyse der Fundamentaldaten beruhen. Dies zwingt Portfoliomanager, ihre Fremdwährungspositionen anzupassen. Die empirische Untersuchung der Hypothese erfolgt durch Anwendung eines Markov-Switching-Ansatzes auf die täglichen US-Dollar/DEM-Terminkurse und Interventionsdaten der Deutschen Bundesbank und der Federal Reserve von 1979 bis 1992. Es zeigt sich, dass sich einfache auf der Chartanalyse beruhende Regeln dann bewährt haben, wenn diese Zentralbanken am Devisenmarkt intervenierten. Ein ähnlicher Zusammenhang kann bei einem Ansatz, der sich auf Fundamentalüberlegungen stützt, nicht nachgewiesen werden.

JEL-Klassifikation: F31, C32, E58, G15

Stichwörter: Wechselkurse, Intervention, Regime-Switching

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1. Introduction

The concerted and unilateral intervention carried out to stop the depreciation of the Euro again revealed central bank's persuasion that buying and selling foreign currency was an effective policy tool in order to influence exchange rates. Especially in the mid 1980s, when the US dollar was perceived to be overvalued against other major currencies, the G5 and G7 meetings decided that co-ordinated multilateral policies were necessary to depreciate the US dollar and to restore equilibrium in current account balances.[1] In addition, central bank intervention should be employed to 'calm disorderly markets' or support other central banks in their foreign exchange market operations. Beyond the question whether exchange rates should be a target of economic policy, it remains unclear why intervention – typically sterilized – affects exchange rates (Sarno and Taylor, 2001). The portfolio balance approach stresses the fact that central bank intervention changes the relative supply of outstanding domestic and foreign bonds. As long as domestic and foreign assets are imperfect substitutes, intervention will affect the risk premium and subsequent portfolio reallocations change the exchange rates.[2] In the signalling channel proposed by Mussa (1981) intervention is supposed to reveal information about the future path of monetary policy inducing expectation revisions and a revaluation of exchange rates. Of course, in this scenario intervention has to be perceived by market participants, so only reported activity can be examined.[3] The noise trading hypothesis of Hung (1997) assumes that there are at least some chartists in the foreign exchange market and the impact of well-designed and secretly conducted intervention operations on exchange rates can be magnified by altering their trading positions. While stressing the role of noise traders for the effectiveness of intervention, only little is said about trading based on exchange rate fundamentals. The model implicitly assumes that the influence of either trading strategy on excess demand for foreign currency remains constant over time, so that the impact of intervention operations depends on the policy goals of the conducting central bank alone.

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1 Schwartz (2000) reviews the record of central bank intervention since 1973.

2 The so-called portfolio balance channel is examined by Dominguez and Frankel (1993a) and Baillie and Osterberg (1997a).

3. Kaminsky and Lewis (1996) provide an empirical investigation of the signalling channel. Although they found that intervention contains useful information to predict future monetary policy, the signals were of the wrong sign on average.

This paper contributes to the noise trading channel hypothesis by allowing intervention to influence the forecasting success of both chartist and fundamentalists, thereby altering the weight of the two groups in the foreign exchange market. As stated in Dooley and Shafer (1983) intervention operations may introduce trends into the evolution of exchange rates that can be exploited by means of chartist forecasting techniques. LeBaron (1999) provided support for this argumentation showing that the profitability of a simple trading rule based on moving averages was magnified whenever the Federal Reserve intervened on the foreign exchange market. Neely and Weller (2001) stressed that these excess returns are not due to the predictive power of the intervention signal itself, but result from strengthening chartists ability to identify empirical regularities in the exchange rate history. Apart from providing the rationale for the application of trading rules, intervention may as well improve the performance of expectations based on fundamentals, especially when central banks try to correct current exchange rate misalignments. As is documented in micro survey studies chartist and fundamentalist techniques are used depending on whether short term or long term forecasts are to be made (Dominguez, 1986; Allen and Taylor, 1989).

To allow for different forecasting strategies the impact of central bank intervention is investigated applying a heterogeneous expectations exchange rate model. Following Frankel and Froot (1986) the excess demand for foreign currency is assumed to be a function of the relative success of chartist and fundamentalist forecasting techniques. As is stated above the performance of chartist or fundamentalist predictions is expected to be temporarily improved by central bank intervention – thereby altering the time series properties of exchange rates. The empirical examination of the hypothesis is done by applying the Markov regime-switching approach originally proposed by Hamilton (1989) to daily Deutsche Bundesbank and Federal Reserve intervention data from 1979 to 1992. Considering the results of Neely and Weller (2001) intervention data is used only to construct a dummy variable distinguishing between intervention and no-intervention periods. Statistically significant estimates of dummy coefficients lead to the conclusion that an impact of central bank intervention on exchange rate expectation cannot be rejected. Furthermore, we re-examine the effects of intervention on exchange rate volatility, where empirical work has reported quite mixed results.[4] The parameter estimates of the Markov switching model suggest that the inconclusive evidence is due to a regime dependent correlation between the intervention and volatility.

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4 Dominguez (1998) estimates GARCH(1,1) models and shows that overt intervention was able to reduce volatility in certain periods. But in general, intervention seemed to have an increasing effect on the conditional variance of exchange rate changes (Baillie and Osterberg, 1997b).

The rest of the paper is organized as follows. We next outline the intervention augmented heterogeneous expectation exchange rate model and its corresponding regime-switching specification. Section 3 reports and discusses the estimation results and the test statistics. Section 4 provides the conclusions of the paper.

2. Central bank interventions in a heterogeneous expectation exchange rate model

In the standard chartist and fundamentalist (c&f) model originally suggested by Frankel and Froot (1986) the (log of the) exchange rate e_t is driven by the decisions of portfolio managers. They buy and sell foreign currency in response to changes in the expected rate of appreciation $E_t[\Delta e_{t+1}]$ and a set of contemporaneous variables included in a vector $\mathbf{z}_t$. Thus, the exchange rate can be written as:

$$e_t = aE_t[\Delta e_{t+1}] + \mathbf{b}\mathbf{z}_t, \qquad (1)$$

where the vector of elasticities of the contemporaneous variables (**b**) and the elasticity of exchange rate expectation (a) should be constant over time. Under the rational expectations hypothesis equation (1) has the well known forward looking solution that e_t is the weighted sum of current and expected future market fundamentals. In contrast to this, Frankel and Froot (1986) assumed that portfolio managers generate their exchange rate expectations using a mixture of chartist $E_t^c[\Delta e_{t+1}]$ and fundamentalist $E_t^f[\Delta e_{t+1}]$ forecasts:

$$E_t[\Delta e_{t+1}] = \omega_t E_t^f[\Delta e_{t+1}] + (1-\omega_t)E_t^c[\Delta e_{t+1}]. \qquad (2)$$

The parameter ω_t, denoting the weight given to fundamentalist views at date t, is dynamically updated by the portfolio managers in a rational Bayesian manner:

$$\Delta\omega_t = \delta\left(\omega_{t-1}^* - \omega_{t-1}\right) \qquad (3)$$

with:

$$\omega_{t-1}^* = \frac{\Delta e_t - E_{t-1}^c[\Delta e_t]}{E_{t-1}^f[\Delta e_t] - E_{t-1}^c[\Delta e_t]},$$

where ω_{t-1}^* is the ex post calculated weight that must have been assigned to fundamentalist forecast in order to predict the current exchange rate change accurately. The value of δ

reflects the extent to which portfolio managers enclose new information in this adaptive process and proves responsible for the exchange rate dynamics. Since portfolio managers always maintain a positive weight for both chartist and fundamentalist forecasts, $\Delta\omega$ has to be restricted so that ω stays in the range between 0 and 1. To make sure that the empirical analysis remains tractable, another feedback rule is introduced. Similar to Lewis (1989), portfolio managers are supposed to optimize the weight assigned to fundamentalist forecasts by means of a Bayesian learning process:

$$\omega_t = \frac{\omega_{t-1} \cdot \varphi_f\left(\Delta e_t \middle| E^f_{t-1}[\Delta e_t]\right)}{\omega_{t-1} \cdot \varphi_f\left(\Delta e_t \middle| E^f_{t-1}[\Delta e_t]\right) + \omega_{t-1} \cdot \varphi_c\left(\Delta e_t \middle| E^c_{t-1}[\Delta e_t]\right)} \qquad (3')$$

where $\varphi_c\left(\Delta e_t \middle| E^c_{t-1}[\Delta e_t]\right)$ and $\varphi_f\left(\Delta e_t \middle| E^f_{t-1}[\Delta e_t]\right)$ are the density functions of Δe_t conditional on the forecasts of chartists and fundamentalists, respectively.

Concerning the expectation formation fundamentalists have in mind some kind of long-run equilibrium $\tilde{e}_t$, to which the exchange rate reverts with a given speed θ over time, i.e.

$$E^f_t[\Delta e_{t+1}] = \theta(\tilde{e}_t - e_t) \qquad (4)$$

This can be explained by the fact that agents have different beliefs about the equilibrium value of the exchange rate, which is certainly not observable. Kilian and Taylor (2001) conclude that the heterogeneity of beliefs will diminish when the exchange rate becomes increasingly overvalued and the supply of foreign exchange should rise. According to (4) fundamentalist expectation can be viewed as distributed symmetrically around $\tilde{e}_t$. We assume that the fundamental value $\tilde{e}_t$ can be described by purchasing power parity (ppp). Takagi (1991) provides evidence from survey data that foreign exchange market participants accept ppp as a valid relationship only in the long run implying low values for θ. This view is recently supported by Taylor and Peel (2000) and Taylor et al. (2001) showing that due to its nonlinear dynamics the exchange rate reverts to the ppp level, but only in the long run. Furthermore, ppp as a measure of the fundamental exchange rate $\tilde{e}_t$ seems to be suitable for the investigation of central bank intervention, because monetary authorities have used it as a target level (Dominguez and Frankel, 1993b). Within this framework, central bank operations on foreign exchange markets can be called effective, if the adjustment of the exchange rate to its long run equilibrium is accelerated. This implies that the observed reversion of the exchange rate to purchasing power – denoted by ζ - is

driven by both fundamentalist speculation and central bank intervention. Denoting the influence of intervention by δ_θ, we can formulate ζ as a function of a 0,1-intervention dummy I_t as follows:

$$\zeta_t = \theta + \delta_\theta I_t \,, \quad \theta, \delta_\theta > 0 \,. \tag{5}$$

Chartists are defined as market participants who believe that exchange rate time series exhibit regularities which can be detected by a wide range of so-called technical trading rules. To reduce the impact of data snooping biases brought on by searching for the best performer we employ a very simple type of trading rule following common practice (Takagi, 1991). Excess returns of moving average (MA) trading rules of daily U.S. dollar quotes for the DM, yen, pound sterling and swiss franc is reported in Neely (1997) and LeBaron (1999). Lee et al. (2001) found MA trading rule profitability for Latin American currencies applying out of sample-tests. These studies show that the length of the short run and long run moving average don't have much influence on the trading rule profitability. To be concrete, chartists are supposed to expect that a future exchange rate increase is predicted by the proportion ψ of the positive difference between the 14 day moving average (ma_{14}) and 200 day moving average (ma_{200}) and vice versa. Hence, their exchange rate expectation at date t is $E_t^c[\Delta e_{t+1}] = \psi(ma_{14,t} - ma_{200,t})$.

As is stated in the noise trader hypothesis of intervention (Hung, 1997), a leaning against the wind-strategy of central banks may introduce trends into exchange rate dynamics. Subsequent changes in noise trader's positions magnify the initial impact of intervention operations. We assume that these kind of trend establishing intervention can be formalized by means of a moving average specification very similar to speculation based on chartist analysis. This implies that a given trend in the exchange rate (η) is due to both chartist speculation and central bank intervention. Denoting the influence of intervention by δ_ψ, we can formulate η as a function of the intervention dummy I_t as follows:

$$\eta_t = \psi + \delta_\psi I_t \,, \quad \psi, \delta_\psi > 0 \,. \tag{6}$$

Of course, neither the chartists, the fundamentalists, nor the portfolio managers have rational expectations about the future exchange rates. Within the model agents could do a better job in expected value terms, if they knew the complete model. But as long as market participants try to compensate the lack of a verified exchange rate model with different forecasting techniques, the imposed informational restrictions are a realistic description of the foreign exchange market.

In order to confront the c&f-model with exchange rate data, the econometric approach should be able to describe the conditional distribution of the exchange rate change by a mixture of (normal) distributions. As is stated in Clarida et al. (2001) the Markov regime-switching model suggested by Engel and Hamilton (1990) and developed further by, among others, Engel (1994), Vigfusson (1997) and Dewachter (2001) is a natural candidate to characterize exchange rate behavior. In our model, the conditional mean μ_t and the conditional variance h_t of exchange rate changes Δe_t are allowed to follow two different regimes – a chartist and a fundamentalist regime - indicated by an unobservable state variable S_t. The regime indicator S_t is parameterised as a first-order Markov process and the switching or transition probabilities P and Q have the typical Markov structure:

$$\begin{aligned} &\Pr[S_t = 0 \mid S_{t-1} = 0] = P \\ &\Pr[S_t = 1 \mid S_{t-1} = 0] = (1-P) \\ &\Pr[S_t = 1 \mid S_{t-1} = 1] = Q \\ &\Pr[S_t = 0 \mid S_{t-1} = 1] = (1-Q). \end{aligned} \tag{7}$$

Thus, under conditional normality, an observed realisation Δe_t is presumed to be drawn from a $N(\mu_{0t}, h_{0t})$ distribution if $S_t = 0$, whereas Δe_t is distributed $N(\mu_{1t}, h_{1t})$ if $S_t = 1$. The evolution of the log first differences of exchange rates can therefore be written as

$$\Delta e_t = \mu_{0t}(1 - S_t) + \mu_{1t} S_t + \sqrt{h_{0t}(1 - S_t) + h_{1t} S_t} \cdot \varepsilon_t, \tag{8}$$

where ε_t is an i.i.d. standard normal variable. The parameter estimation of the mean (μ_t) and variance (h_t) equations in the regime switching model are derived from maximisation of the log-likelihood function

$$\begin{aligned} L = \sum_{t=1}^{T} \log \Bigg[& p_{1t} \frac{1}{\sqrt{2\pi h_{1t}}} \exp\left\{ \frac{-(\Delta e_t - \mu_{1t})^2}{2h_{1t}} \right\} \\ & + (1 - p_{1t}) \frac{1}{\sqrt{2\pi h_{2t}}} \exp\left\{ \frac{-(\Delta e_t - \mu_{2t})^2}{2h_{2t}} \right\} \Bigg]. \end{aligned} \tag{9}$$

$p_{1t} = \Pr(S_t = 1 \mid \Phi_{t-1})$ is the probability that the analyzed process is in regime 1 at time t and is updated by means of Bayesian inference using information available at time t - 1. Therefore, p_{1t} and (1 - p_{1t}) can be regarded as weights assigned to regime dependent forecasts resulting from a rational learning process as outlined in the theoretical exchange rate model.

For comparison purposes, we first specify the mean equations without taking into account foreign exchange market activities of central banks. However, the important results of the

study are derived from mean equations that include intervention dummies as it is done in the second specification.

(1) The standard regime-switching-c&f model: RS-CF

The mean equation of the first regime represents the fundamentalist regime including the deviation of the exchange rate from its fundamental value $\tilde{e}_t$ described by purchasing power parity as outlined above. The second regime's mean equation contains chartist expectations, i.e. the moving average trading consisting of the difference between ma_{14} and ma_{200}:

$$\mu_{0t} = \theta(ppp_{t-1} - e_{t-1})$$
$$\mu_{1t} = \psi(ma_{14,t-1} - ma_{200,t-1}).$$

The variance of Δe_t, i.e. the volatility of e_t, is assumed to be constant within regimes, $h_{0t} = \sigma_F^2$ and $h_{1t} = \sigma_C^2$, so that the only source of conditional heteroskedasticity is the regime-switching behavior.

(2) The intervention augmented regime-switching-c&f model: RS-CF-Int

To introduce intervention operations into the regime-switching framework, we define that the dummy variable $I_t = 1$, if the central bank intervenes at time t and $I_t = 0$, otherwise and rewrite the mean equations of the standard c&f model as follows:

$$\mu_{0t} = \zeta_t (ppp_{t-1} - e_{t-1}), \quad \text{with } \zeta_t = \theta + \delta_\theta I_t$$
$$\mu_{1t} = \eta_t (ma_{14,t-1} - ma_{200,t-1}), \quad \text{with } \eta_t = \psi + \delta_\psi I_t$$

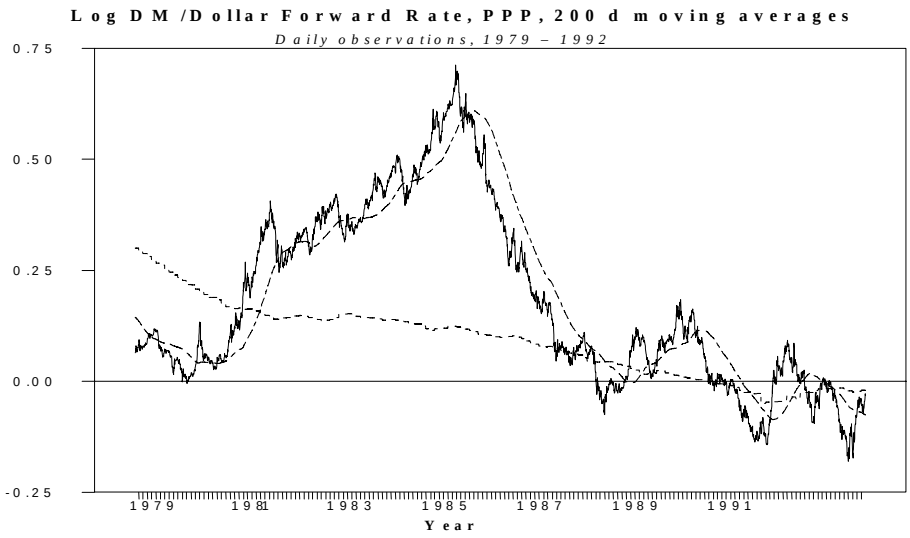
As long as interventions do not occur, i.e. $I_t = 0$, this more general formulation boils down to the standard RS-CF model. More interestingly, if the foreign exchange intervention of the central bank had an impact on the forecasting performance of chartists and fundamentalists, a change of coefficients represented by significant estimates of the various δs should be observed. By introducing intervention dummies in the specification of second moments, $h_{0t} = \sigma_F^2 + \delta_{\sigma_F^2} \cdot I_t$ and $h_{1t} = \sigma_C^2 + \delta_{\sigma_C^2} \cdot I_t$, we are able to re-examine the relationship between central bank intervention and exchange rate volatility, where the existing literature provided mixed evidence (Baillie and Osterberg,1997b and Dominguez, 1998).

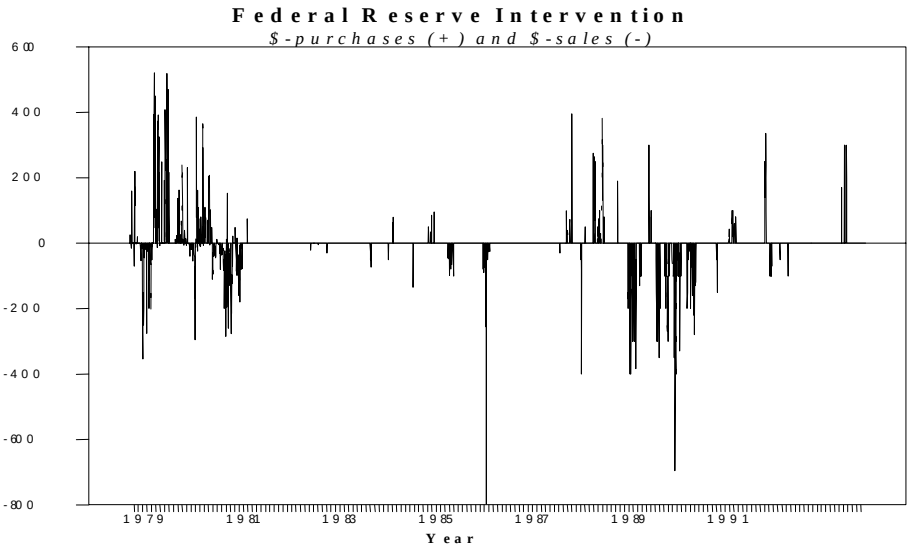
3. Empirical Results

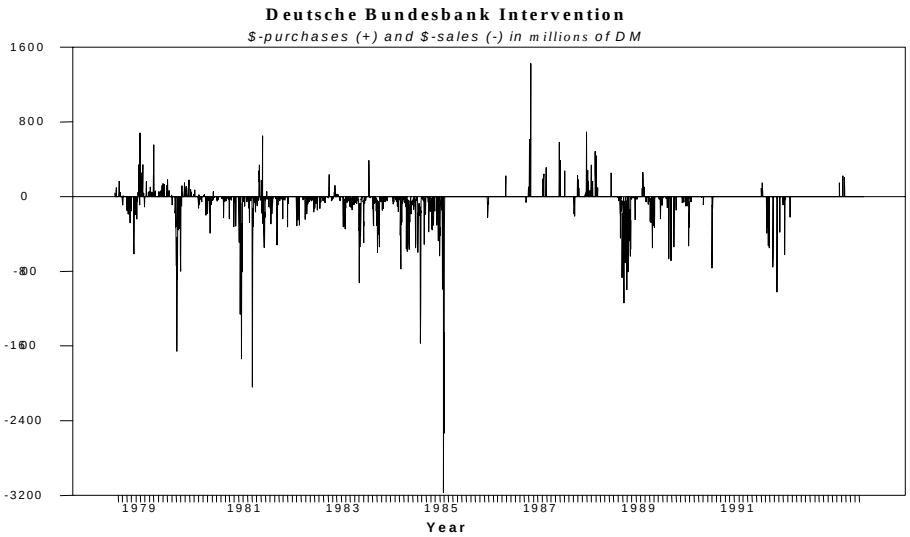
The models described above were estimated by maximum likelihood. Parameter estimates were obtained using the BFGS algorithm, and the reported t-statistics are based on heteroskedastic-consistent standard errors (White, 1982). The estimates are derived from the daily DEM/US-Dollar forward exchange rate series kindly supplied by the Deutsche Bundesbank. The purchasing power parity was constructed using monthly observed consumer price indices. The intervention dummy series is based on intervention data from the Deutsche Bundesbank and the Federal Reserve Bank.[5] The Fed intervention series only includes active trades made by the Federal Reserve for reasons of influencing foreign exchange rates. Purchases and sales of the Deutsche Bundesbank are reported whenever they changed their net foreign assets. The sample extends from January 1979 to December 1992. The series of the forward exchange rate, the PPP relation and the 200 day moving average are presented in upper graph, the Federal Reserve purchases and sales of Dollars against DEM can be found in the middle graph, and the Deutsche Bundesbank purchases and sales of Dollars against DEM in the lower graph of Figure 1.

5 I am grateful to Blake LeBaron for making intervention data available to me.

Fig. 1: DM/$ forward rate, PPP, 200 d moving averages and Central Bank Intervention







As can be seen in the lower graphs intervention of both the Federal Reserve and the Deutsche Bundesbank were sporadic and clustered. The fraction of trading days that intervention is going on is 0.134 and 0.249. The average intervention of the Federal Reserve was –2.1 million dollars indicating that buying and selling has been relatively balanced. In contrast, the Deutsche Bundesbank has sold dollars in this period, the average intervention was –26.56 million DEM. Conditional on the intervention occurring the mean absolute value of purchases or sales is 112.1 million dollars (Federal Reserve) and 158,3 million DEM (Deutsche Bundesbank), respectively.

Table 1 contains the estimates of both the RS-CF and the RS-CF-Int models. As regards the transition probabilities, the models differ slightly at best. P and Q range above 0.95 thereby indicating high persistence of regimes. The unconditional probability of the fundamentalist regimes $\overline{P} = \frac{1-Q}{2-P-Q}$ is lower than the one assigned to chartist regimes. This is also reflected in the expected duration of regimes. The (first) fundamentalist regimes are expected to last up to 33 trading days whereas the (second) chartist regimes have a longer duration of at least 34 trading days. Significant estimates of variances point to regime dependent heteroskedasticity capturing periods of high and low volatility: The second moment in the second regimes is three times as high as the variance in the first regimes. The estimates of chartist and fundamentalist coefficients ψ and θ are statistically significant and of the correct sign.

Table 1

Parameter estimates of regime-switching models for the Dollar/DM forward exchange rate (1979 – 1992)

	RS-CF	RS-CF-Int (FED)	RS-CF-Int (BBK)	RS-CF-Int (concerted)
θ	$2.95 \cdot 10^{-3}$ (2.15)**	$2.43 \cdot 10^{-3}$ (1.81)*	$4.72 \cdot 10^{-3}$ (3.41)***	$2.66 \cdot 10^{-3}$ (1.73)*
δ_θ		$9.38 \cdot 10^{-3}$ (0.76)	$-5.75 \cdot 10^{-3}$ (1.27)	$1.04 \cdot 10^{-2}$ (0.62)
ψ	$8.02 \cdot 10^{-3}$ (3.15)***	$4.98 \cdot 10^{-3}$ (1.72)*	$1.99 \cdot 10^{-4}$ (0.06)	$5.91 \cdot 10^{-3}$ (2.40)**
δ_ψ		$3.69 \cdot 10^{-2}$ (2.87)***	$3.17 \cdot 10^{-2}$ (5.46)***	$5.84 \cdot 10^{-2}$ (2.99)***
σ_F^2	$8.89 \cdot 10^{-5}$ (13.76)***	$8.25 \cdot 10^{-5}$ (13.57)***	$8.17 \cdot 10^{-5}$ (9.60)***	$8.48 \cdot 10^{-5}$ (10.19)***
$\delta_{\sigma_F^2}$		$8.16 \cdot 10^{-5}$ (2.52)**	$2.45 \cdot 10^{-5}$ (1.44)	$8.41 \cdot 10^{-5}$ (3.31)**
σ_C^2	$2.27 \cdot 10^{-5}$ (11.13)***	$2.31 \cdot 10^{-5}$ (10.07)***	$1.99 \cdot 10^{-5}$ (6.92)***	$2.22 \cdot 10^{-5}$ (8.99)***
$\delta_{\sigma_C^2}$		$1.47 \cdot 10^{-6}$ (0.42)	$5.39 \cdot 10^{-6}$ (2.16)**	$8.46 \cdot 10^{-6}$ (1.64)
P	0.9697 (139.70)***	0.9690 (111.75)***	0.9684 (104.13)***	0.9689 (114.17)***
Q	0.9741 (151.53)***	0.9753 (137.67)***	0.9708 (116.31)***	0.9742 (144.22)***
$\overline{P}$	0.46	0.44	0.48	0.45
$\overline{Q}$	0.54	0.56	0.52	0.55
$(1-P)^{-1}$	33	32.26	31.65	32.15
$(1-Q)^{-1}$	38.61	40.49	34.25	38.76
Log-Likelih.	13029.27	13054.42	13056.90	13054.64
LRT		50.29 ***	55.26 ***	50.88 ***

Notes: The sample contains daily observations of the DM/Dollar forward exchange rate from January 1979 to December 1992. See text for meaning of symbols. t-statistics in parentheses are based on heteroskedastic-consistent standard errors. The likelihood ratio test statistic is asymptotically χ^2 (df)-distributed with df indicating the numbers of restrictions. *, ** and *** denotes significance at the 90%,95% and 99% level, respectively.

Table 2 reports Ljung-Box Q-statistics relating to the residuals as well as to the squared standardised residuals of the estimated models thereby testing for serial correlation and autoregressive conditional heteroskedasticity. The figures show that the model is able to capture the mean dynamics as well as conditional heteroskedasticity of short term exchange rates by regime-switching, and it can be concluded that the intervention augmented c&f model does a good job in modelling the DM/US-Dollar forward rate.[6]

Table 2
Specification Tests (Ljung-Box Q-Statistic)

	RS-CF	RS-CF-Int (FED)	RS-CF-Int (BBK)	RS-CF-Int (Concerted)
AR(1)	0.67 (0.41)	0.58 (0.45)	1.32 (0.25)	0.70 (0.40)
AR(2)	0.71 (0.70)	0.63 (0.73)	1.38 (0.50)	0.73 (0.70)
AR(3)	4.61 (0.20)	4.55 (0.21)	5.17 (0.15)	4.94 (0.18)
AR(4)	7.38 (0.12)	7.19 (0.13)	7.37 (0.12)	7.59 (0.11)
AR(5)	9.25 (0.10)	9.20 (0.10)	8.69 (0.12)	9.58 (0.09)
ARCH(1)	0.12 (0.73)	0.42 (0.51)	0.01 (0.91)	0.28 (0.60)
ARCH(2)	0.21 (0.90)	0.93 (0.63)	0.09 (0.96)	1.07 (0.58)
ARCH(3)	2.52 (0.47)	2.37 (0.50)	2.50 (0.47)	2.67 (0.45)
ARCH(4)	6.54 (0.16)	5.93 (0.20)	6.27 (0.18)	4.26 (0.37)
ARCH(5)	6.54 (0.26)	5.97 (0.31)	6.30 (0.28)	4.31 (0.51)

Notes: AR(p) denotes the Ljung-Box statistic for serial correlation of the residuals out to p lags. ARCH(q) denotes the Ljung-Box statistic for serial correlation of the standardized squared residuals out to q lags. p-values are in parentheses.

However, the most important results from these Markov switching procedures are significant parameter estimates of chartist and fundamentalist forecasting techniques within the heterogeneous expectations framework. As has been outlined in the theoretical section of the paper, central bank interventions are supposed to affect exchange rates by influencing chartist and fundamentalist forecasting success. Because the standard RS-CF model is nested in the more general RS-CF-Int model, the hypothesis can be examined by the values of the log-likelihood functions, the likelihood ratio test (LRT) statistic and the estimates of the various δs in Table 1.

6 The regime classification might be driven by state-dependent heteroskedasticity, which is often explained by the dominance of second moments in characterizing the distribution of high frequency data. Therefore, we first tested a four state regime switching model allowing for independent switches in means and variances, but the EM algorithm did not converge. Second, both the chartist and the fundamentalist parameters were included in each regime to control for the correct assignment of mean specifications to high and low variance regimes. The fundamentalist forecast in the low volatility regime as well as the chartist forecast in the high volatility regime were insignificant at common levels, leading us to the specifications reported in the text. The results are available on request.

As the LRT statistic suggests, the consideration of intervention dummies explain a significant improvement in the log-likelihood function. Hence, the hypothesis that exchange rate expectations are not affected by central bank interventions has to be rejected. Particularly, the results of parameter estimates give rise to the conclusion that foreign exchange activities of the Federal Reserve as well as the Deutsche Bundesbank could have supported moving average trading rules. The dummy coefficient δ_ψ for both central banks is highly significant and reports a large increase of η whenever $I_t = 1$. However, the predictive ability of these rules can only be confined completely to periods of central bank activity in the case of the Deutsche Bundesbank. When looking at the link between central bank intervention and fundamentalist exchange rate expectations, we recognize no significant change of ζ. This implies that the adjustment of the exchange rate to its long run equilibrium has not been accelerated in periods when both fundamentalists dominated the market and central banks intervene. The results remain valid, when concerted intervention are considered. The corresponding intervention augmented c & f model in the last column of table 1 show no significant departure from the parameter estimates of unilateral intervention. Given that fundamentalists dominate the foreign exchange market, a contemporary intervention of the Deutsche Bundesbank has not lend much support to a given Federal Reserve activity trying to correct current misalignments and vice versa.

Of course, the fact that the chartist intervention dummy δ_ψ is statistically significant whereas the fundamentalist intervention dummy is not, might be due to an asymmetric distribution of intervention across regimes. If - by chance - only a small number of intervention occurs within the fundamentalist regime, an insignificant intervention dummy is inevitable. Therefore, we report the distribution of both unilateral intervention and concerted intervention in table 3.

Table 3
The number of intervention within chartist and fundamentalist regimes

	Total number of intervention	Intervention within chartist regimes	Intervention within fund. Regimes
Federal Reserve	476	71,6% (58,4%)	28,4% (41,6%)
Deutsche Bundesbank	913	62,0% (53,5%)	38,0% (46,5%)
Concerted	242	67,4% (57,3%)	32,6% (42,7%)

Notes: Intervention within chartist and fundamentalist regimes are fractions of the total number of intervention of the Federal Reserve, the Deutsche Bundesbank, and concerted intervention, respectively. Fractions of chartist and fundamentalist dominated regimes are in parentheses.

A benchmark is constructed assuming that central bank intervention is equally distributed across regimes. In this case, the assigned fraction of intervention to either regime should be equal to the relative number of regimes itself as it is reported in the parentheses. Indeed, compared to this benchmark the figures indicate more operations carried out within the

chartist regime than in the fundamentalist regime for all types of intervention. But the number of intervention within the fundamentalist regime are in any case large enough to constitute a statistically significant estimate of the fundamentalist intervention dummy.

However, the results must be interpreted cautiously. Before quickly concluding that the contributions of the Federal Reserve and the Deutsche Bundesbank to bring back exchange rates to the ppp level are deniable, a particular property of the model has to be considered: Due to the construction of chartist and fundamentalist expectations, forecasts of equal sign are generated, when the exchange rate reverts to it's equilibrium value. Obviously, central banks could also made use of the noise trader channel and provided support to chartist speculation when the exchange rate already moved into the 'right' direction. If this is the empirically relevant case, we would expect only a small number of intervention operations within the chartist regime whenever the exchange rate deviates from ppp. Therefore, table 4 reports the number of operations in chartist dominated periods depending on the direction of the corresponding exchange rate change.

Table 4
The number of intervention within chartist regimes

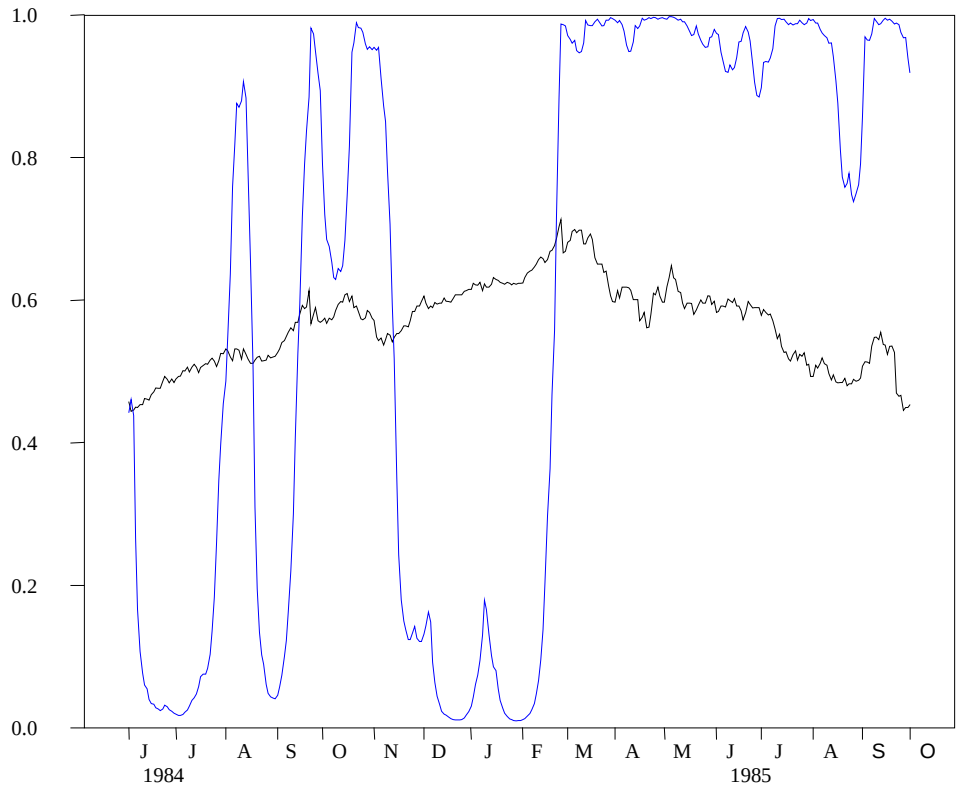
	Total number of intervention in chartist regimes	**Number of Intervention when the exchange rate deviates from ppp**	**Number of Intervention when the exchange rate approaches ppp**
Federal Reserve	341	188	153
Deutsche Bundesbank	566	339	227
Concerted	163	99	64

The table shows that the number of intervention operations are in any case higher in ‘deviating’ periods than in ‘approaching’ periods lending no support to the view that the Federal Reserve or the Deutsche Bundesbank might have systematically used the noise trader channel of intervention. In contrast, if the impact of an intervention on exchange rate is magnified by chartist activities, an overall destabilizing influence is not rejected by the distribution of operations across regimes.

The empirical results presented so far can be examined in more detail by means of the following case study. In figure 2 the log of the exchange rate is plotted together with the smoothed fundamentalist regime probabilities from July 1984 to September 1985. High smoothed regime probabilities imply that the foreign exchange market relies on

fundamentalist techniques to forecast exchange rates whereas low values indicate a preference for chartist forecasts.

Fig. 2: Log DM/$ forward rate and smoothed fundamentalist regime probabilities



In line with the theoretical considerations, the increase of the dollar was driven by chartist expectations, temporary interrupted in periods of fundamentalist dominance. The upward trend is reversed in March 1985, when market participants became aware that the Dollar was overvalued and applied fundamentalist forecasts for several month. As can be seen from figure 1, the Deutsche Bundesbank as well as the Federal Reserve terminated their operations at the end of the upward trend. Since central bank intervention was associated with a deviating exchange rate, the model can only identify support for chartist expectations. Conversely, intervention operations are interpreted as incapable to bring back the exchange rate to the ppp value in the mid 1980s.

In the case of Federal Reserve intervention, the intervention dummy identifies fundamentalist dominated periods in which the exchange rate volatility is estimated nearly twice as high. The statistically significant coefficient $\delta_{\sigma_F^2}$ indicates an important structural break in the volatility of the fundamentalist regime. In contrast, if there is any change in

volatility within the chartist regime, then it is obviously not correlated with central bank intervention. In the case of Deutsche Bundesbank intervention, the dummy identifies a structural break in the volatility of the chartist regime, but not in the fundamentalist regime. Again, parameter estimates are not changed very much, when concerted intervention are considered. These result can be interpreted to be in favour of the heterogeneous expectation approach. The finding that the correlation between exchange rate volatility and central bank intervention is strongly regime dependent may explain the mixed evidence reported from conventional single regime frameworks.

Following the theoretical considerations in section 2, intervention operations supporting chartists or fundamentalists supposedly force the market to alter the weight assigned to either forecasting strategy, which should be reflected in time varying transition probabilities. Therefore, a natural extension of the econometric model is to specify the transition probabilities as functions of central bank intervention. However, estimated dummy coefficients are not statistically significant implying that an impact of intervention on transition probabilities has to be rejected.[7]

4. Conclusion

Although there is evidence that monetary authorities tried to avoid misalignments and counter 'disorderly markets', the impact of central bank intervention on foreign exchange rates repeatedly turned out to be low when assessed by means of conventional single regime approaches. It becomes even more difficult to imagine a rational expectations model capable of explaining these results, when taking into account that intervention seems to increase the profitability of technical trading rules (LeBaron, 1999). On the basis of the theoretical heterogeneous expectation framework, a generalisation of Hung's (1997) noise trading channel is estimated by means of an intervention augmented two state Markov regime-switching model. We show that the predictive power of simple chartist forecasting techniques was enhanced whenever the Federal Reserve or the Deutsche Bundesbank intervened on the foreign exchange market, whereas the more sophisticated fundamentalist approach approximated by the deviation of the current exchange rate from the ppp level was not strengthened in these periods. However, intervention seems not to had an influence on the weight assigned to either forecasting strategy.

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7 The impact has been examined using different lags of the dummy as well as the intervention data itself. The results are available from the author on request.

If chartist analysis tends to be destabilizing as is widely accepted in the literature, a volatility enhancing impact of central bank intervention on exchange rates cannot be ruled out. This is confirmed by the finding that the intervention dummy identified periods in which the volatility is nearly doubled. Of course, we have to address a serious causality problem: Before quickly concluding that exchange rate volatility is due to intervention operations, ‘disorderly markets’, i.e. high volatility, may have challenged central bank activities. But as long as this reverse causality is not confirmed, central bank intervention remains an ambiguous policy tool in influencing exchange rates.

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