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The Effectiveness of Central Bank Intervention in the EMS: The Post 1993 Experience

Peter Brandner, Harald Grech, Helmut Stix

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Editorial

In this paper Peter Brandner, Harald Grech and Helmut Stix analyze the effectiveness of intervention in the European Monetary System by using data on the D-mark-intervention activity of six European central banks, covering the period from August 1993 to April 1998. The estimation results of EGARCH and three regime MS-ARCH models show that interventions had mixed effects on the conditional means and variances. Given their approaches (EGARCH and MS-ARCH), the authors conclude that there does not seem to be a systematic and predictable impact of mark-intervention on the level and volatility of the six exchange rates.

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The Effectiveness of Central Bank Intervention in the EMS: The Post 1993 Experience*

Peter Brandner
Austrian Institute of Economic Research, P.O. Box 91, A-1103 Vienna, Austria

Harald Grech
Oesterreichische Nationalbank, Economic Studies Division, P.O. Box 61, A-1011 Vienna, Austria

Helmut Stix
Oesterreichische Nationalbank, Economic Studies Division, P.O. Box 61, A-1011 Vienna, Austria

Abstract

We analyze the effectiveness of intervention in the European Monetary System by using daily data on the DEM-intervention activity of six European central banks, covering the period from August 1993 to April 1998. To test for the influence of intervention we apply EGARCH models. To allow for regime specific intervention effects we also estimate Markov Switching autoregressive conditional heteroscedasticity models.

The results from the EGARCH models show that interventions influenced the conditional mean in only one case. Both volatility increasing and decreasing effects are found for the conditional variance. In the MS-ARCH model more effects on the mean are found. If significant, intervention tends to affect the level of the six ERM I exchange rates only in periods of low and medium volatility. For the conditional variance more volatility decreasing than increasing effects are found. Overall, given our approaches (EGARCH and MS-ARCH), the results show that even in the same institutional framework, intervention does not seem to affect the means and variances in a consistent and predictable manner.

JEL-Code: E58, F31, F33

Keywords: Foreign Exchange Intervention, European Monetary System, EGARCH, Markov Switching ARCH

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1 Introduction

Monetary authorities use intervention in the foreign exchange market mainly for two reasons: first to influence the level of exchange rates and second to "smooth disorderly markets". Whether intervention has been effective at achieving the desired goals has been a subject of heated debate. To contribute to this discussion this paper provides new evidence about the effectiveness of central bank intervention. While most of the empirical literature deals with intervention in floating exchange rate regimes this paper provides results about the effectiveness of central bank intervention in a target zone, in particular the European Monetary System (EMS) from August 1993 to April 1998.[1]

Empirical results for floating exchange rate regimes—mostly focusing on the exchange rate relations between the US Dollar (USD), the Deutsche Mark (DEM) and the Japanese Yen (JPY)—provide only meager support for significant effects of interventions on the first and second moments.[2] Furthermore, if there are any significant effects at all, empirical findings based on survey data and econometric evidence demonstrate that intervention rather increases than decreases volatility.[3] Anyway, there is no evidence that interventions affect either the level or the variance of exchange rates in a consistent and predictable manner.

In the EMS central banks intervened at the edges of the bands (marginal interventions) and within the band (intra-marginal interventions). The basic target zone model of Krugman (1991) maintains that a credible commitment to intervene at the edges would keep the exchange rate within the band without actual intervention. The implications of the model, however, have been rejected in a number of empirical tests when confronted with data from the EMS. To improve the model it has been proposed—inter alia—that the simple intervention rule assumed in the basic target zone model should be extended to include intra-marginal intervention (Svensson, 1992; Lindberg and Söderlind, 1994). Flandreau (1998) and Serrat (2000) analyze multilateral target zone models. In this framework, intra-marginal interventions can arise endogenously. These extensions render the theoretical target zone models more in line with actual intervention behavior.

The theoretical role of intervention in target zone regimes as well as the fact that intervention has been widely used in the EMS makes an empirical study of the effectiveness of intervention particularly interesting.[4] Thus, we take a closer look at the intervention activ-

[1]Since the Exchange Rate Mechanism (ERM) lies at the heart of the European Monetary System (EMS), the abbreviation EMS will be used as a synonym for ERM. If not otherwise specified, EMS refers to ERM I, the period from 1979 until the end of 1998.

[2]There are few other papers dealing with different currency pairs: Fischer and Zurlinden (1998) with the CHF/USD exchange rate, Aguilar and Nydahl (1998) with the USD/SEK and DEM/SEK exchange rates. Mundaca (1993) analyzed the NOK against a trade-weighted basket of foreign currencies and against the ECU. Weber (1996) discussed foreign exchange interventions among Germany, Japan and the United States and among EMS countries.

[3]Cheung and Chinn (1999) conduct a survey of United States foreign exchange traders asking about their beliefs. According to the answers, 61% of the respondents believe that interventions increase market volatility. Only 49% of the traders think that interventions achieve the desired goal.

[4]In particular after the Basle-Nyborg Agreement 1987, EMS central banks intervened predominantly

ities of the European Exchange Rate Mechanism member countries. Also, an evaluation of the effectiveness of intervention in the ERM I can be useful for target zone arrangements like the ERM II.

The data which are analyzed in this paper comprise DEM-interventions undertaken by the Banque de Belgique, the Danmarks Nationalbank, the Banco d'Espana, the Banque de France, the Central Bank of Ireland and the Banco de Portugal. We cover the period from the widening of the bands in August 1993 to April 1998, shortly before the official announcement of the European Monetary Union Stage III start-up member countries. In particular, we try to answer the following questions:

- First, does intervention significantly influence the mean and variance of the six ERM currencies? And if so, is the impact country specific or is there a common pattern in the effectiveness across our sample?

- Second, is there a difference in the intervention behavior and the impact of interventions with respect to different subperiods? A visual inspection of the exchange rate series suggests that our sample contains different regimes: the post August 1993 period with high exchange rate volatility and large deviations from the central parity, a period of high volatility and moderate deviations from the parity and a period of convergence to the central parity in the run-up to EMU with low volatility.

We follow the standard approach and estimate conditional volatility models (GARCH-models) in order to test for the effects of central bank intervention. In our specification DEM-purchases and DEM-sales enter into the equations separately. Also, the absolute deviation of the exchange rate from the bilateral DEM-central rate is considered as a conditioning variable. Within the GARCH-framework volatility is modeled as a time dependent process associated with a continuum of states. This implies that the intervention effect is constant and independent of the state of the economy. Nevertheless, it cannot be ruled out that the effect of central bank intervention depends on the state of the economy since central banks intervene not only in periods of exchange rate turbulence. This perception calls doubts upon the adequacy of the GARCH-approach in this context. To cope with this shortcoming and to supplement the GARCH results, Markov Switching autoregressive conditional heteroscedasticity (MS-ARCH) models are estimated. This approach allows to study the impact of interventions conditional on different regimes and to account for nonlinearities in target zone exchange rate behavior.

The paper is organized as follows: Chapter 2 discusses the effects of central bank intervention on exchange rates. Also, we give a brief review of the empirical literature. The data and some stylized facts are presented in Chapter 3. In Chapter 4 we discuss the EGARCH and MS-ARCH models and the estimation results. Chapter 5 concludes.

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intra-marginally.

2 Intervention: a short overview

In this section we briefly discuss the theoretical background by giving an overview of the different channels through which sterilized intervention can affect exchange rates. Then the empirical evidence on the effectiveness of interventions with a special focus on the volatility effect is reviewed.

2.1 How does intervention affect exchange rates?

Foreign exchange interventions can either be sterilized or unsterilized. Unsterilized interventions alter the relative supply of domestic and foreign money supply and there is little dispute that unsterilized interventions like a monetary policy operation affect the exchange rate. The story is less clear cut in case the central bank decides to eliminate undesired liquidity effects by undertaking offsetting transactions in the money market. In conjunction with sterilized intervention two main transmission channels are discussed in the literature: The portfolio channel and the signalling channel.

According to the portfolio channel, sterilized interventions change the currency composition of domestic and foreign investors' portfolios (see e.g. Almekinders, 1995). Bonds denominated in different currencies are regarded as imperfect substitutes; risk averse investors will hold bonds in one currency only if they get the risk premium deemed adequate. A sale of domestic bonds in order to offset liquidity effects caused by the intervention purchase of foreign currency will induce investors to purchase these bonds only if they are compensated for the additional risk. The higher expected return has to balance the increased foreign exchange exposure, leading to depreciation of the domestic currency.

The signalling channel relies on asymmetric information between the central bank and market participants. Sterilized intervention could therefore provide market participants with new relevant information which is previously not known or not fully incorporated in the current exchange rate level (Dominguez and Frankel, 1993). Monetary authorities dispose of certain information which is conveyed to the public by intervention. A decrease of inflation expectations might be achieved by sterilized purchases of the domestic currency, signalling a future reduction of the money supply. The use of foreign assets reinforces the commitment of the central bank. If market participants judge the foreign exchange operations of the central bank to be credible they will—although todays money supply remains unchanged—reshape their expectations on future monetary policy and hence reshape their expectations on future spot rates.

Montgomery and Popper (1997) discuss another transmission channel, the information sharing channel. As the authors argue, their approach does not rule out the other two approaches, but is to be regarded as a supplement. One remarkable difference with respect to the volatility aspect is that "... the type of intervention discussed in this paper could reduce volatility; other proposed channels have no clear implications for exchange rate volatility ...". There are other differences as well: The information sharing channel is concerned with transitory effects of intervention as opposed to permanent effects in a signalling-context. Moreover, the information sharing channel could also affect the volume of foreign exchange transactions. The suggested model is based on an asymmetric information model and the microstructure of foreign exchange markets thereby describing the interaction between the central bank and heterogeneously informed foreign exchange dealers. By intervening, central banks use the information sharing channel and—quite similar to the signalling channel—transmit information on the future course of monetary policy to foreign exchange market participants. Foreign exchange dealers, in first place those belonging to the trading pool of the central bank (the "information sharing group"), are therefore enabled to get a better signal of future fundamentals and trade among themselves before the information on intervention is revealed to the public. Information sharing takes place not only between traders and the central bank, but also among heterogeneously informed traders. This affects the unconditional variance of the equilibrium exchange rate. Montgomery and Popper (1997) find that volatility diminishes as the information sharing process develops, since more information about future fundamentals is contained in the equilibrium exchange rate. Moreover, the information sharing channel works in both directions: FX-dealers in their turn, have to inform the central banks about conditions in the markets, otherwise they would be excluded from trading activity with the central bank. After having aggregated relevant information, the central bank disseminates the average of the information back to the information sharing group of traders.

Vitale (1999) suggests a different interpretation of the signalling role for sterilized central bank intervention. Again, central banks possess some private information on the fundamental value of a foreign currency. They can influence the expectations of the dealers (market makers) who use their flow of order to update their expectations of the fundamental value of the currency. If the central bank intends to target a certain exchange rate level different from the fundamental value, the goals of sterilized intervention should not be disclosed. It's attempt to 'fool' the market is more successful when the intervention activity is concealed.

Summarizing the literature reviewed, sterilized intervention activity potentially has an effect on the level of exchange rates. However, the influence on volatility is rarely modeled in an explicit way.

2.2 Empirical evidence in the literature

In this section we review some of the empirically oriented papers, whereby our focus is mainly on the work dealing with the volatility effect.[5] For comprehensive surveys we refer to Almekinders (1995), Dominguez and Frankel (1993), Edison (1993), Girardin (2000), Sarno and Taylor (2001) and Schwartz (2000).

Papers estimating the effect of intervention on volatility adopt the conditional volatility and/or the option implied volatility approach: Baillie and Osterberg (1997a) analyze the effects of USD-interventions, undertaken by the Federal Reserve System, the Deutsche Bundesbank and the Bank of Japan on the level and volatility of the USD/DEM- and

[5]Galati and Melick (1999) estimate probability density functions of the JPY/USD-rates and relate intervention activities not only to mean and variance, but also to skewness and kurtosis.

the USD/JPY-market rate. The authors use a martingale-GARCH process on a daily basis. The period under review covers the Louvre and the Plaza-agreement, ranging from August 1985 to March 1990. Little evidence is found that intervention has an impact on the conditional mean of exchange rate returns. The volatility of exchange rate returns, however, might have been slightly increased.

In another study, motivated by a theoretical model including spot market interventions, Baillie and Osterberg (1997b) explain the risk premium in the forward foreign exchange market. The currencies under investigation are the USD, the DEM and the JPY, the sample period is 1985 to 1990. The conditional variance equation of the USD/DEM-risk premium does not show any significant influence of spot market interventions. In the USD/JPY-forward market, evidence is found that intervention rather increases than decreases volatility.

Dominguez (1998) postulates that the ability of intervention transactions to influence market rates crucially hinges on their public awareness, full credibility and unambiguousness. Assuming that exchange rates are efficient aggregators of information and that market expectations are formed rationally, she differentiates between eight possible scenarios, capturing the features "Credible and Unambiguous", "Not Credible and Ambiguous" for the criterion "Nature of Intervention Signal" and the features "Efficient" and "Inefficient" for the criterion "Exchange Market Efficiency". Four scenarios are referring to the exchange rate level, the other four to volatility. If interventions are fully credible, unambiguous, and if foreign exchange markets are efficient, interventions should either have no influence or a reducing effect on the conditional variance of exchange rates. Vice versa, interventions are likely to increase volatility. In addition, she distinguishes between overt and secret interventions. According to Dominguez (1998), a credible target zone model could be an example where clear signals on an envisaged reduction in volatility would effectively reduce the variance of spot rates. By estimating a GARCH model for the USD/DEM and USD/JPY, she demonstrates that secret interventions had an increasing effect on volatility, thus providing evidence in support that ambiguous signals increase volatility. The results are confirmed when implied volatilities from foreign exchange options are used. In contrast, overt interventions in the mid 1980s appear to have reduced volatility. Nevertheless, for the whole period (1977–1994) central bank intervention generally leads to higher exchange rate volatility.

Aguilar and Nydahl (1998) investigate the impact of interventions on the level and volatility of the Swedish Krona (SEK) /USD- and SEK/DEM-rate from January 1993 to November 1996, a period when the SEK was floating. A bivariate GARCH-framework and as a second approach, implied volatilities from currency options were used. For the whole period no significant effect for the exchange rate level and only weak evidence for a reduction in volatility is found.

Mundaca (1993) investigates the development of the Norwegian Krona from October 1986 to February 1990. In a first approach she analyzes the effects of intra-marginal intervention of the Norges Bank on the spot rate in a qualitative manner (Probit model) while in a second approach the effect of the amount of intervention is estimated. She specifies the intervention equations together with a GARCH-model for the exchange rate process. Both the exchange rate and the intervention decisions are endogenous variables. Mundaca finds that interventions were more effective—in terms of level and volatility—the closer the spot rate centered around the parity rate. Furthermore, volatility effects are not symmetrical, the exchange rate variance appeared to be higher near the weaker end of the band and lower near the upper end.

Bonser-Neal and Tanner (1996) estimate ex ante volatility using implied volatilities of currency options (USD/DEM, USD/JPY). In testing the influence of intervention, they control for the effects of US macroeconomic announcements. They find that over the period from 1985 to 1991 central bank intervention generally augments volatility or exerts no significant influence. For subperiods the evidence is mixed: from 1987 to 1989 intervention increased volatility whereas from 1990 to 1991 the opposite effect is found, although with weak evidence.

The above mentioned papers primarily deal with the question of whether at all intervention transactions influence volatility and if in which direction. A priori it cannot be ruled out that intervention is rather caused by volatile markets. Baillie and Osterberg (1997a, 1997b) and Dominguez (1998) used Probit models to test reverse causality—volatility inducing central banks to intervene—and reject this hypothesis. Almekinders and Eijffinger (1994), however, obtain different results. Applying a Tobit analysis for the USD/DEM-rate from 1985 to 1989, they find that an increase in the conditional variance (derived from a GARCH model) leads central banks to increase the volume of intervention. Döpke and Pierdzioch (1999) employ a multinomial Logit approach to estimate an intervention reaction function for the Deutsche Bundesbank over various subsamples covering a period from 1985 to 1997. They use options implied volatilities to capture anticipated exchange rate volatility. Their results establish an asymmetric response of the Deutsche Bundesbank to the volatility of the DEM/USD exchange rate for two of the three subsamples. In Brandner, Grech, Stix (2001) a Tobit approach is applied to estimate reaction functions of EMS central banks. Significant effects are found for the exchange rate position in the band (deviation from central parity). The influence of volatility on the intervention activity is less clear cut, depending on the specification of the volatility variable. Nevertheless there is some evidence that a change in market conditions—as expressed in the volatility variables—induces central banks to intervene.

To sum up, there is no evidence that interventions affect either the level or the variance of exchange rates in a consistent and predictable manner. In addition, there is very limited evidence about the effectiveness of interventions in target zones. To shed more light on this issue we now turn to the empirical analysis.

3 The Data and Stylized Facts

We analyze the period from August 3, 1993, the first day after the widening of the bands to ±15%, to April 30, 1998, the last day before the start-up member countries for the European Monetary Union were officially announced. Our sample contains daily bilateral Deutsche Mark exchange rates and intervention data for the following currencies: the

Belgian Franc (BEF), the Danish Krone (DKK) , the Spanish Peseta (ESP), the French Francs (FRF), the Irish Pound (IEP) and the Portuguese Escudo (PTE).

3.1 Intervention Data

The daily intervention figures are collected from concertation protocols. Each day, EMS and a few other central banks communicate the amounts of DEM-purchases and DEM-sales in four concertation rounds. The first round takes place at 9:30 and the last round at 16:00. The intervention data we use are cumulated intervention volumes for a time period of 24 hours, starting from 16:00 previous day until 16:00 today. Intervention undertaken after 16:00 are reported at the first concertation round next day at 9:30 and are therefore included in next day's intervention figure.

Intervention transactions may not only be transactions to e.g. support a weak currency, either unilateral or in a concerted manner, but may also be purchases or sales intended,

- to influence a certain exchange rate trend (e.g. "leaning with/against the wind") or
- to calm disorderly market conditions (smoothing transactions) or
- to reshuffle foreign exchange reserves for portfolio considerations (central banks usually follow certain portfolio strategies) or
- to assist other central banks in their foreign exchange operations.

Since we are not able to separate the intervention data according to the above mentioned motivations, we might be subject to misinterpretation. Thus, a certain degree of caution is necessary when interpreting our results. Furthermore, intervention decisions might have been taken on a case-by-case-situation and not been the outcome of a long lasting intervention strategy.

Since intervention figures are not publicly available, we are only able to present some aggregate statistics.[6] Average daily DEM-sales conducted by any of the six central banks range from around DEM 70 million to around DEM 1.200 million. However, there was a tendency towards the lower end of the range. Average daily DEM-purchases are in general smaller than -sales (about DEM 100 million to DEM 330 million). Inter alia, this may reflect the fact that replenishment operations were often undertaken in small amounts over longer—sometimes continuous—periods in order not to create market disturbances.

Intervention intensity as measured as the percentage of intervention days in relation to the total of 1238 trading days, range from 1.3% to 22.3% for DEM-purchases and from 4.4% to 11.8% for DEM-sales. The most active central bank was in the market, either buying or selling Deutsche Mark, on one third of all trading days.

[6] Our agreement with the six central banks involves presenting results using the intervention data in such a way so that individual daily operations are not revealed.

Another interesting stylized fact is the maximum number of days where central banks continuously intervened in the same direction (either purchasing or selling). The central bank with the longest period of consecutive DEM-sales did so for 7 days. The longest period of DEM-purchases endured for 41 days. However, often prolonged periods of intervention were interrupted by one or two trading days without intervention activity.

EMS interventions are usually not communicated to the public. In our sample, all of the intervention transactions were undertaken intra-marginally with more or less public unawareness. We therefore classify our intervention data—following the characterization of Dominguez (1998)—as "secret".

Intervention should work—according to the EMS agreement—in a symmetric way. Different sterilization behavior exerts asymmetric alignment pressure on weak versus strong EMS currencies. However, the evidence on the degree of sterilization behavior is mixed and may differ across EMS central banks. Mastropasqua et al. (1988) report that for the period 1979 to 1987 the Deutsche Bundesbank sterilized on average between 60 and 80 percent, whereas the Banque de France and the Banca d'Italia, typically representing currencies more often under market pressure, sterilized a lower share (around 40 and 30 percent respectively). In another study on German monetary policy, von Hagen (1989) finds that the Bundesbank only partly sterilized its intervention transactions in the EMS context. Weber (1996) reports that all EMS central banks—and not only the Deutsche Bundesbank—sterilized their interventions. In line with other papers we do not differentiate between sterilized and unsterilized interventions in our empirical work.

3.2 Exchange Rate Data

The exchange rate data are Bank for International Settlement USD exchange rate series, laid down at the daily concertation procedure of central banks at 14:15. The DEM cross rates are calculated by assuming that the no-triangular-arbitrage condition holds. Exchange rates (S_t) are expressed in terms of DEM per 100 units of local currency.[7] The exchange rate returns (Δs_t) are calculated as 100 times the log difference of the exchange rate.

There are two well established facts about exchange rate returns in target zones: first, the unconditional distribution of exchange rate returns is leptokurtic, as the distribution has fatter tails and is more peaked than the normal distribution, and second, periods of turbulence are followed by periods of turbulence and quiescent periods are followed by quiescent periods (volatility clustering).[8]

The fat tail property of target zone exchange rates is well based on theoretical findings: Krugman's (1991) target zone model as well as other extensions (e.g. Serrat, 2000) imply that one should observe fat tails because interventions prevent the exchange rates from

[7] An appreciation means that $S_t > S_{t-1}$.

[8] The persistence in the variance process can be directly linked to leptokurtosis as remarked by de Vries (1992) who finds that EMS exchange rates are characterized by thicker tails than free floating exchange rates. Engle and Gau (1997) reach a similar conclusion.

moving outside the bands. The exchange rate is more inelastic with respect to changes in fundamentals at the boundaries and thus its distribution has fatter tails than free floating rates. Lewis (1995) gives a rationale for the thick tail characteristics in the presence of intra-marginal interventions. Her simulations show that the asymptotic distribution of returns in target zones with intra-marginal and stabilizing interventions is truncated multimodal. In finite samples it can happen that a researcher only observes exchange rate returns between two truncation points where the distribution has extreme fat tails. A similar argument has been put forth in Lindberg and Söderlind (1994) who argue that intra-marginal interventions can generate hump-shaped distributions. In a multilateral target zone model Flandreau (1998) derives an exchange rate distribution with two humps, corresponding to intra-marginal targets.

Another stylized fact typically observed for fixed but adjustable exchange rates is that the distribution of returns is skewed representing the fact that rates drift predominantly in one or the other direction. For example, some EMS exchange rates are typically found to be weaker (stronger) than the Deutsche Mark which can be traced to differences in monetary policy (de Vries, 1992).

Table 1 presents some descriptive statistics for the exchange rate returns. The results strongly emphasize the importance of the stylized facts mentioned above: excess kurtosis and skewness. As expected, the Jarque-Bera test for normality is overwhelmingly rejected for all currencies. Kurtosis is quite high for all currencies and extremely high for the Belgium Franc. The result of the Ljung-Box Q-statistics, $Q(20)$, indicate that the daily returns are serially correlated for all cases but the Irish Pound. The results for the $Q^2(20)$ test strongly indicate the presence of volatility clusters. Also, we report the results of unit root tests (both Phillips-Perron and Augmented Dickey-Fuller) which cannot reject the null hypothesis of a unit root (except for the Belgium Franc). This is consistent with the finding of Iannizzotto and Taylor (1999) who report that Monte Carlo experiments show that the null hypothesis of a unit root typically can not be rejected when in fact the target zone is fully credible and the exchange rate is mean reverting.

Figure A.1 and Figure A.2 show the exchange rate positions within the band and the percentage deviation from the central rate, respectively. In our sample the weakest position in the band was a 10% downward deviation from the central parity for the Spanish Peseta briefly before it was realigned in 1995. The strongest position was observed for the Irish Pound in 1997 (upward deviation around 12%). All other currencies fluctuated not more than ±6%, most of the time even less.

The daily exchange rate returns are depicted in Figure A.3 which shows the typical pattern of strong volatility clusters as well as the presence of considerable within-the-band changes for all currencies except the Irish Pound. There seem to be three distinct regimes in the data. First, a turbulent period with relatively large deviations from the central parity (a) shortly after the widening of the bands and (b) during 1995 when the Peseta and the Escudo were realigned.[9] Second, a period with moderate fluctuations in-between and third, at the end of the sample a period with minor fluctuations around the central parity

[9] The Escudo and the Peseta were realigned on March 6, 1995.

reflecting strong policy convergence among the then prospective EMU Stage III member countries. This observation seems to hold for all currencies except the Irish Pound which showed bigger fluctuations within the band and a short calm period at the end of the sample.[10]

The discussion suggests that a parametric model of the post-1993 EMS exchange rates must be able to model the following stylized facts: (1) volatility clustering, (2) fat tails and (3) reversion to the parity.

4 Estimating the Effect of Intervention on Volatility

In modeling volatility, one can follow two avenues: on the one hand observed option prices can be used in connection with a pricing model to derive implicit ex-ante measures of volatilities. This approach has the advantage that the derived volatilities are based on market participants' expectations. However, this comes at the cost of assuming efficient option markets and the appropriateness of the assumed option pricing model. On the other hand, time series methods can be used to derive ex-post measures of volatilities. Theoretically and empirically it is not clear which approach is preferable. Ideally, one should therefore test hypotheses based on both approaches as in Dominguez (1998).

In this paper we restrict our attention to ex-post models of volatility. Specifically, we assume that past exchange rate fluctuations can be represented by a EGARCH model and/or a Markov Switching ARCH model. This approach is motivated by the stylized facts of highly non-normal unconditional distributions and the above mentioned volatility clustering.

4.1 The EGARCH Model

Estimating exchange rate volatility with GARCH models has become the standard approach. However, in the context of EMS rates several empirical studies report that the persistence in the conditional variance implied by parameter estimates of single regime GARCH models is high.[11] To lower the persistence of shocks, it has been proposed that the effect of negative shocks should be separated from the effect of positive shocks. Models that incorporate this leverage effect are the Threshold GARCH (Zakoian, 1994) and the Exponential GARCH model (Nelson, 1991). By applying these models in a target zone framework, it is typically found that negative shocks increase volatility more than positive shocks.[12]

[10] The Irish Pound was realigned on March 16, 1998.

[11] For example Bekaert and Grey (1998) report estimates which imply a (near-)integrated process for the volatility for the FRF/DEM exchange rate. The implication that shocks have an (almost) infinite impact on the level of volatility is hardly plausible because realignments often had a pressure relieving effect on volatility. To overcome the high persistence, Bekaert and Grey (1998) estimate a jump diffusion model.

[12] This can be the case if market participants believe that central banks care more about depreciations than appreciations. Observed interventions in times of pronounced depreciations against the German

Since the EGARCH model outperforms the GARCH models in terms of likelihood values we will focus on the EGARCH model. The model we estimate takes the following form:

$$\Delta s_t = c_0 + c_1 \cdot D_{t-1}^{(C)} + c_2 \cdot I_{t-1}^{(P)} + c_3 \cdot I_{t-1}^{(S)} + \sqrt{h_t} \cdot \epsilon_t \ , \quad (1)$$

where $\Delta s_t = 100 \cdot \Delta \log S_t$ and ϵ_t is an independently, identically and normally distributed error term with zero mean and unit variance.

The equation for the conditional mean contains the following variables: $D_{t-1}^{(C)} = \log S_{t-1} - \log(\text{Central Parity})_{t-1}$ measures the deviation from the central parity and will be included to capture mean reversion in EMS exchange rates.[13] In particular, if the level of the exchange rate is above the central parity ($D_{t-1}^{(C)} > 0$), then the exchange rate should revert back to its long run level (Δs_t should be negative). Therefore, we would expect $c_1 < 0$. The variables $I_{t-1}^{(P)}$ and $I_{t-1}^{(S)}$ denote the logarithm of the amounts of DEM-purchases and DEM-sales by the central bank. DEM-sales should result in a currency appreciation—a positive change in Δs_t—and DEM-purchases should result in a currency depreciation. Thus we would expect $c_2 < 0$ and $c_3 > 0$.

The conditional variance evolves according to,

$$\begin{aligned} \log h_t \quad = \quad & \phi_0 + \phi_1 \cdot \mid \frac{\epsilon_{t-1}}{\sqrt{h_{t-1}}} \mid + \phi_2 \cdot \frac{\epsilon_{t-1}}{\sqrt{h_{t-1}}} + \phi_3 \cdot \log h_{t-1} \\ & + \delta_1 \cdot \mid D_{t-1}^{(C)} \mid + \delta_2 \cdot I_{t-1}^{(P)} + \delta_3 \cdot I_{t-1}^{(S)} \ . \end{aligned} \quad (2)$$

Note, that the parameter ϕ_2 allows the impact of a negative shock on $\log h_t$ to be different from a positive shock. If $\phi_2 < 0$, negative shocks (depreciations) increase next period's conditional volatility more than positive shocks whereas if ϕ_2 is statistically not significantly different from zero, then positive innovations have the same effect on volatility as negative innovations. If $\phi_3 < 1$, the conditional variance is stationary. The log-specification implies that no constraints have to be imposed on the parameters to guarantee strict positivity of h_t. The conditional variance equation also contains $\mid D_{t-1}^{(C)} \mid$, the absolute value of the deviation from the central parity as well as DEM-sales and -purchases. As bilateral target zone models predict, the exchange rate becomes less sensitive to movements in fundamentals the closer it approaches the boundaries. Therefore we would expect that

Mark could therefore reflect increased vulnerability of the domestic currency. As an effect volatility would increase. Market uncertainty could be enhanced even further if traders do not share the central bank's exchange rate target.

[13] Often the interest rate differential is used to account for differences in the stance of monetary policy (e.g. Dominguez, 1998). As expected, this variable is highly correlated with the deviation from the central parity in our sample. Therefore, using the interest rate differential instead of the deviation from the central parity does not change the results qualitatively.

$\delta_1 < 0$.[14] However, empirically it is often found that $\delta_1 > 0$.[15]

We use lagged intervention to circumvent the problem of simultaneity. If the effect of intervention is short lived (e.g. dies out on the same day[16]) then we might fail to detect any effect. Since intervention activity in our sample is often conducted over several consecutive days we do not consider this to be of crucial importance in context of this analysis.

4.2 Results of the EGARCH Model

In this subsection we discuss the maximum likelihood estimation results for the EGARCH model. In order to find the best specification for all six currencies we proceed as follows: First, we apply a simple-to-general specification search based on likelihood ratio test. We start with a martingale specification. Then we use the deviation from the central parity, the amount of DEM-purchases and -sales and both the deviation from the central parity and interventions. We then choose a preferred model for the conditional mean and use it as a basis for the specification search for the conditional variance. Here we follow the same strategy by including the absolute deviation from the parity, DEM-purchases and -sales and finally all three variables. Based on likelihood ratio tests we select one model. Then we test whether individually insignificant variables can be excluded. The final models are summarized in Table 2.

The results of the preferred models (Table 2) can be summarized as follows: For the conditional mean, the coefficient of the deviation from the central parity has the expected sign (negative) and is significantly different from zero for the Belgian and French Franc and for the Danish Krone.[17] Interventions do not significantly influence the mean except for the Escudo where the coefficient of DEM-purchases is significant at the 10% level with a positive coefficient.

In line with the empirical literature, the deviation from the central parity in the conditional variance significantly increases the conditional variance for all currencies except for the Belgium Franc where no effect is found. Furthermore, DEM-purchases have no effect on the conditional volatility of four currencies and an increasing effect on the volatility of two currencies (Peseta, French Franc). DEM-sales have no effect on the conditional variance of three currencies, a volatility reducing effect on two currencies (Krone, Peseta) and an increasing effect on one currency (French Franc). The effects of the interventions

[14] Note that in a multilateral target zone model the volatility of the exchange rate is not necessarily a monotonic function of its position within the band (Serrat, 2000). Since we consider only country-specific variables, our analysis could be seen in the spirit of a bilateral target zone model. In this sense our design closely ressembles the setup of the EMS II with the Deutsche Mark instead of the euro.

[15] E.g. Engle and Gau (1997).

[16] E.g. Dominguez (1999), Fischer and Zurlinden (1998).

[17] In the case of the Danish Krone there is still some moderate evidence of autocorrelation in the residuals. The daily percentage changes of the Danish Krone are quite small with few big "outliers" around the realignment of the Peseta and the Escudo. The autocorrelation problems for the Danish Krone can be traced to these observations. However, the null hypothesis of no serial correlation has to be rejected at the 5% significance level but not at the 1% level (critical value 37.57).

on the conditional variances are summarized in a non-technical way in Table 3.

As argued in the introduction, an alternative way of capturing the effects of intervention on volatility will now be presented.

4.3 The Markov Switching ARCH Model

In Markov switching (MS) models, it is assumed that there are several regimes characterized by different conditional means and/or different conditional variances. For example, it has been advanced that EMS exchange rates can be characterized as being drawn either from a regime with low volatility or from a regime with high volatility where the latter corresponds to a realignment or speculative attack regime.[18]

There are some well known advantages of the MS model: Among them are the possibility to model fat tailed (and/or multimodal) distributions and volatility clustering. Consequently, MS models have been applied successfully to EMS exchange rates.[19] Apart from these two advantages—fat tails and volatility clustering—there are other arguments in favor of MS models which suggest the usefulness of this approach.

Hamilton and Susmel (1994) propose a regime switching ARCH model in order to reduce the high persistence of the conditional variance which is typically implied by single regime GARCH models. In their specification the intra-regime variance is characterized by a low-order ARCH process. Since the parameters of the lagged squared residuals are restricted across regimes, the dynamics of the conditional variance is the same within each regime. However, the scale of the conditional variance switches across regimes.[20] The combination (an autoregressive component in the conditional variance process and the presence of endogenously determined regime changes) lowers the implied persistence of shocks and seems to generate better volatility forecasts than a single regime GARCH model.[21]

Furthermore, in a standard single regime GARCH model, the impact of interventions on the conditional mean and variance is—per definition—the same across regimes. Therefore, if a significant effect of interventions is estimated one might be inclined to interpret this as if interventions are effective irrespective of the market context. However, this can be misleading. For example, it can be the case that interventions are able to influence the exchange rate only in calm periods. In turn, interventions in turbulent periods may further increase the conditional variance, in particular in the presence of uncertainty about the goals of the intervention activity. Also, central banks might have different objectives across

[18] Another type of model which assumes that the exchange rate is drawn from a mixture of distributions is the jump diffusion model. For example, Bekaert and Gray (1998) and Vlaar (1998) apply such a model to EMS exchange rates.

[19] Martinez Peria (1999) and Engle and Hakkio (1994), for example, model EMS exchange rates as being drawn from two distributions which are separated by their level of volatility.

[20] An extension of this model which also allows the dynamics of the conditional variance process to be different across regimes has been proposed by Gray (1996). Gray (1996) also allows for the presence of lagged conditional variance terms.

[21] See evidence from Hamilton and Susmel (1994), Gray (1996) and Klaassen (1999).

regimes. For example, it is conceivable that central banks want to smooth disorderly markets in turbulent regime whereas in a calm regime the main motivation behind an intervention is the intention to influence the exchange rate trend. In contrast to single regime GARCH models, such regime specific effects of intervention can be identified with the Markov switching model.

Another argument in favor of the Markov switching model can be derived from the presence of nonlinearities and/or nonlinear mean reversion in target zone exchange rates.[22] Because the overall degree of mean reversion represents a weighted sum of the regime specific mean reversion, Markov switching models can generate such nonlinearities.[23] This also implies, that the MS model can account for reversion to regime specific different means.[24]

Given these arguments, we assume that the exchange rate changes evolve according to,[25]

$$\Delta s_t = c_{i0} + c_{i1} \cdot D_{t-1}^{(C)} + c_{i2} \cdot I_{t-1}^{(P)} + c_{i3} \cdot I_{t-1}^{(S)} + \sqrt{h_{i,t}} \cdot u_t \tag{3}$$

where Δs_t is the exchange rate return between time $t-1$ and time t and u_t is an independently, identically Student-t distributed error term with ν degrees of freedom, a mean of zero and a unit variance. The subscript i indicates that the exchange rate return Δs_t depends on an unobserved regime variable Z_t which can take r values ($i = 1, \ldots, r$) and evolves according to a first-order Markov chain.[26] This implies that the conditional probability that the process is in regime i at time t depends on the regime it was in at time $t-1$, $P(Z_t = i \mid Z_{t-1} = j)$. To allow for mean reversion in Δs_t we assume that the conditional mean in regime i depends on the deviation from the central parity. This formulation encompasses regimes with no mean reversion ($c_{i1} = 0$), different degrees of mean reversion ($c_{i1} \neq c_{j1} \quad i, j = 1, \ldots, r$) and reversion to different long run levels of s_t ($c_{i0} \neq c_{j0} \quad i, j = 1, \ldots, r$).

Although the regimes are not directly observable, it is possible to draw some inference about the regime probabilities. For example, $p_{i,t} = P(Z_t = i|\Omega_{t-1})$ measures the probability that the process is in regime i at time t conditional on the information set Ω containing information up to time $t-1$. Then, the distribution of exchange rate returns is generated

[22]For example, Gray and Bekaert (1998) do find evidence of nonlinear mean reversion in EMS exchange rates.

[23]For example, it could be the case that in one regime the exchange rate follows a random walk and in another regime it exhibits mean reversion. If the "random walk" regime happens with high probability over a wide range of the fluctuation band and the mean reverting regime occurs with high probability at the edges of the band, then the overall degree of mean reversion can be a nonlinear function of the deviation from the central parity.

[24]Labhard and Wyplosz (1996) find some evidence of the presence of narrow bands inside deep bands for the EMS from 1993 until 1995. Furthermore, the narrow bands are found to be asymmetric, not necessarily centered around the central parity. Also for Sweden, Lindberg and Söderlind's (1996) results suggest the presence of several regimes with different parities.

[25]The model is essentially based on Gray (1996). In contrast to Gray (1996) we do not allow for GARCH terms.

[26]Frequently, it is found that the regimes are driven by different levels of volatility.

by a mixture of r different distributions each weighted with probability $p_{i,t}$:[27]

$$\Delta s_t \sim t(\mu_{i,t}, h_{i,t}, \nu) \text{ with probability } p_{i,t} \quad i = 1, \ldots, r. \tag{4}$$

Lastly, the conditional variance equation for regime i is specified as,

$$h_{i,t} = \omega_i + \sum_{j=1}^{p} \alpha_j \cdot \epsilon_{t-j}^2 + \phi \cdot D_{t-1} \cdot \epsilon_{t-1}^2 + \delta_{i1} \cdot I_{t-1}^{(P)} + \delta_{i2} \cdot I_{t-1}^{(S)} \ , \tag{5}$$

where D_{t-1} is a dummy variable which takes a value of one if $\epsilon_{t-1} < 0$ and zero else. Thus, ϕ is—similar to ϕ_2 in the EGARCH model—capturing the effect of negative innovations. The error term ϵ_{t-1} is given by,

$$\begin{aligned} \epsilon_{t-1} &= \Delta s_{t-1} - E(\Delta s_{t-1} \mid \Omega_{t-2}) \ , \\ &= \Delta s_{t-1} - \sum_{i=1}^{r} p_{i,t-1} \cdot \mu_{i,t-1} \ . \end{aligned}$$

As mentioned, the most general specification of the conditional variance process potentially allows for different ARCH dynamics within each regime. Since such flexibility would come at the cost of being computationally intractable, we restrict the ARCH parameters α_j to be the same across regimes and only allow the intercepts to be regime dependent.[28] Although not identical, this is comparable to the specification of Hamilton and Susmel (1994) who also restrict the coefficients of the ARCH terms, but allow for a multiplicative scaling parameter which affects the level of the conditional variance equation. In our formulation, the different levels of volatility between regimes are expressed by different values of the intercepts ω_i, but the dynamics of the regime specific conditional variances are the same. If the regime switches, the change in ω_i leads to a sudden change in the scale of the conditional variance. The persistence in the conditional variance is generated by the within regime persistence implied by the ARCH parameters as well as by the transition probabilities.

Notice that in equation (3) and (5), the effects of interventions as measured by $c_{i2}, c_{i3}, \delta_{i1}$ and δ_{i2} depend on the regime. More precise, these coefficients measure the effect of intervention (that takes place at time $t-1$) on the regime specific conditional mean and conditional variance at time t.

4.4 Results of the MS-ARCH Model

The estimation results of the preferred MS-ARCH model for each currency are reported in Table 4.[29] We first describe the specification search which leads to preferred models,

[27] $\mu_{i,t-1}$ denotes the conditional mean from equation (3).

[28] Since there is a high degree of persistence in daily exchange rate changes, a high number of lagged squared residuals would be needed for each regime.

[29] The MS-ARCH model is estimated by maximum likelihood using the GAUSS MAXLIK package.

then we discuss the results of the estimated models. After having amended the preferred models by including interventions we will discuss the estimates of the intervention effects.

Obviously, the first specification search should deal with the number of regimes. However, because the presence of unidentified parameters under the null hypothesis renders the distribution of the likelihood ratio statistics nonstandard, the asymptotic test distribution would need to be simulated. Since this is computationally quite complex, we do not conduct such a formal test for the number of regimes but rather take a less formal approach. In this sense, we start by estimating a two regime model and compute the likelihood ratio test statistics of one regime versus two regimes. For all currencies, this test statistic is high, indicating statistical significance of the presence of two regimes. Then we proceed by conducting the same test for two versus three regimes and typically find reassuringly high likelihood ratio statistics. Despite the lack of correct critical values we take these results as strong evidence that a three regime model is appropriate. This holds for all currencies except the Irish Pound where a two regime model is adequate.

The estimation results of the three regime models with unconstrained transition probabilities show that the probability of going from regime 1 to regime 3 and vice versa is zero for all currencies. Thus we restrict these two parameters to be zero and estimate all subsequent models with this restriction imposed. In general, the point estimates of the transition probability matrix show a similar pattern, that is a very high persistence of staying in a regime once the process is there.

The estimates for the regime specific conditional means show—as expected—that the degree of mean reversion is different across regimes and currencies. For example, the French Franc showed a tendency to revert to a mean value which was below the official parity in the first and second regime.[30] The Belgian Franc and the Escudo showed mean reversion in the second regime whereas mean reversion is found in the third regime in the case of the French Franc and the Escudo. It is interesting to compare the result with the EGARCH model. For example, for the Belgian Franc the estimates imply a negative drift in the EGARCH martingale model. Once the deviation from the parity was added, the drift became insignificant but the mean reversion got significant. In the MS-ARCH model we find both effects: a significant mean reversion parameter in the second regime and a significant negative drift in the third regime.

The number of ARCH terms differs across currencies ranging from just one in the case of the Irish Pound, up to five plus a leverage term in the case of the French Franc. As expected, the point estimates of the ARCH parameters imply a much lower persistence for the conditional variance than the EGARCH model. The $Q(20)$ and $Q^2(20)$ test statistics reported in Table 4 show no evidence of serial correlation in the standardized or squared standardized residuals, except for the Danish Krone with a moderate level of serial correlation.[31] An additional indication—apart from the high likelihood ratio statistics—for the presence of three regimes is that the ARCH parameters and the regime specific variance

[30] For the French Franc a likelihood ratio test justifies to restrict the degree of mean reversion in the first and second regime to be the same. Therefore we present the restricted estimates in Table 4.

[31] A similar problem turned up in the EGARCH model. See also footnote 17.

intercepts (ω_i) are typically estimated with a marginal significance level below 5%.

Labelling the regimes is ambiguous given the results for the means and variances. For example, the estimates for the Irish Pound yield a mean reverting regime and a random walk regime. Simultaneously, the first regime has a higher variance than the second. Now, labellig the regimes according to the level of variance "high volatility"and "low volatility" regimes is certainly not completely adequate as this terminology subdues the role of mean reversion, and *vice versa*. However, the results for all currencies together indicate that the regimes are separated more according to the level of variance than according to the different means. Keeping these difficulties in mind, we therefore label the regimes as "high volatility", "medium volatility" and "low volatility".

The difference between ω_1, the intercept in the "high volatility" regime and ω_2, the intercept in the "medium volatility" regime is quite dramatic for the Belgian Franc where ω_1 is about 100 times greater than ω_2. For the other cases, this difference ranges from a factor of about 3 (Irish Pound) to 8 (Peseta). The huge difference for the Belgian Franc can be explained by the fact that the exchange rate variations are only small throughout most of the sample except for a short period after the widening of the bands in August 1993 (Figure A.3). The ratios of the intercepts in the "medium volatility" and "low volatility" regimes range from about 3 (Irish Pound) to 24 (French Franc). The differences of the volatility levels between the regimes is smallest for the Irish Pound and largest for the Belgian Franc. The presence of large exchange rate fluctuations and thick tails, is also reflected in the low estimates of ν, the degrees of freedom for the t-distribution.

Figure A.4 to A.6 show the evolution of the ex-post regime probabilities.[32] In general, the pattern of the probabilities shows that the regimes are clearly separated. As is visible in Figure A.4, the "high volatility" regime occurred mainly at the beginning of the sample after the widening of the bands. Subsequently, varying from currency to currency, the "high volatility" regime has been replaced by the "medium volatility" regime. This occurred quite fast for the Belgian Franc and the French Franc and later also for the Escudo and the Peseta. However, in March 1995 the probability of the "high volatility" regime increased sharply again. Interestingly, the ex-post probabilities rose already before the realignment in the case of the Peseta, the Irish Pound and to a lesser extent in the case of the French Franc and the Escudo. Only for the Belgian Franc the increase in this probability is modest and transitory.

The convergence of the exchange rates to the central parity and the evolution of a stable regime with little fluctuations in the months before the decision about EMU start-up member countries can be seen in Figure A.6. The Belgian Franc entered the calm and stable "low volatility" regime already around 1996. The fact that the probability of regime three is very close to one until the end of the sample might be taken as an indication that the market participants started to consider Belgium quite early as a start-up member

[32]In the literature typically the smoothed probabilities are shown. The difference between the two probabilities lies in the information set which is used to calculate them. While the ex-post probability is the probability that the exchange rate is in regime i at time t conditional on information up to time t, the smoothed probabilities use as conditioning information the whole sample.

of Stage III of EMU. In contrast, the regime classification for the French Franc is less clear cut with a period of frequent switches between the "medium volatility" and the "low volatility" regime in 1997. The French Franc finally entered and locked into the "low volatility" regime about at the same time as the Peseta and the Escudo.

Summarizing the discussion of the preferred MS-ARCH models, we conclude that the regime classification is not only statistically but also economically meaningful. Furthermore, some exchange rates show evidence of nonlinear mean reversion. Finally, the persistence of regime specific conditional variances are lower than in the EGARCH model. Given these estimates we now turn to the inclusion of intervention variables.

In a first step, this is done by including DEM-sales and -purchases into the three regime specific mean equations of the preferred models. The signs and significance of the estimated coefficients of either DEM-sales or -purchases are summarized in Table 5.[33] Lagged DEM-purchases enter with the anticipated negative sign for the Belgian Franc and the Peseta. Purchases of the Belgian Franc and Peseta lead to an depreciation of the DEM/BEF and DEM/ESP exchange rate.[34] In contrast, the coefficient for the Danish Krone implies an appreciation when the Danmarks Nationalbank sold Deutsche Mark. For the amount of DEM-sales, correctly signed and significant coefficients are found for the Peseta and the Krone. For the Escudo, however, the respective sign is negative.

Next, we estimate the MS-ARCH model with the intervention variables entering the conditional variance equation in all three regimes simultaneously.[35] As argued, this allows to quantify the effects of interventions on the variance conditional on the exchange rate regime i at time t. Thus, for each currency we estimate the preferred models as shown in Table 4 amended by either DEM-sales or purchases in the conditional mean with the intervention variables added to the conditional variance equation.[36]

The results are summarized in Table 6. The results show only a few significant effects. For DEM-purchases we find a negative and significant effect in the case of the Peseta and the Danish Krone in the "high volatility" regime and, again, for the Danish Krone, a negative coefficient for the "medium volatility" regime. Interestingly, for DEM-purchases no other significant effects were found. More significant intervention effects are caused by DEM-sales: In the "low" and "medium volatility" regime, DEM-sales reduce the conditional variance for the Krone, the Peseta and the Escudo. In contrast, sales increase the

[33]By including intervention variables, the results for those coefficients already reported in Table 4 do not change much. Thus, we do not report them again. Of course, detailed tables can be obtained from the authors.

[34]All these coefficients are significant at a 5% level.

[35]However, for some cases there are too few interventions in some regimes. Moreover, the conditional variance must be constrained to be positive for each regime which is technically not always possible for all regimes (e.g. if all effects are negative and more than one constraint is binding). Therefore, in the cases where simultaneous estimation is not possible we include the amount of DEM-sales or purchases as explanatory variables into the regimes separately. An asterisk next to the currency code indicates that the model was estimated with all three interventions entering simultaneously. For those cases where joint estimation is possible we find that the results do not change qualitatively if interventions enter separately.

[36]For reasons of parsimony, only those variables enter the conditional mean equation that were found to be significant according to t-tests.

conditional variance for the Belgian Franc in the "medium" and "high volatility" regime.

Overall, no effects of either DEM-sales or -purchases are found for the French Franc and the Irish Pound. For those currencies where DEM-sales decrease the conditional variance, the effects appear either in the "low" or "medium volatility" regime but not in the "high volatility" regime—which is similar to the results for the conditional mean. Apart from two exceptions, DEM-sales and -purchases did not influence the conditional mean and variance in the "high volatility" regime.

A comparison of the results of the MS-ARCH model with the EGARCH model yields that more significant effects are found for both DEM-sales or -purchases in the MS-ARCH model. Furthermore, apart from DEM-purchases for the Krone, all significant results for the mean are found to be either in the "low" or "medium volatility" regime. In fact, this implies that the separation of regimes is important in detecting intervention effects. Concerning the effects on volatility, the results differ in comparison to the EGARCH model in two respects: First, more significant effects are found and second, in the majority of these cases intervention reduces volatility. However, similar to the EGARCH models also in the MS-ARCH models most of the estimated intervention effects are not significant. Therefore, we conclude that there is no systematic and predictable impact of intervention.

5 Conclusion

In this paper we analyze the effects of interventions undertaken by the Banque de Belgique, the Danmarks Nationalbank, the Banco d'Espana, the Banque de France, the Central Bank of Ireland and the Banco de Portugal on the conditional mean and variance in the period from August 1993 to April 1998. We apply GARCH and Markov switching ARCH models. In general, our results show that there are nonlinearities in exchange rate behavior and that different periods are characterized by different degrees of mean reversion. Furthermore, it seems that mean reversion is not generated by central bank intervention but may be caused by stochastic processes of other fundamentals.

The results from the EGARCH-models show that interventions influenced the conditional mean in only one case. With regard to the conditional variance, for three out of six currencies we do not detect any significant intervention effect at all. For the remaining currencies, we find—depending on whether DEM-purchases or -sales are considered—volatility increasing and decreasing effects.

In contrast to the EGARCH model, the MS-ARCH model allows that the effect of intervention is different across regimes. In general, the MS-ARCH results reveal more significant effects of intervention on the conditional means and variances. For the conditional variance, the results—if significant—show that in the majority of cases DEM-purchases or -sales decreased volatility. Furthermore, the effects on the mean are found to appear only in periods of low and medium volatility. However, similar to the EGARCH models, also in the MS-ARCH models most of the estimated intervention effects are not significant.

Given our approaches (EGARCH and MS-ARCH), we therefore conclude that there does not seem to be a systematic and predictable impact of DEM-intervention on the level and volatility of the six ERM I exchange rates. This is in line with the empirical literature about the impact of interventions in floating exchange rate regimes.

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A Appendix

Appendix: Data Description

- Our sample ranges from 3/8/1993 to 30/4/1998.
- Δs_t … The dependent variable is 100 times the log difference of units of local currency expressed in Deutsche Mark (DEM). An appreciation of the local currency corresponds to a positive change. The exchange rate series are taken from the BIS database (USD exchange rates). The USD rates are converted to bilateral rates by assuming that the no-triangular-abitrage condition holds.
- $I_t^{(S)}$ … the amount of sales by the local central bank expressed in DEM.
- $I_t^{(P)}$ … the amount of purchases by the local central bank expressed in DEM. Both intervention series record the cumulated daily intervention volume as reported in the daily concertation rounds (source: own calculation). In estimation we use the natural logarithm of the intervention amounts if positive and zero else.
- $D_t^{(C)} = \log S_t - \log(\text{Central Parity})_t$ … the log deviation of the exchange rate from the central parity. The variable used in the tables is divided by 0.15.
- In the EGARCH estimation results for the Danish Krone (DKK), the Spanish Peseta (ESP), the French Francs (FRF), the Irish Pound (IEP) and the Portuguese Escudo (PTE) a realignment dummy in the mean equation is used which takes a value of 1 on March 6, 1995 and zero else. For IEP an additional dummy is used for the realignment of the Irish Pound on March 16, 1998.

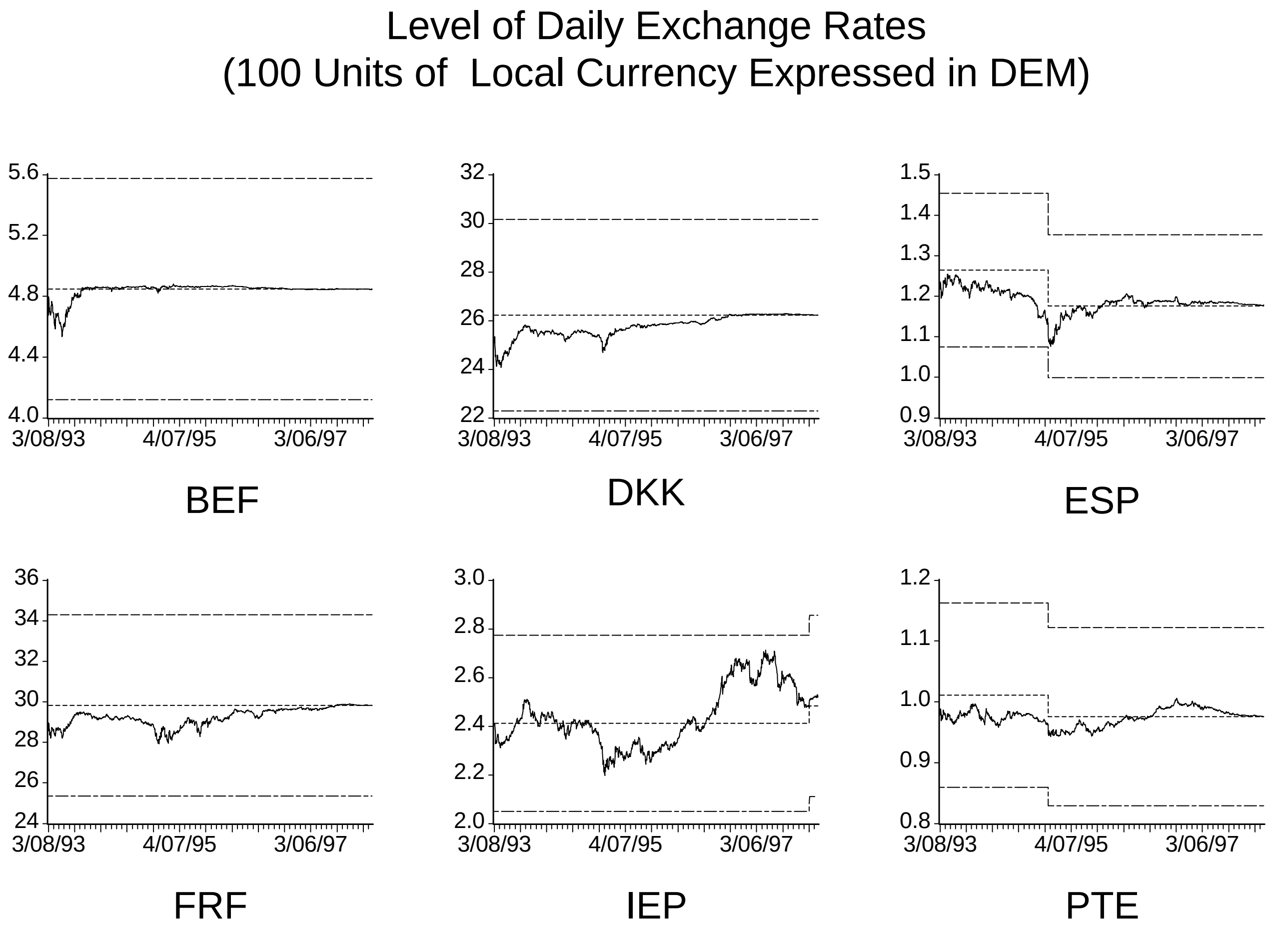


Figure A.1: The Position of the Exchange Rates in the Band, 3/8/1993–30/4/1998

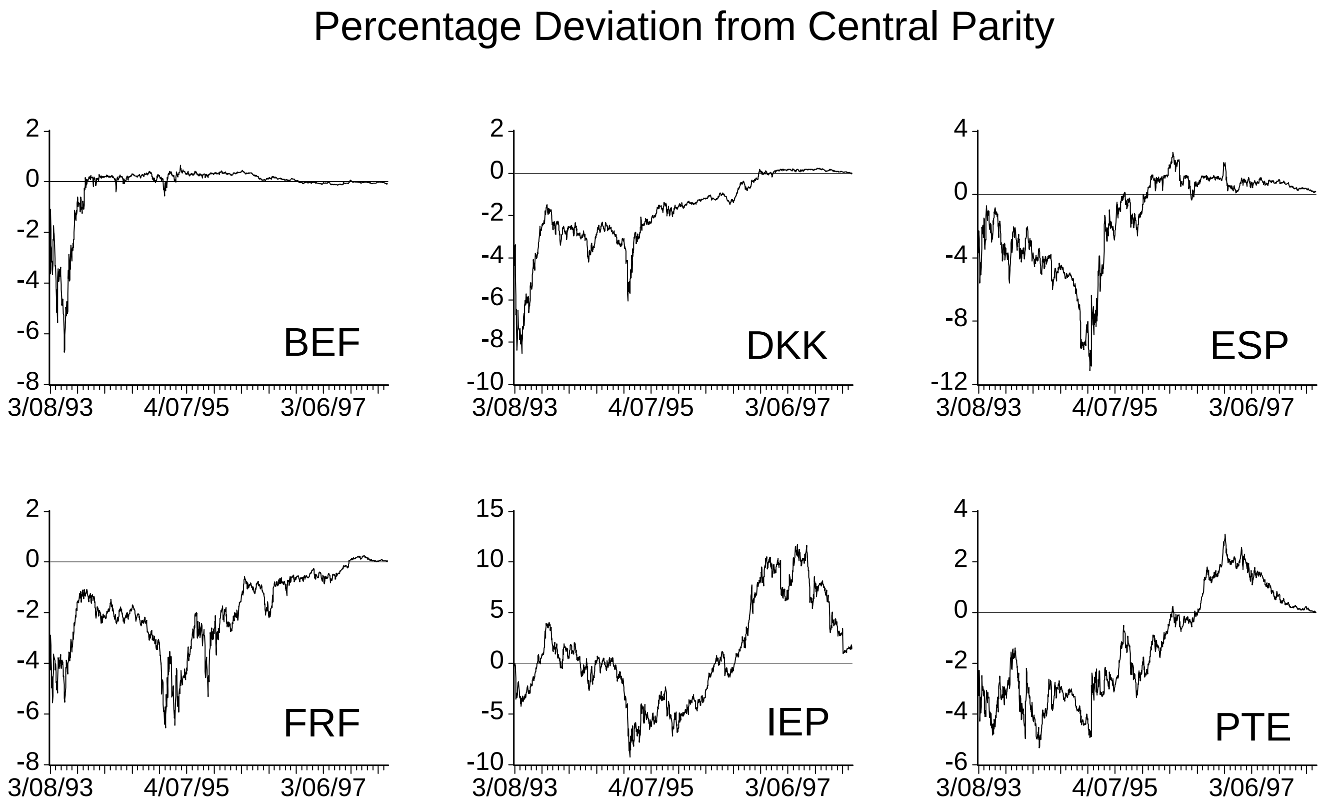


Figure A.2: Percentage Deviation from Central Parity, 3/8/1993–30/4/1998

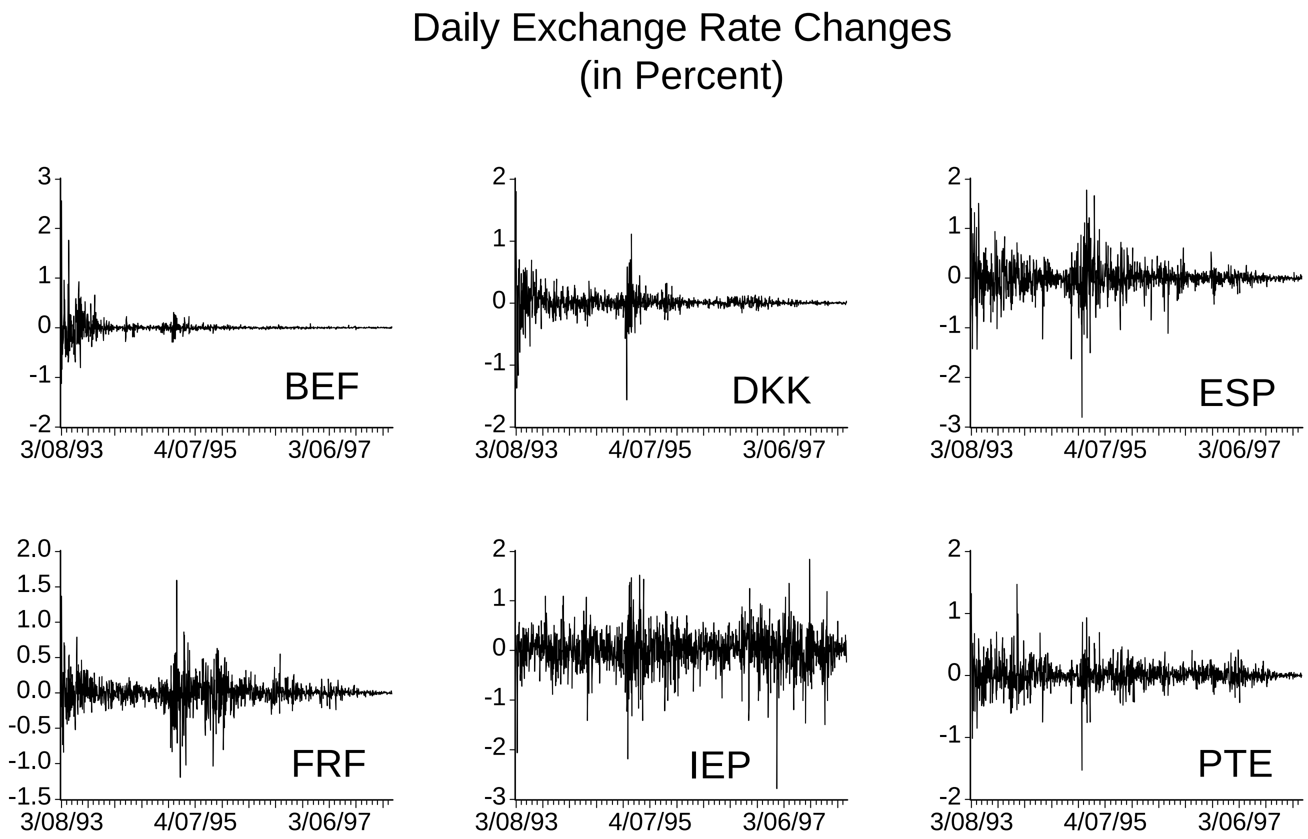
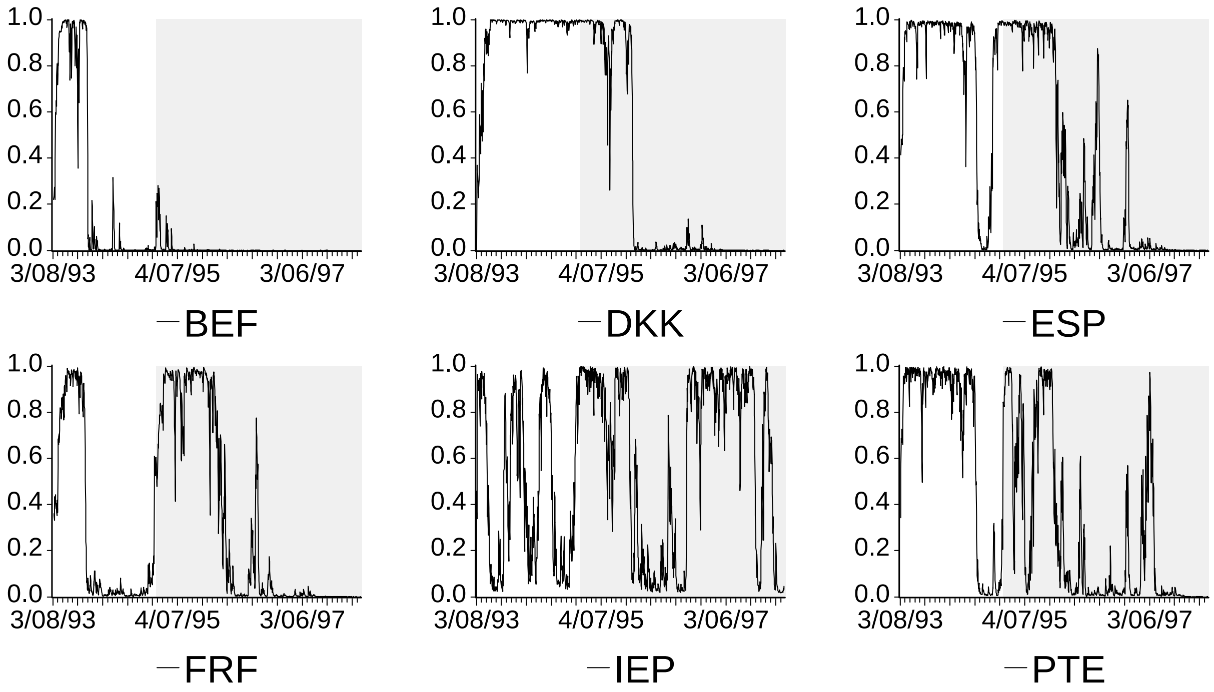


Figure A.3: Daily Exchange Rate Returns, 3/8/1993–30/4/1998

Ex-Post Probability of Regime 1
("High Volatility")



The start date of the shaded area represents the realignment
of the Peseta and the Escudo (March 6, 1995)

Figure A.4: MS-ARCH Model, Ex-Post Probabilities of Regime 1, $P(Z_t = 1 \mid \Omega_t)$

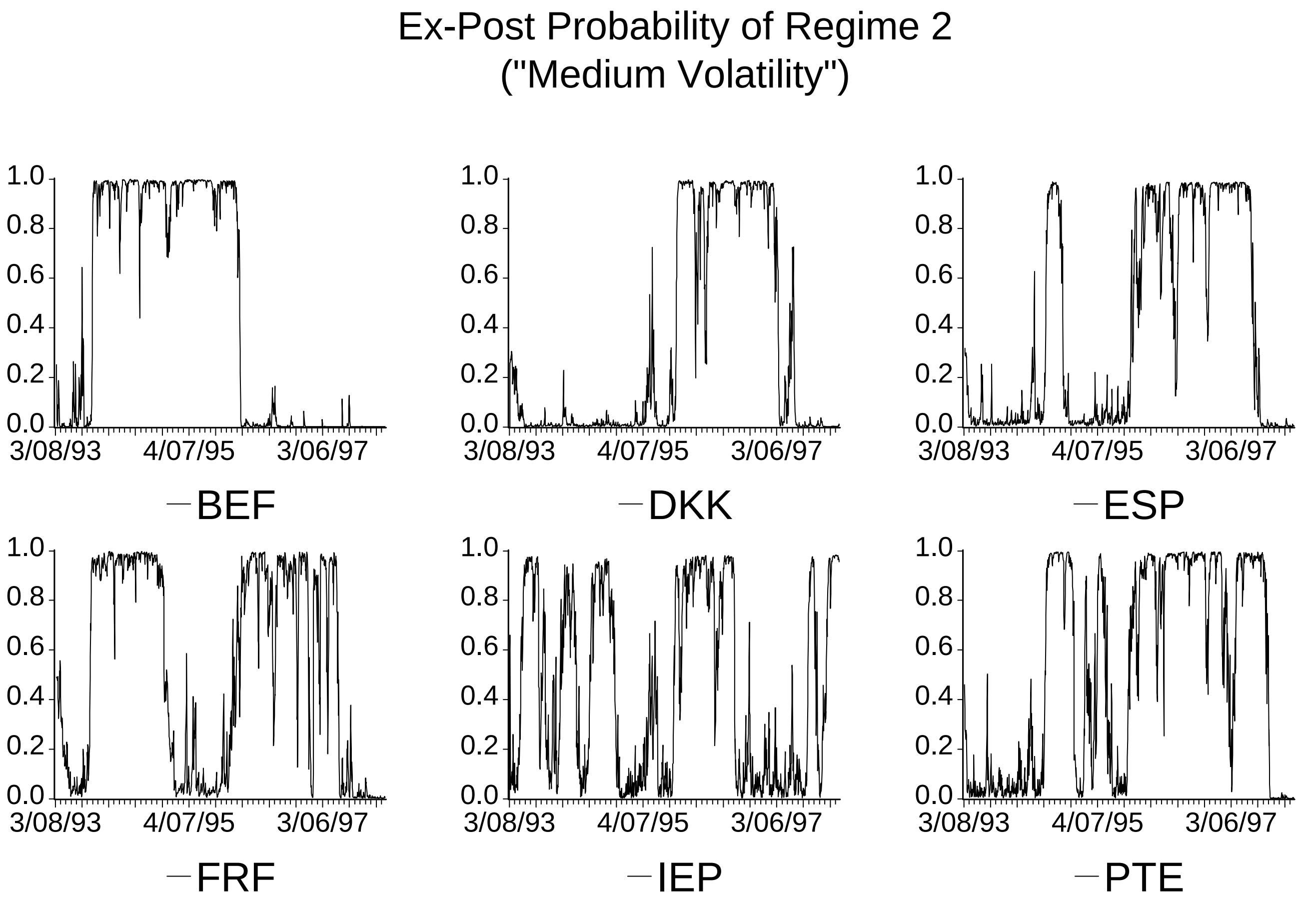


Figure A.5: MS-ARCH Model, Ex-Post Probabilities of Regime 2, $P(Z_t = 2 \mid \Omega_t)$

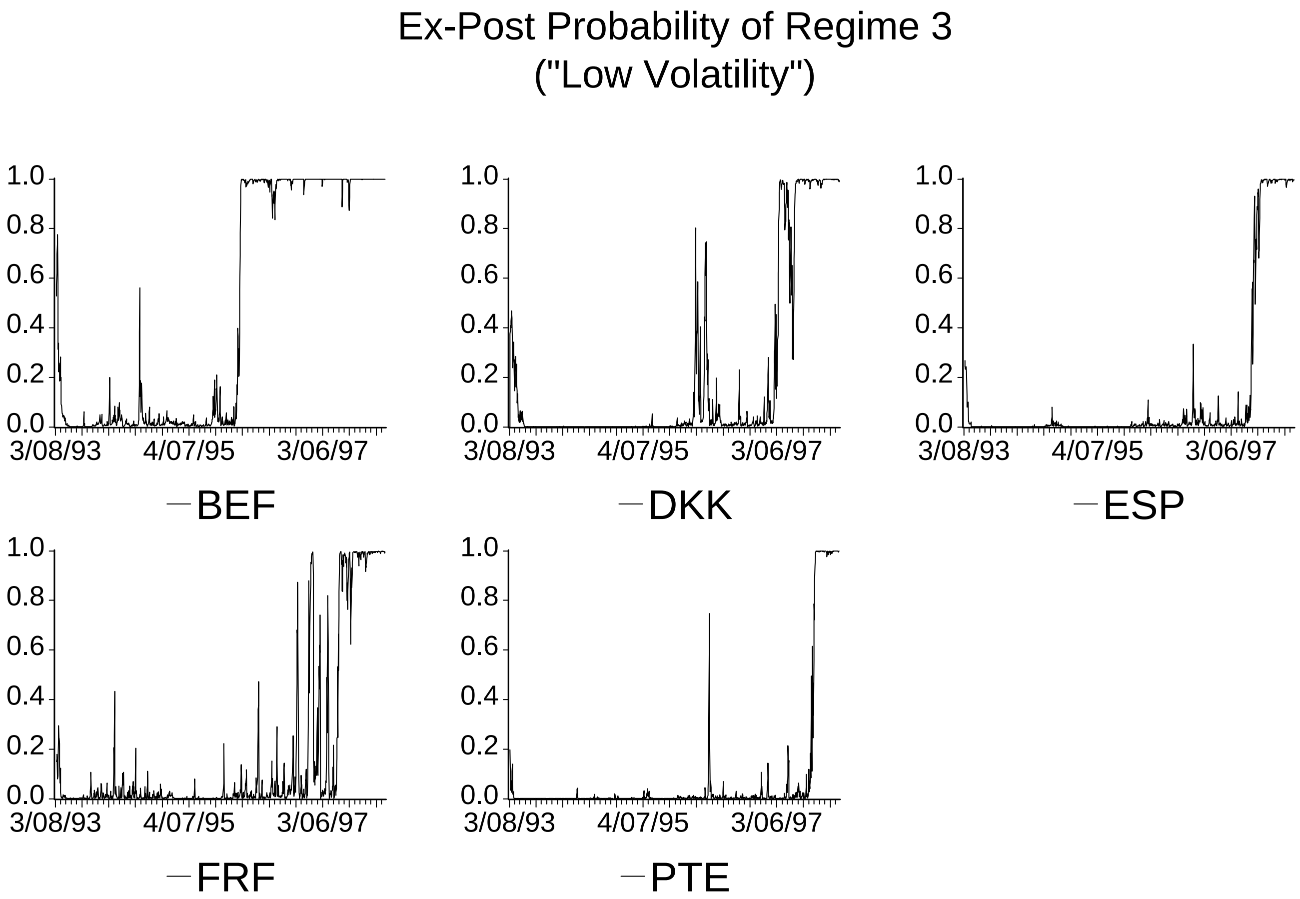


Figure A.6: MS-ARCH Model, Ex-Post Probabilities of Regime 3, $P(Z_t = 3 \mid \Omega_t)$

Table 1: Descriptive Statistics for Daily Exchange Rate Returns

		BEF	DKK	ESP	FRF	IEP	PTE
Δs_t	Mean ($\times 10^2$)	0.20	0.50	-0.16	0.33	0.40	0.08
		[0.65]	[0.28]	[0.85]	[0.54]	[0.73]	[0.88]
	Median ($\times 10^2$)	-0.03	0.01	0.00	0.00	0.91	0.00
	Maximum	2.56	1.80	1.78	1.59	1.84	1.47
	Minimum	-1.13	-1.57	-2.81	-1.19	-2.79	-1.53
	Std. Dev.	0.15	0.16	0.30	0.19	0.40	0.19
	Skewness	4.84	-0.30	-0.53	0.34	-0.59	0.28
	Kurtosis	88.98	34.62	15.35	14.65	7.45	14.16
	Jarque-Bera	386201.80	51606.23	7927.35	7028.45	1094.20	6435.59
	$\rho(1)$	-0.10	0.10	0.08	0.00	-0.07	-0.03
	$Q(20)$	110.87	99.64	40.65	42.61	23.50	34.36
		[0.00]	[0.00]	[0.00]	[0.00]	[0.27]	[0.02]
	$Q^2(20)$	206.43	751.40	580.79	623.65	113.47	300.07
		[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
$\log S_t$	Phillips-Perron	-3.37	-1.77	-2.33	-2.13	-1.27	-2.12
	ADF	-2.75	-2.29	-2.24	-2.07	-1.30	-2.02

Note: Δs_t is 100 times the log difference of the amount of Deutsche Mark per 100 units of local currency (S_t). P-values in brackets. P-values below the means are based on a test of the null hypothesis of zero mean. P-values below Jarque-Bera are based on the respective test for normality. $\rho(1)$ denotes the value of the autocorrelation function at the first lag, $Q(20)$ and $Q^2(20)$ denote the Ljung-Box Q-statistics with lag length 20. The respective p-values are below the test statistics. Phillips-Perron and ADF give the test statistic for the respective unit root tests. The 5% (10%) critical values are -2.86 (-2.57). The sample ranges from 3/8/1993 - 30/4/1998 and contains N=1238 daily observations.

Table 2: EGARCH Estimation Results

$$\Delta s_t = c_0 + c_1 \cdot D^{(C)}_{t-1} + c_2 \cdot I^{(P)}_{t-1} + c_3 \cdot I^{(S)}_{t-1} + \sqrt{h_t} \cdot \epsilon_t$$

$$\log h_t = \phi_0 + \phi_1 \cdot \mid \frac{\epsilon_{t-1}}{\sqrt{h_{t-1}}} \mid + \phi_2 \cdot \frac{\epsilon_{t-1}}{\sqrt{h_{t-1}}} + \phi_3 \cdot \log h_{t-1} + \delta_1 \cdot \mid D^{(C)}_{t-1} \mid + \delta_2 \cdot I^{(P)}_{t-1} + \delta_3 \cdot I^{(S)}_{t-1}$$

	BEF	DKK	ESP	FRF	IEP	PTE
c_0	-0.001	0.000	-0.004	-0.001	0.012	-0.003
	(0.001)	(0.001)	(0.003)	(0.001)	(0.010)	(0.002)
c_1	-0.167 **	-0.056 **		-0.058 **		
	(0.061)	(0.020)		(0.029)		
c_2 ($\times 10^2$)						1.681 *
						(0.938)
c_3 ($\times 10^2$)						
ϕ_0	-0.200 **	-0.314 **	-0.189 **	-0.201 **	-0.290 **	-0.243 **
	(0.037)	(0.070)	(0.046)	(0.050)	(0.110)	(0.055)
ϕ_1	0.188 **	0.230 **	0.143 **	0.121 **	0.163 **	0.216 **
	(0.045)	(0.034)	(0.031)	(0.028)	(0.051)	(0.041)
ϕ_2	-0.093 **	-0.067 **	-0.054 *	-0.068 **	-0.024	0.012
	(0.043)	(0.031)	(0.034)	(0.020)	(0.031)	(0.045)
ϕ_3	0.991 **	0.978 **	0.985 **	0.987 **	0.935 **	0.987 **
	(0.002)	(0.008)	(0.006)	(0.005)	(0.035)	(0.006)
δ_1		0.207 *	0.163 **	0.192 **	0.150	0.187 *
		(0.123)	(0.059)	(0.095)	(0.108)	(0.101)
δ_2 ($\times 10^2$)			1.568 **	0.827 **		
			(0.542)	(0.317)		
δ_3 ($\times 10^2$)		-0.031 *	-1.582 *	2.577 **		
		(0.019)	(0.809)	(0.659)		
LogL	2508.61	1614.96	338.30	1026.52	-538.24	719.51
Diagnostics						
$Q(20)$	21.12	33.13 **	18.07	17.74	19.75	14.88
$Q^2(20)$	12.39	21.04	13.66	23.59	16.20	14.48
Kurtosis	9.06 **	4.23 *	8.31 **	4.74 **	5.77 **	5.46 **
J-B	1896.78 **	77.61	1492.39 **	170.29 **	436.74 **	338.18 **

Note: QML standard errors in parentheses. A ** (*) means that the coefficient is significantly different from zero at a 5% (10%) level. The variables are defined above. $Q(20)$ and $Q^2(20)$ denote the test statistics for the Ljung-Box Q-test with lag length 20. The null of no autocorrelation in the standardized residuals is rejected at a 5% (10%) significance level if the test statistic is greater than 31.41 (28.41). J-B gives the Jarque-Bera test statistic for normality. The null hypothesis is rejected at a 5% significance level if the test statistic is greater than 5.99. The asterisks in the kurtosis row are based on a test whether the excess kurtosis is different from zero. The mean equations contain realignment dummies for DKK, ESP and PTE. The sample ranges from 3/8/1993 - 30/4/1998 and contains N=1238 daily observations.

Table 3: Summary of EGARCH Estimation Results: Effect of Intervention on Volatility

	BEF	DKK	ESP	FRF	IEP	PTE
DEM-purchases	·	·	++	++	·	·
DEM-sales	·	−	−	++	·	·

Note: The table entries represent the signs of the effects of either DEM-sales or DEM-purchases on the conditional variance in the EGARCH model. A "−−" or "++" ("-" or "+") means that the coefficient is significantly different from zero at a 5% (10%) level. The effects are taken from Table 2 in the Appendix.

Table 4: MS-ARCH Estimation Results

		BEF	DKK	ESP	FRF	IEP	PTE
Mean	c_{10}	0.757	-4.391	-0.060	-1.477 **	0.736	-4.830 **
		(2.553)	(3.251)	(0.197)	(0.673)	(1.746)	(2.252)
	c_{11}		-0.288		-0.136 **		-0.214 **
			(0.172)		(0.053)		(0.106)
	c_{20}	2.693 **	0.429 **	-0.060	-1.477 **	2.602 **	0.446
		(0.576)	(0.208)			(1.076)	(0.394)
	c_{21}	-1.493 **			-0.136 **	-0.125 **	
		(0.313)				(0.057)	
	c_{30}	-0.075 **	-0.153 *	-0.060	0.283 **		0.242
		(0.036)	(0.086)		(0.125)		(0.368)
	c_{31}				-0.485 **		-0.562 **
					(0.083)		(0.257)
Variance	ω_1	7.662 **	1.328 **	9.073 **	3.444 **	21.194 **	4.848 **
		(2.471)	(0.323)	(1.660)	(0.542)	(2.085)	(0.658)
	α_1	0.393 **	0.200 **	0.147 **	0.102	0.090 **	0.127 **
		(0.096)	(0.073)	(0.048)	(0.063)	(0.041)	(0.045)
	α_2	0.111 *	0.339 **	0.209 **	0.162 **		0.117 **
		(0.061)	(0.094)	(0.060)	(0.052)		(0.051)
	α_3	0.175 **	0.203 **	0.088 **	0.114 **		0.081 *
		(0.071)	(0.069)	(0.043)	(0.047)		(0.041)
	α_4	0.18 **		0.134 **	0.009		
		(0.056)		(0.054)	(0.029)		
	α_5				0.175 **		
					(0.047)		
	ϕ				0.233 **		
					(0.100)		
	ω_2	0.077 **	0.155 **	1.097 **	0.448 **	6.198 **	0.900 **
		(0.016)	(0.041)	(0.230)	(0.071)	(0.671)	(0.118)
	ω_3	0.007 **	0.019 **	0.102 **	0.018 **		0.054 **
		(0.001)	(0.005)	(0.026)	(0.005)		(0.013)

Note: Robust (QML) standard errors in parentheses. If there is no standard error reported then the point estimate is restricted. The sample ranges from 3/8/1993 - 30/4/1998 and contains N=1238 daily observations. See continuation on next page.

Table 4: MS-ARCH Estimation Results (continued)

		BEF	DKK	ESP	FRF	IEP	PTE
Probabilities	p_{11}	0.998 **	0.999 **	0.997 **	0.995 **	0.989 **	0.992 **
		(0.006)	(0.002)	(0.003)	(0.003)	(0.000)	(0.005)
	p_{12}	0.002 *	0.001	0.004	0.003		0.006
		(0.001)	(0.001)	(0.003)	(0.003)		(0.004)
	p_{22}	0.997 **	0.997 **	0.995 **	0.994 **	0.986 **	0.993 **
		(0.002)	(0.004)	(0.003)	(0.004)	(0.000)	(0.004)
	p_{33}	0.999 **	0.999 **	0.998 **	0.993 **		0.998 **
		(0.000)	(0.002)	(0.001)	(0.007)		(0.011)
d.o.f.	ν	3.566 **	3.386 **	3.804 **	6.499 **	5.876 **	4.773 **
		(0.376)	(0.404)	(0.399)	(1.399)	(1.018)	(0.732)
Diagnostics	Log L	2622.82	1607.13	403.31	1036.55	-496.25	757.67
	$Q(20)$	24.35	39.66 **	16.99	16.96	21.21	21.56
	$Q^2(20)$	7.6	19.29	12.94	27.24	16.87	12.01

Note: Robust (QML) standard errors in parentheses. For all currencies except the Irish Pound, the estimated model is a 3 regime SWARCH(-L) model where,

$$\begin{aligned} \Delta s_t &= c_{i0} + c_{i1} \cdot D^{(C)}_{t-1} + c_{i2} \cdot I^{(P)}_{t-1} + c_{i3} \cdot I^{(S)}_{t-1} + \sqrt{h_{i,t}} \cdot u_t \ , \\ h_{i,t} &= \omega_i + \sum_{j=1}^{p} \alpha_j \cdot \epsilon^2_{t-j} + \phi \cdot D_{t-1} \cdot \epsilon^2_{t-1} \ , \\ \epsilon_t &\sim iid \text{ Student-}t\ (0, 1, \nu) \ . \end{aligned}$$

where i indexes the regimes and D_{t-1} is a dummy variable taking a value of one if $\epsilon_{t-1} < 0$. Notice, that the α_j's are restricted to be the same across regimes. The error term is defined as,

$$\begin{aligned} \epsilon_{t-1} &= \Delta s_{t-1} - E(\Delta s_{t-1} \mid \Omega_{t-2}) \ , \\ &= \Delta s_{t-1} - \sum_{i=1}^{3} p_{i,t-1} \cdot \mu_{i,t-1} \ , \end{aligned}$$

where $p_{i,t-1}$ is the time $t-1$ probability of regime i conditional on information up to time $t-2$ and $\mu_{i,t-1}$ denotes the conditional mean. The transition probability matrix takes the following form,

$$P = \begin{pmatrix} p_{11} & p_{12} & 0 \\ p_{21} & p_{22} & p_{23} \\ 0 & p_{32} & p_{33} \end{pmatrix} , \tag{6}$$

where $p_{ij} = P(Z_t = j \mid Z_{t-1} = i)$. For the Irish Pound a 2-regime model is estimated without restrictions on the transition probability matrix. The variables are defined on page 31. Log L denotes the log likelihood value. $Q(20)$ and $Q^2(20)$ denote the test statistics for the Ljung-Box Q-test with lag length 20. The null of no autocorrelation in the standardized or squared standardized residuals is rejected at a 5% (10%) significance level if the test statistic is greater than 31.41 (28.41).

Table 5: Summary of MS-ARCH Estimation Results:
Effect of Intervention on Regime Specific Means

	Regime	BEF	DKK	ESP	FRF	IEP	PTE
DEM-purchases	High vol.	x	++	·	·	·	x
	Medium vol.	·	·	−−	·	x	·
	Low vol.	−−	·	x	·		x
DEM-sales	High vol.	·	x	·	·	·	·
	Medium vol.	·	++	++	·	·	−−
	Low vol.	·	·	·	x		·

Note: Summary of the estimation results for the MS-ARCH models. The table entries represent the sign of the coefficient of either DEM-sales or DEM-purchases on the conditional mean in the respective regime (as shown in Eq. 3). A "−−" or "++" ("-" or "+") means that the coefficient is significantly different from zero at a 5% (10%) level. "x" indicates that there were less than ten interventions in that regime, thus intervention were not included in this regime. Notice, that for IEP a two regime model is estimated. Thus for IEP, the entries for the "low volatility" regime are empty. QML standard errors are used to calculate the individual t-statistics.

Table 6: Summary of MS-ARCH Estimation Results:
Effect of Intervention on Regime Specific Variances

	Regime	BEF	DKK*	ESP*	FRF*	IEP*	PTE
DEM-purchases	High vol.	x	−−	−−	·	·	x
	Medium vol.	·	−−	·	·	x	·
	Low vol.	·	·	x	·		x
	Regime	BEF*	DKK	ESP	FRF	IEP*	PTE
DEM-sales	High vol.	+	x	·	·	·	nc
	Medium vol.	+	−−	−	·	·	−−
	Low vol.	·	−−	−−	x		−

Note: Summary of the estimation results for the MS-ARCH models amended by either DEM-sales or purchases (as shown in Eq. 5). The table entries represent the sign of the coefficient of either DEM-sales or DEM-purchases in the respective regime specific conditional variance. An asterisk ("*") next to the currency code indicates that the model was estimated with all three interventions entering simultaneously. A "−−" or "++" ("-" or "+") means that the coefficient is significantly different from zero at a 5% (10%) level. "x" indicates that there were less than ten interventions in that regime, thus no model was estimated. "nc" means that the respective model did not converge. QML standard errors are used to calculate the individual t-statistics.

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1) vergriffen (out of print)
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