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Why Did Central Banks Intervene in the EMS?
The Post 1993 Experience*

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Abstract

In this paper, we present stylized facts of exchange rate and intervention behavior in the Exchange Rate Mechanism I (ERM I), in particular in light of the recent literature on multilateral target zone models. We estimate bilateral exchange rate distributions of the maximum spot rate deviations of six ERM-currencies explicitly taking the multilateral setting of the ERM I into account. In a further analysis, we estimate short term reaction functions for the Banque de Belgique, the Danmarks Nationalbank, the Banco d'España, the Banque de France, the Central Bank of Ireland and the Banco de Portugal by applying a Tobit analysis. The period under review ranges from August 1993 to April 1998. Daily exchange rate and intervention data are used. The exchange rate position in the band (deviation of the DEM-spot rates from the DEM-central parity) significantly induces intervention activity. There is less evidence that changes in volatility trigger central bank intervention.

JEL-Classification: E58, F31, F33

Keywords: Foreign Exchange Intervention, European Monetary System, Central Bank's Reaction Function

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1 Introduction

The effectiveness of foreign exchange intervention is heavily disputed and the issue is far from being settled by empirical evidence. Still central banks use foreign exchange intervention to influence exchange rate behavior. Why then do central banks intervene? In general, FX-interventions are primarily undertaken to maintain or defend a certain exchange rate commitment. Another important motivation is the countering of disorderly market conditions or the dampening of short term excess volatility. This kind of intervention is for instance foreseen in the Article IV of the Articles of Agreement of the International Monetary Fund.[1]

In a target zone environment, interventions are intended to keep the exchange rate within a preannounced band. The basic target zone model of Krugman (1991) maintains that the credible commitment by itself to intervene at the edges (marginal intervention) would keep the exchange rate in the band. Perfect credibility of the band would relieve the central bank from actually intervening. The Krugman model however performed poorly when applied to real-world target zones. Various extensions to the basic target zone framework evolved, one of which were the modelling of intra-marginal intervention.

More recently, the focus has turned from bilateral target zone models and its implications to multilateral target zone models, see Jørgensen and Mikkelsen (1996), Flandreau (1998) and Serrat (2000). The economics of multilateral target zones as for example the ERM I and II are different from the economics of bilateral target zones, one important aspect being endogenous intra-marginal intervention which arise from cross-currency constraints. In the ERM I, in particular after the Basle/Nyborg-Agreement in 1987, intra-marginal interventions gained a lot of practical importance and were heavily used during the 1992/93 ERM-crises. Detailed empirical evidence on ERM I-intervention behavior is rare, since ERM-intervention data are not publicly available.

Foreign exchange intervention activity in the European Monetary System[2] was recently analyzed in Brandner, Grech and Stix (2001). Covering the period from August 1993 to April 1998, they tested for the effects of intra-marginal DEM-intervention of six EMS-central banks[3] on the level and the volatility of DEM-spot rates. Applying EGARCH and Markov Switching ARCH (MS-ARCH) models, the results of that paper show that even in the same institutional framework (ERM I), intervention (DEM-purchases and/or -sales) did not affect the

[1] " ... each member undertakes to collaborate with the fund and other members to assure orderly exchange rate arrangements and to promote a stable system of exchange rates." Article IV, Section 1. *General obligations of members, Articles of Agreement, International Monetary Fund.*

[2] Although not identical, in our paper we treat the EMS and the Exchange Rate Mechanism (ERM) as synonyms, since all currencies in our empirical analysis were members of the EMS and also participated in the ERM.

[3] Banque de Belgique, Danmarks Nationalbank, Banco d'España, Banque de France, the Central Bank of Ireland and Banco de Portugal.

conditional mean and variance in a consistent and predictable way. Moreover, the effects of intervention on exchange rates were not the same across different currencies.

In this paper, we present stylized facts of exchange rate and intervention behavior in the ERM I, in particular in light of the recent literature on multilateral target zone models. We estimate bilateral exchange rate distributions of the maximum spot rate deviations of six ERM I-currencies explicitly taking the multilateral setting of the ERM into account. The kernel density estimations were undertaken for intervention days (days of DEM-purchases and DEM-sales seperatedly) and trading days without intervention. In a further analysis, we estimate short term reaction functions for the Banque de Belgique, the Danmarks Nationalbank, the Banco d'España, the Banque de France, the Central Bank of Ireland and the Banco de Portugal by applying a Tobit analysis. The period under review ranges from August 1993 to April 1998. Daily exchange rate and intervention data are used, covering unilateral DEM-purchases and -sales of the six ERM-central banks.

Exchange rate stability was one of the five convergence criteria in order to qualify for Stage III of EMU. Therefore central banks might have preferred the spot rates to remain inside an informal band narrower than the official bandwidth of ±15%. Potential candidates for EMU might have also favored stable market conditions with low exchange rate volatility during the run up to Stage III. Hence, some form of exchange rate smoothing may possibly also have played a role in intervention decisions. Our reaction function results show that the exchange rate position in the band (deviation of the DEM-spot rate from the DEM-central parity) significantly induces intervention activity. In contrast, there is only small evidence that a change in the conditional volatility triggers central bank intervention.

The paper is organized as follows: Chapter 2 discusses possible objectives of central bank intervention, Chapter 3 briefly reviews the empirical literature. In Chapter 4 the economics of target zone models is described. The data and stylized facts on exchange rate and intervention behavior are presented in Chapter 5. Chapter 6 discusses the intervention reaction functions, specified as Tobit models. In Chapter 7, we present our empirical results for the total period and various subsamples. Chapter 8 concludes.

2 Objectives of Central Bank Intervention

The objectives of central bank intervention can be classified in several ways. The Jurgensen report (1983) for instance, differentiates between interventions which are pursued on a short-term or a long-term basis; Almekinders (1995), in another classification, distinguishes between interventions, undertaken to

- reverse the current market trend (trend breaking intervention). In a target zone, like the ERM I, a fixed but adjustable exchange rate system, trend breaking interventions are intended to defend the exchange rate band. In floating rate regimes, central banks might use trend breaking interventions to correct possible misalignments, where a particular currency is generally viewed as undervalued, however without having precise and consistent ideas of the degree of misalignment. Trend breaking interventions are often undertaken simultaneously by more than one central bank (concerted or coordinated intervention).

- counter erratic short term exchange rate movements but not to alter the current trend (smoothing transactions or also termed "leaning against the wind" policy). In some situations, excess short term volatility might be harmful for political events (e.g. elections). In other situations, monetary authorities may wish to provide a guiding signal to market participants on future exchange rate developments (direction indicating interventions).

- reshuffle foreign exchange reserves for portfolio considerations and/or to assist bi- or unilaterally other central banks in conducting their foreign exchange operations (other interventions).

In the ERM I,[4] interventions had to take place whenever spot rates reached the bilateral intervention points (obligatory or marginal interventions). In addition, interventions were conducted intra-marginally to correct exchange rate levels deemed not adequately.[5] In contrast to the ERM II (see below), the ERM I relied on a 'parity grid-approach': whenever a country wanted to join the ERM I, formerly in first place, the ECU-central rate was determined. Then as a second step, the bilateral central rates (including the intervention points) were calculated. As in the ERM I all currencies were formerly linked to each other via their bilateral central rates and as intervention obligations existed in a mutual way, the ERM I truely was a multilateral target zone.

In practice however, what is extensively known, the formaly symmetrically designed ERM I, soon evolved as an asymmetric exchange rate system, where the Deutsche Mark assumed the anchor role. Consequently the bilateral DEM-central rates and fluctuations of the DEM-spot rates practically gained more importance than any other rates or deviations in the system. Another consequence was

[4] The most important basic documents were the *"Resolution of the European Council on the establishment of then European Monetary System (EMS) and related matters (1978)"* and *"The Agreement of the 13th March 1979 between the Central Banks of the Member States of the European Economic Community laying down the operating procedures for the European Monetary System"*

[5] "When a currency crosses its 'threshold of divergence', this results in a presumption that the authorities concerned will correct this situation by adequate measures, namely (a) diversified intervention; (b) measures of domenstic monetary policy; (c) changes in central rates; (d) other measure of economic policy.", *Resolution of the European Council on the establishment of the European Monetary System (EMS) and related matters (1978),* Section 3.6 .

that—already in the eighties—intervention activity shifted from the US Dollar to the Deutsche Mark; the Deutsche Mark became the most important ERM-intervention currency.

On December 31, 1998 the EMS (and the ERM I) ceased to exist and was replaced by the ERM II which entered into force on 1 January 1999.[6] Compared to its predecessor, the ERM II has adopted a different approach, the "hub-and spokes-approach". Currencies of Member States outside the euro area are linked to the euro only and not vis-a-vis each other. Fluctuation bands are set at ±15% around the euro-central rates or narrower, depending on progress towards convergence. Interventions have to be undertaken symmetrically and obligatory at the margins, however with the right for both sides to suspend the automatic intervention, if a conflict with the primary objective of maintaining price stability arises. In contrast to the ERM I, no bilateral central rates between the non euro-member currencies and no bilateral intervention obligations between the non euro-member currencies exist. In addition to obligatory interventions, the ERM II also entails provisions for intra-marginal interventions.[7] The most recent example for intervention activity in the ERM II are the euro-interventions undertaken by the Danmarks Nationalbank after the Danish EU referendum in September 2000.

In the next section, we briefly review the empirical evidence of intervention reaction functions.

3 Empirical Evidence in the Literature

There is a lot of empirical research on the effectiveness of foreign exchange intervention, where the effects of intervention on the level and the volatility are analyzed.[8] In this line of research, intervention is generally assumed to be an exogenous signal. But if intervention policy is motivated by the objective of

[6] The rules and regulations are mainly laid down in the *Agreement of 1 September 1998 between the European Central Bank and the National Central Banks of the Member States outside the Euro Area laying down the Operating Procedures for an Exchange Rate Mechanism in Stage Three of Economic and Monetary Union* and in the *Agreement of 1 December 1998 between the European Central Bank and the National Central Banks of the Member States outside the Euro Area establishing the Manual Procedures implementing the Agreement of 1 September 1998 laying down the Operating Procedures for an Exchange Rate Mechanism in Stage Three of Economic and Monetary Union.*

[7] "... Whereas intervention shall be used as a supportive instrument in conjunction with other policy measures, including appropriate monetary and fiscal policies conducive to economic convergence and exchange rate stability. There will be the possibility of coordinated intramarginal intervention decided by mutual agreement between the ECB and the respective participating non-euro area NCB, in parallel with other appropriate policy responses, including the flexible use of interest rates, by the latter; ... " and "... The ECB and participating non-euro area NCBs may agree to conduct coordinated intramarginal intervention ... ".

[8] For comprehensive surveys see, e.g., Dominguez and Frankel (1993), Edison (1993), Almekinders (1995), Schwartz (2000), Girardin (2000) and Sarno and Taylor (2001).

"calming disorderly markets", the correlation of exchange rate volatility and intervention may be the result of "reversed causation". To address the issue of "reverse causality", intervention reaction functions have been estimated. The main findings of the more recent contributions are based on qualitative choice models and are briefly described as follows:

Almekinders and Eijffinger (1994) apply a Tobit-analysis for the USD/DEM-rate for the period September 1987 to October 1989 (four subsamples) and find that an increase in the conditional variance leads central banks to increase the volume of intervention for DEM-purchases and DEM-sales. In another paper, Almekinders and Eijffinger (1996) combine a GARCH model with a loss function for the central bank to derive formally the intervention reaction function. They consider the sample period from February 1987 to October 1989 and employ a friction model to estimate the reaction function for the Bundesbank and the Fed. Both central banks appear to have "leaned against the wind" and reacted to increases in the conditional variance of the DEM/USD-returns.

Lewis (1995) applies a multinomial Logit-model for the USD/DEM- and USD/JPY-rate from February 1987 to October 1987 in order to test for the existence of implicit bands during the Louvre period. She finds that the intervention probability of the Fed, the Bundesbank and the Bank of Japan increases as the spot rate moves away from the target levels agreed in the Plaza-Agreement.

Baillie and Osterberg (1997a, 1997b) investigate the effects of intervention in the USD/DEM and USD/JPY-market for the period August 1985 to March 1990. In the first paper, the authors find that for the USD/DEM-rate the deviation from a target level Granger-causes intervention. Excess volatility, however, did not increase the probability of intervention. For the USD/JPY-market, they find mixed evidence. Increased volatility led to USD-purchases—but no evidence for DEM-sales. The deviation from a target value—in contrast to the USD/DEM-market—did not trigger intervention transactions. In the second paper, results from Probit-models provide no evidence that the volatility of the forward premium Granger-causes intervention.

Dominguez (1998) analyzes the reverse causality for the USD/JPY and USD/DEM-exchange rates and the intervention behavior of the three central banks involved for the period from February 1985 to December 1994 (and in various subsamples). She applies Probit-models and rejects the hypothesis that exchange rate volatility Granger-causes central bank intervention.

Döpke and Pierdzioch (1999) use a multinomial Logit model to estimate reaction functions of the Deutsche Bundesbank. The period under review is January 1985 to December 1997, four subsamples being formed. Both, the deviation from a target value as well as a change in volatility in the USD/DEM-rate, measured via an option based approach, have an impact on the intervention decisions of the Bundesbank. They also find that the Bundesbank's reaction function is not stable over the entire sample. Furthermore, they find asymmetric responses of the Bundesbank to changes in volatility in two of four subsamples.

Galati and Melick (1999) analyze the relationship between central bank intervention and market expectations of the USD/JPY-exchange rate. The authors estimate probability density functions of future USD/JPY-rates and draw not only on mean and variance, but also on skewness and kurtosis to describe and interpret daily market conditions. Instead of actual intervention data, they use press reported data. The results of the estimations for the Fed show that—in the eyes of the market—interventions were undertaken to support the US Dollar when the Dollar was already appreciating. The Bank of Japan, in contrast, seems to have responded to deviations from a target spot rate level, but not to variations in the spot rate volatility.

Summarizing these contributions, we observe that most of the empirical literature focuses on floating exchange rate regimes, predominantly analyzing the exchange rate relations between the US Dollar, the Deutsche Mark and the Japanese Yen. When estimating reaction functions, interventions were mainly found to be driven by attempts to correct spot rates deviations from levels which were regarded as being fundamentally justified. There is mixed evidence that an increase in volatility triggered intervention.

4 Modelling Target Zones

4.1 The Basic (Bilateral) Target Zone Model

In the basic target zone model of Krugman (1991), the exchange rate is determined by some fundamentals and by the expected change of the exchange rate. Under an intervention commitment, monetary authorities are obliged to react whenever spot rates hit the edges of the target zone by changing the fundamentals. If the assumptions of the model hold, no interventions would take place, since the credible commitment by itself would keep the exchange rate in the band. The linkage between the fundamentals and the exchange rate would be non-linear ("S-shaped") with a slope in general—and at the margins in particular—less than one ("honeymoon effect"). The second result of the Krugman model, the "smooth pasting condition" reflects the idea that the closer the exchange rate approaches the margin, the less sensitive the exchange rate reacts to underlying shocks because of expected stabilizing intervention by the monetary authority. Combining the "honeymoon effect" and "smooth pasting condition", the unconditional exchange rate distribution would be U-shaped (bimodal) with a high density mass of spot rate observations close to the edges of the target zone. This would imply that the introduction of a target zone is able to reduce exchange rate volatility, since spot rates, in a target zone predominately moving near the edges of the band, are less sensitive to changes in fundamentals. Therefore, compared to a free float solution, a target zone would provide less exchange rate variability. Svensson (1992) and Kempa and Nelles (1999) surveyed the theory of exchange rate target zones in a more comprehensive way.

However, when confronted with data from the EMS, the predictions of the model have been rejected in a number of tests. Empirical research shows, that—inter alia—exchange rate distributions in the EMS are rather hump-shaped than U-shaped, demonstrating that exchange rates show a tendency to gather around bilateral parities (e.g. Flood, Rose and Mathieson 1991, Dominguez and Kenen 1992, Beetsma and Van der Ploeg 1994). Chen and Giovannini (1992) show that the unconditional distributions of EMS-exchange rates can take several different shapes. To improve the basic Krugman model, it has been proposed—inter alia—to extend the simple marginal intervention rule by including bilateral intra-marginal intervention (e.g. Lindberg and Söderlind, 1994).

4.2 The Multilateral Target Zone Model

More recently, the focus has turned from bilateral target zone to multilateral target zone models. Jørgensen and Mikkelsen (1996), Flandreau (1998) and Serrat (2000) analyze exchange rate behavior and intra-marginal intervention in a multilateral target zone context. As already mentioned earlier, in the ERM I exchange rates were linked in a cobweb and not via an isolated set of bilateral bands. Consequently, the results of the basic target zone model cannot be directly applied to a multilateral setting.[9] In general, the exchange rate between any two countries will depend on the fundamentals of other countries in a multilateral target zone. The larger the number of participating currencies in a multilateral exchange rate system, the larger the number of restrictions and the less flexibility the system offers.[10] Flandreau (1998) argues that interventions by one central bank undertaken in order to influence one spot rate generate "externalities" in a sense that the other exchange rates are influenced as well. Intra-marginal interventions, potentially creating unpleasant externalities to other currencies, are causing intra-marginal interventions by other central banks, which ultimately leads to situations where exchange rates fluctuate around the mid of the band. This is clearly in opposite to the predictions of the Krugman model.

With respect to exchange rate volatility, the multilateral target zone framework also differs considerably from the implications of the basic bilateral target zone. In a bilateral target zone, the exchange rate volatility is a decreasing monotonic function of the distance from the bilateral central rate to the the margins.

[9] For example, the Krugman model implies that the volatility of the exchange rate is always less than the exchange rate volatility under a free float regime. In a multilateral target zone, however, exchange rate volatility can be even larger than under a free float (Serrat 2000): Cross-currency constraints add more macroeconomic uncertainty to an exchange rate via the other participating currencies, compared to a free-float regime, where only the fundamentals of two currencies determine the bilateral exchange rate.

[10] In a n-country target zone system there are $(n-1)n/2$ bilateral exchange rates with $n-1$ being independent.

This does not hold for multilateral target zones: The exchange rate volatility is no longer a monotonic function of the distance. It might even vanish with the exchange rate being well inside the band, see Serrat (2000). Jørgensen and Mikkelsen (1996) reach similar conclusions.

Honohan (1993, 1998) and Pill (1996) point out that in the ERM I, exchange rate distributions are to be analyzed in a multilateral framework and not, as was common practice in earlier research, in a bilateral DEM-setting. Honohan (1998) argues that it could be misleading to analyze the position of a currency within the band simply by referring to the bilateral position vis-à-vis the Deutsche Mark. A currency could be well around or even at the bilateral central rate against the Deutsche Mark, nevertheless this does not rule out that the same currency could simultaneously be at the margin against a third currency. Even under the assumption of a uniform multivariate exchange rate distribution, the bilateral distribution would be hump-shaped. With an increasing number of participating currencies, the bilateral exchange rate distributions would converge to an inverted V-shape. Hence, the stylized fact of hump-shaped bilateral exchange rate distributions may therefore be mainly due to the multilateral nature of the ERM.[11] In Flandreau's (1998) three currency-model, the multilateral exchange rate distribution shows two humps, reflecting two intra-marginal targets. The higher the externalities, the closer the two humps approach, in the end collapsing to a hump-shaped density form. Furthermore, higher externalities result in effective exchange rate bands which are narrower than the formerly agreed nominal bands.

5 Stylized Facts of Exchange Rate and Intervention Behavior

5.1 Data

We analyze the period from August 3, 1993, the first day after the widening of the bands to ±15%, to April 30, 1998, the day before the European Monetary Union Stage III start-up member countries were officially announced. Our sample contains daily bilateral Deutsche Mark (DEM) exchange rates and intervention data for the following currencies: the Belgian Franc (BEF), the Danish Krona (DKK), the Spanish Peseta (ESP), the French Franc (FRF), the Irish Pound (IEP) and the Portuguese Escudo (PTE). Since the Deutsche Mark assumed the pivot role in the ERM I, we focus on bilateral Deutsche Mark spot rates and interventions denominated in Deutsche Mark. Interventions in other currencies occurred on rare occasions.

[11] Pill (1996) argues along the same lines, stressing the importance of using adequate tests for target zone models, which are able to incorporate the multilateral features of the ERM I.

The exchange rate data are USD exchange rate series from the database of the Bank for International Settlement, 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[12] and exchange rate returns (Δs_t) are calculated as 100 times the log difference of exchange rates.

The daily intervention data are collected from confidential concertation protocols. According to the rules of the EMS-framework, EMS central banks and a few other central banks met four times a day by telephone conferences to exchange market information, one of which were intervention volumes. The first round usually took place at 9:30 and the last round at 16:00. The intervention data used in our empirical analysis are cumulated intervention volumes for a period of 24 hours, starting from 16:00 h previous day to 16:00 h next day. Interventions, undertaken the same day but after 16:00 h are reported at the first concertation round next day at 9:30 and are therefore included in next day's total intervention volume.

5.2 Exchange Rate Behavior

As already mentioned in Section 2, foreign exchange intervention may be triggered not only by deviations of the spot from target rates but also by excess short term volatility. Hence, we classify the trading days according to two criteria: The first criterion is based on the spot rate volatility of the six currencies, estimated by EGARCH and MS-ARCH models.[13] In Figure 1, the deep dark shaded areas mark the high volatility periods, the dark shaded areas are periods of medium volatility, and the light shaded areas are periods of low volatility. The spot rate volatility of the six currencies is shown in Figure 2. The second criterion rests upon the position in the band.

Figure 1 shows deviations of the DEM-spot rates from the respective bilateral DEM-central parities. All six currencies sharply depreciated after the widening of the bands on August 2, 1993. The depreciation was more pronounced for some currencies (Belgian Franc, Danish Krona) than for others. All six currencies re-strengthened at the end of 1993 and—with the exception of the Belgian Franc—dropped again until March 1995 partly to levels actually lower than recorded after the bands were widened in 1993. The Belgian Franc appreciated quickly in December 1993 and fluctuated around the bilateral parity with minor deviations from February 1994 onwards. After the ERM-crises in March 1995 (realignment of the Spanish Peseta and the Portugese Escudo) the Danish Krona, the Spanish

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

[13] The estimation results are taken from Brandner, Grech and Stix (2001). Based on the regime probabilities obtained in that paper, we divide the total period into three sub-periods, a regime with high, medium and low volatility. If the regime probability exceeds the value of 0.5, a trading day is assigned to one of the three regimes.

Peseta, the French Franc, the Irish Pound and the Portugese Escudo appreciated gradually towards the bilateral DEM-central rates, with however different speed. At the end of 1996, the Irish Pound started to record significant positive deviations (up to around 10%). The Spanish Peseta and the Portugese Escudo showed modest positive deviations (around 2–3%) and the Danish Krona and the French Franc remained well around the DEM-parities.

In order to see if a currency predominately stayed above or below the central rate in our sample period, the respective trading days are cumulated (for detailed figures see Table 1). The Belgian Franc mainly stayed above the central parity (62% of all trading days), the Spanish Peseta and the Irish Pound are approximately equally distributed and the Danish Krona, French Franc and Portugese Escudo mainly stayed below the central parity (74%, 89% and 64% respectively).

With respect to volatility, the Belgian Franc, for instance, remained predominantly in the medium and low volatility regime, the Danish Krona in the high volatility and the French Franc and Portugese Escudo in the medium volatility regime. Interestingly, periods of high volatility coincide with periods of large deviations of the central rates. In low volatility regimes, spot rates showed only minor fluctuations around the central rates.

5.3 Intervention Behavior

When describing intra-marginal DEM-intervention activity in the ERM I after 1993, it is interesting to note that although EMS-central banks did not come under speculative market pressure comparable to the 1992/93-episodes, interventions were conducted in substantial amounts and over sometimes prolonged periods of time.[14]

Our sample covers 1238 trading days. DEM-intervention occurred on 843 days (68%), DEM-purchases on 596 days (48%) and DEM-sales on 355 days (29%). DEM-purchases and -sales, undertaken on the same day but by different central banks, occurred on 108 trading days (8%). Figure 3 presents scatter plots of accumulated daily DEM-interventions (Figure 3(a): purchases and Figure 3(b): sales) versus the daily position of the six currencies in the band. Both plots show that most of the interventions occurred in a band of approximately ±3% around the central parities.

An interesting aspect is to see how many central banks intervened on the same day. Just one central bank bought Deutsche Mark on 322 days (26% of the total number of 1238 trading days). Two central banks—on the same day—purchased Deutsche Mark on 187 days (15%). Five central banks bought Deutsche Mark on 3 days. The figures for DEM-sales are: only one central bank sold Deutsche Mark on 258 days (21%), two central banks on 72 days (6%). Detailed figures are reported in Table 2. Obviously, intervention where conducted on a rather

[14] For a description of the 1992/93 ERM turmoils, see e.g. Buiter, Corsetti and Pesenti (1998).

unilateral basis than in a concerted way.

Table 3 describes the intervention behavior dependent on the position of the spot rate in the band, differentiating between a "weak" regime, where the spot rate was below the central rate and a "strong" regime, vice versa. Surprisingly, a lot of DEM-purchases were undertaken in "weak" regime-periods and substantial DEM-sales occured in "strong" regime periods. We take these stylized facts as evidence that obviously other motives than the reduction of spot rate deviations may have played a role in intervention decisions.

Table 4 presents the intervention activity in different volatility-regime specific periods (high, medium and low volatility), showing that the majority of DEM-purchases occurred in periods of medium volatility. DEM-sales were undertaken in all three regimes.

5.4 Bilateral Exchange Rate Distributions in the Multilateral Framework

The distribution of exchange rates has been one of the main issues when discussing the empirical implications of target zone models (see also Chapter 4). As already noted, the empirical analysis on exchange rate distributions in the ERM I has been confined to bilateral relationships against the Deutsche Mark. In particular, the agreement on bilateral fluctuation margins of ±15% vis-à-vis more than one currency does not mean that a currency has permanent room for maneuver up to 30% vis-à-vis all other currencies in a multilateral setting, given the cross-currency constraints of the parity grid. This would rather be the exception than the rule. The only situation in which this would be true is if all spot rates are in perfect conformity with the agreed bilateral central rates. Deviations of the spot rates from their central rates result in time-varying effective bandwidths, which could shrink to 15% at a minimum.

Following Honohan (1993), the effective bandwidth b^{eff} of a currency i is given as

$$b_i^{\text{eff}}(t) = 0,30 - (\max(s_{ik}(t) - s_{ik}^*) - \min(s_{ik}(t) - s_{ik}^*)), \quad k \neq i \tag{1}$$

where s_{ik} is the log of the spot rate of currency i expressed in units of currency k at time time t and s_{ik}^* is the respective bilateral central rate. Figure 4 displays the effective bandwidths of the six currencies.

In order to account for the multilateral setting, bilateral exchange rate distributions are obtained as the maximum spot rate deviation of a currency against the bilateral central rate of any other ERM-currency. The (positive or negative) deviations are calculated as

$$\begin{aligned} d_i^+(t) &= \max(s_{ik}(t) - s_{ik}^*) \\ d_i^-(t) &= \min(s_{ik}(t) - s_{ik}^*) \end{aligned} \tag{2}$$

The maximum deviation is then given as

$$d_i^{\max}(t) = \begin{cases} d_i^+(t) & = \text{ if } \quad |d_i^+(t)| \geq |d_i^-(t)| \\ d_i^-(t) & = \text{ if } \quad |d_i^-(t)| > |d_i^+(t)|. \end{cases} \tag{3}$$

Figure 5 displays the kernel density estimations of the deviations from the DEM-central parities, Figure 6 displays the estimation results of the maximum spot rate deviations from the bilateral central rates in the multilateral target zone framework.[15] The calculations were undertaken for intervention days (days of DEM-purchases and DEM-sales separately) and days without interventions.
Two aspects deserve special attention:

- With respect to intervention behavior (DEM-purchases and -sales) comparing Figure 5 and Figure 6, a remarkable difference emerges by simple visual inspection. The kernel density estimations of the deviations from the DEM-central parities display a more or less "normal" intervention pattern (Figure 5). Deutsche Mark are predominately purchased when spot rates are above the central rates ("DEM-strong currency regime") and Deutsche Mark are sold when spot rates are below the central rates ("DEM-weak currency regime"). In contrast, kernel density estimations in the multilateral target zone framework reveal an "abnormal" intervention pattern (Figure 6). DEM-purchases often occurred with the effective position in the band of one currency being negative ("effective-weak currency regime") and DEM-sales vice versa mainly occurred with the effective position in the band being positive ("effective-strong currency regime"). From both kernel estimations we suspect that central banks obviously attached more weight to the spot rate position vis-à-vis the Deutsche Mark than to any other currency in their internal decision-making on (intra-marginal) intervention. Our empirical analysis on intervention reaction functions is therefore built on the spot rate deviations from the DEM-central rates.

- The estimated densities in Figure 5 confirm the suspicion that the objectives of central bank intervention are widespread and cannot be simply subordinated under one objective. As already stated above, central banks obviously not only had in mind to bring the spot rates back to the levels of the bilateral DEM-parities. As central banks also bought Deutsche Mark in periods of negative spot rate deviations and also sold Deutsche Mark in periods of positive spot rate deviations, one could interpret these intervention transactions as efforts to stabilize spot rates at current levels (or "lean against the wind"). Market conditions seemed to have played a role in central banks' intervention decisions. We therefore also include the

[15]The unconditional distribution was estimated with a non-parametric procedure. For the density estimation, we choose the Epanechnikov kernel. Various window sizes were tested to safeguard against oversmoothing.

conditional volatility (or the deviation from a pre-specified target volatility into the intervention reaction functions (see equations (4)–(5) below).

6 Intervention Reaction Functions

Reaction functions can be formulated ad hoc or derived from a model, specifying the behavior of the exchange rate and a policy loss function of the central bank. For the latter approach see for instance Eijffinger and Verhagen (2001). They formulate a loss function describing the trade-off between intervention costs and undesired deviations of the spot rate from a certain target level.

As we analyze intervention behavior in a target zone, our framework differs from the (bilateral) floating regime setting of Eijffinger and Verhagen (2001). In our context, the trade off does not primarily exist between intervention costs and undesired exchange rate levels, but between the exchange rate position in the band and volatility levels. The closer the spot rate is to the central parity, the higher the volatility would be and vice versa. As already mentioned in Chapter 4, these implications must not hold in a multilateral framework. But since we conduct our analysis in a bilateral framework, we would be able to disregard the fact that in a multilateral target zone model the volatility of any exchange rate is no longer a monotonic function of its distance from the central rate.

We empirically test wether the spot rate position within the band and/or market volatility triggered central bank intervention. Hence we specify the following central bank's reaction functions:[16]

$$I_t^P = \beta_0^P + \beta_1^P(s_{t-1} - s^*) + \beta_2^P(\sigma_{t-1} - \sigma_{t-1}^*) + \epsilon_t \tag{4}$$

$$I_t^S = \beta_0^S + \beta_1^S(s_{t-1} - s^*) + \beta_2^S(\sigma_{t-1} - \sigma_{t-1}^*) + \epsilon_t \tag{5}$$

where ϵ_t is an independently and identically distributed error term. The variables are defined in the following way: s_{t-1} is the the log of the spot exchange rate (Belgian Franc, Danish Krona, Spanish Peseta, French Franc, Irish Pound and Portugese Escudo) at $t-1$. The intervention variables I_t^P and I_t^S denote DEM-purchases and DEM-sales of the respective central bank, taken as logarithms. $(s_{t-1} - s^*)$ is the deviation of the exchange rate from the bilateral DEM-central rate at $t-1$. The other variable $(\sigma_{t-1} - \sigma_{t-1}^*)$ is the deviation of conditional volatility from the target volatility. In our specification the target volatility

[16]The issue of simultaneity is well known in empirical work on foreign exchange intervention. We use lagged explanatory variables to avoid this problem. If the effects of intervention are predominantly short-lived (e.g. die out on the same day) then endogeneity would not be a crucial point when using daily data. Brandner, Grech and Stix (2001) found that DEM-interventions have been effective on level and/or volatility only in very few cases.

is defined as the moving average of the last $d = 5, 10$ and 20 days, $\sigma^*_{t-1} = \frac{1}{d} \cdot \sum_{i=1}^{d} \sigma_{t-i}$. Furthermore, the conditional volatility itself is used as a regressor variable. The conditional standard deviations σ_{t-1} are estimated from EGARCH and MS-ARCH models (see Brandner, Grech and Stix 2001).

Equations (4) and (5) each represent a censored regression model (Tobit model), since the intervention variable contains a cluster of zeros. The Tobit models are estimated by maximizing the log-likelihood function. Although the type of the likelihood is nonstandard (since it is a mixture of discrete and continuous distributions), proceeding in the usual fashion will produce an estimator with all the desirable properties for ML-estimators (see Amemiya 1973).[17]

The empirical specification of the reaction functions also includes the lagged spot rate change as additional regressor to capture not explicitely modelled effects. The estimation results of all models (coefficients and marginal effects of 96 equations) are presented in non-technical tables.[18]

7 Empirical Results

Reaction functions are estimated for the total period, and various subsamples. Sample selection is driven by a position-in-the-band and a volatility-criterion (see Chapter 5). The position-in-the-band-criterion identifies periods of weak and strong currency regimes, i.e. periods when the spot rate was below or above the DEM-central rate. The volatility criterion is based on the results of the MS–ARCH models, differentiating between regimes of high, medium and low volatility. We also check for the sensitivity of the estimation results with respect to different specifications of the volatility variable and different subsamples.

The results of our estimations are shown in Tables 5–10. Tables 5–6 refer to estimation results for the total period, Tables 7–8 show results of subsamples following the weak/strong-criterion and Tables 9–10 presents results of the volatility criterion (high, medium, low volatility).

7.1 Results for the Total Period

An increase in the exchange rate (appreciation of the currency vis-a-vis the Deutsche Mark) raises the volume of DEM-purchases of all six central banks (Tables 5–6). A depreciation raises or leaves the volume of DEM-sales unchanged in most specifications, Denmark being an exception. The results are more or less insensitive to the choice of the conditional volatility variables.

[17] The estimations have been done with the EViews software package.

[18] Six currencies, DEM-purchases and -sales, four different volatility variables each based on two volatility specifications. Due to the fact that we analyze not only the total period, but also various subsamples, the presentation problem explodes to nearly 600 estimation results.

In contrast to the significant impact of the deviations from the DEM-central rates, deviations from the target volatilities exert less influence on intervention behavior. An increase in the conditional volatility triggers DEM-sales more often then DEM-purchases. Estimations based on EGARCH-volatilities lead to more significant results then estimations based on MS-ARCH volatilities. Market-smoothing objectives seem to play a less prominent role for intervention decisions than the spot rate position in the band.

7.2 Results of Subsamples

We start with the discussion of the results of subsamples according to the weak/strong-criterion (Tables 7–8). Independent of the position in the band, in general, an appreciation of the exchange rate led to DEM-purchases. A depreciation triggered DEM-sales, however, less often. A typical intervention behavior was found in two cases: Ireland for DEM-purchases and Denmark for DEM-sales. These findings hold irrespective of the specification of the volatility variable.

No consistent picture arises for the influence of market volatility on intervention decisions. Results differ a lot across currencies and specifications of the volatility variable (conditional volatility, deviation from 5-day-, 10-day or 20-day moving averages). While results slightly differ between EGARCH- and MS-ARCH-model based volatility measures, the general finding of no systematic effect on the intervention behavior remains.

A second group of subsamples was constructed according to the volatility criterion. The results, shown in Tables 9–10, demonstrate that intervention behavior is not the same across volatility regimes. All central banks, except Belgium, Spain (DEM-purchases only) and Ireland (DEM-sales only), reacted differently to deviations from the DEM-central rates, depending on the volatility regime prevailing. Regime-specific results for the volatility variable differ even more. This finding holds irrespective of the choice of the conditional volatility variable.

8 Summary and Conclusions

In this paper, we present stylized facts of exchange rate and intervention behavior in the ERM I, in particular in light of the recent literature on multilateral target zone models. The economics of multilateral target zones is different from the economics of bilateral target zones. An important aspect in this respect is endogenous intra-marginal intervention which arise from cross-currency constraints.

We estimate bilateral exchange rate distributions of the maximum spot rate deviations vis-a-vis all central parities to account for the multilateral setting of the ERM I. In a further analysis, we estimate short term reaction functions for the Banque de Belgique, the Danmarks Nationalbank, the Banco d'España, the

Banque de France, the Central Bank of Ireland and the Banco de Portugal by applying a Tobit analysis, using daily exchange rate and DEM-intervention data.

In general, our reaction function results show that the exchange rate position in the band (deviation from DEM-central parity) significantly induces intervention activity. There is less evidence that a change in market conditions—as expressed in the volatility variables—triggers central banks intervention. These general conclusions are insensitive to the choice of the modelling of the conditional volatility variables. The influence of the explanatory variables (deviation from the DEM-central rate and from a target volatility), however, differs across subsamples and currencies.

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Figure 1: Deviation from central parity (in percent) and volatility regimes

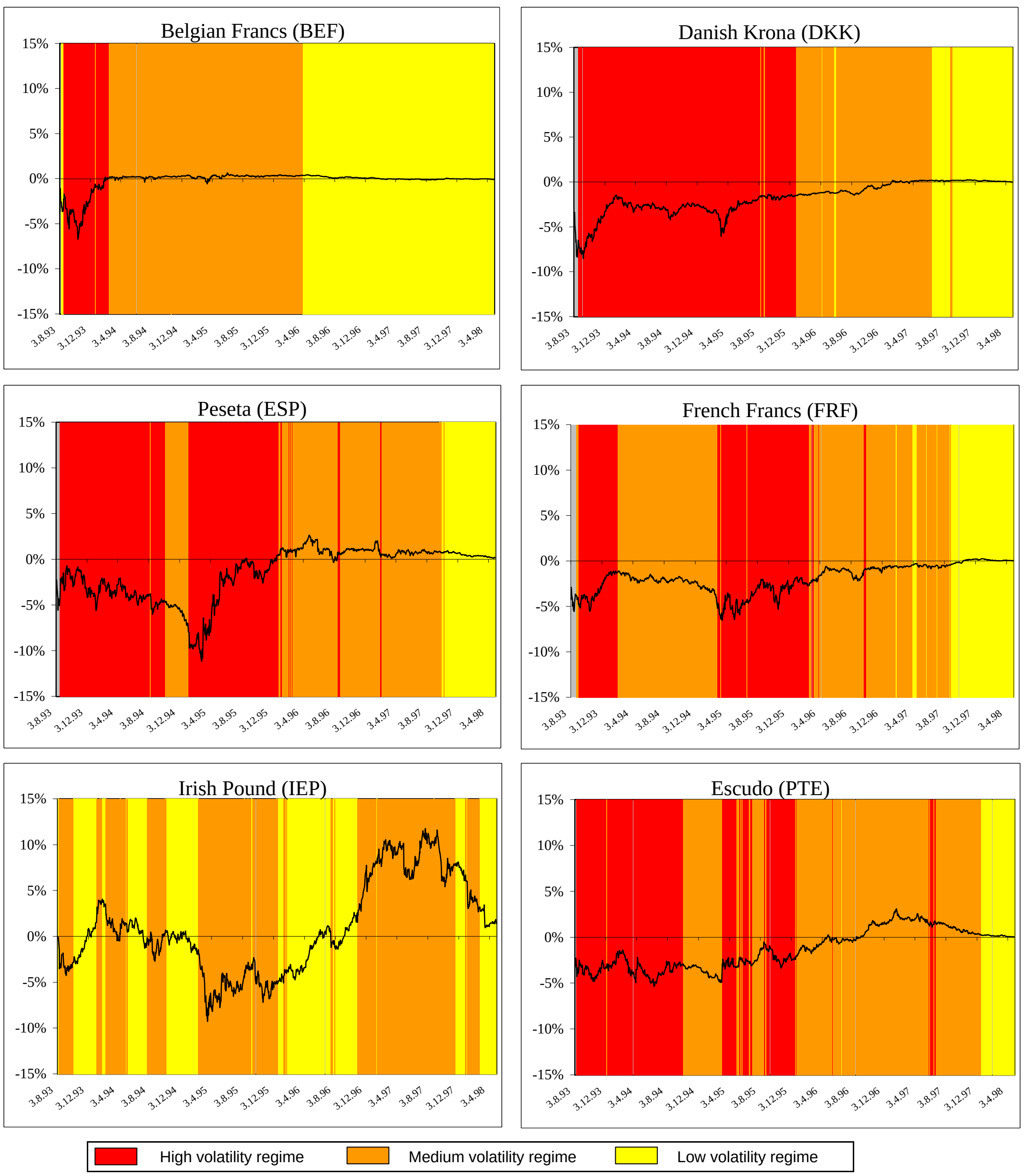


Figure 2: Conditional volatilities

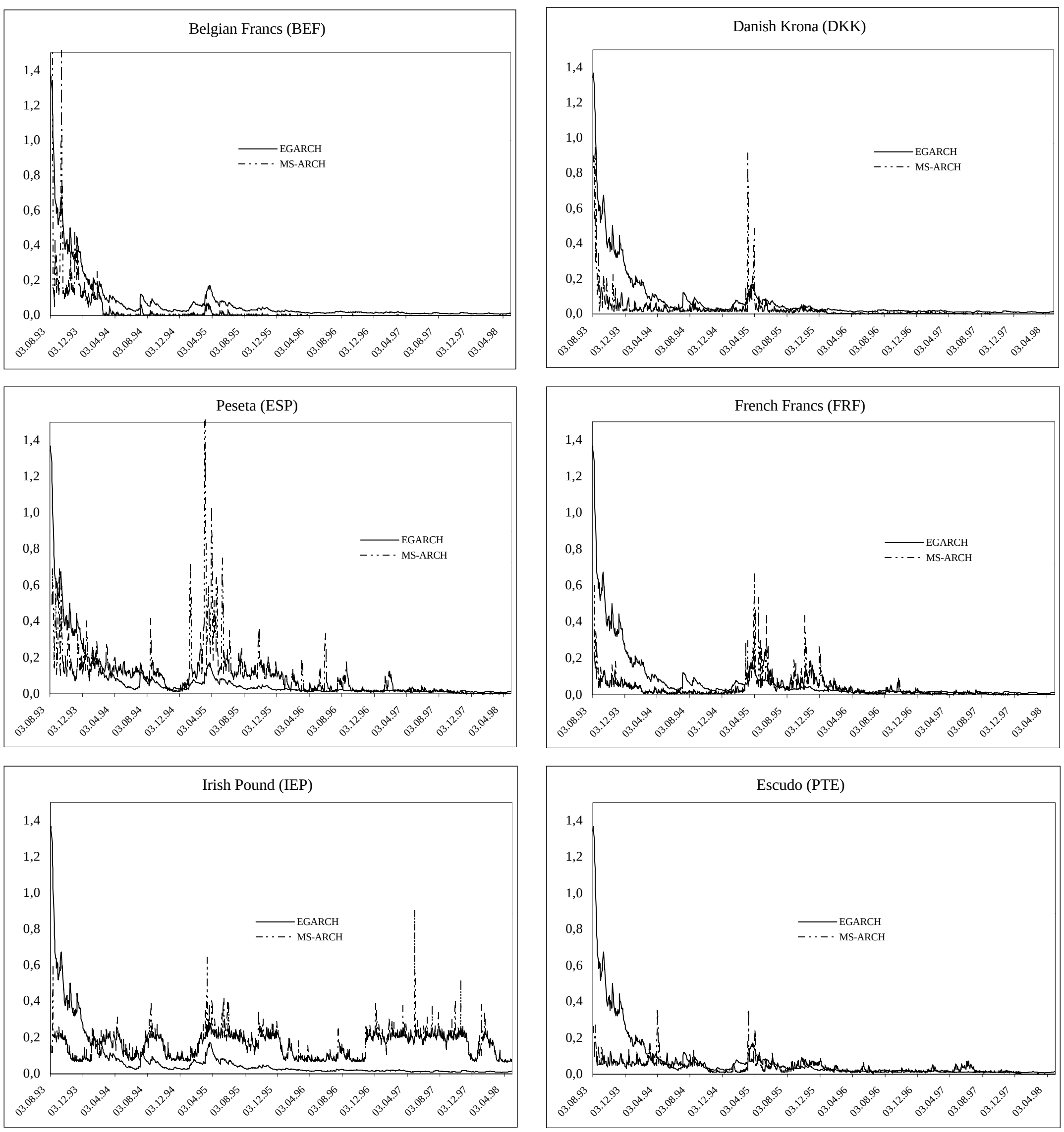
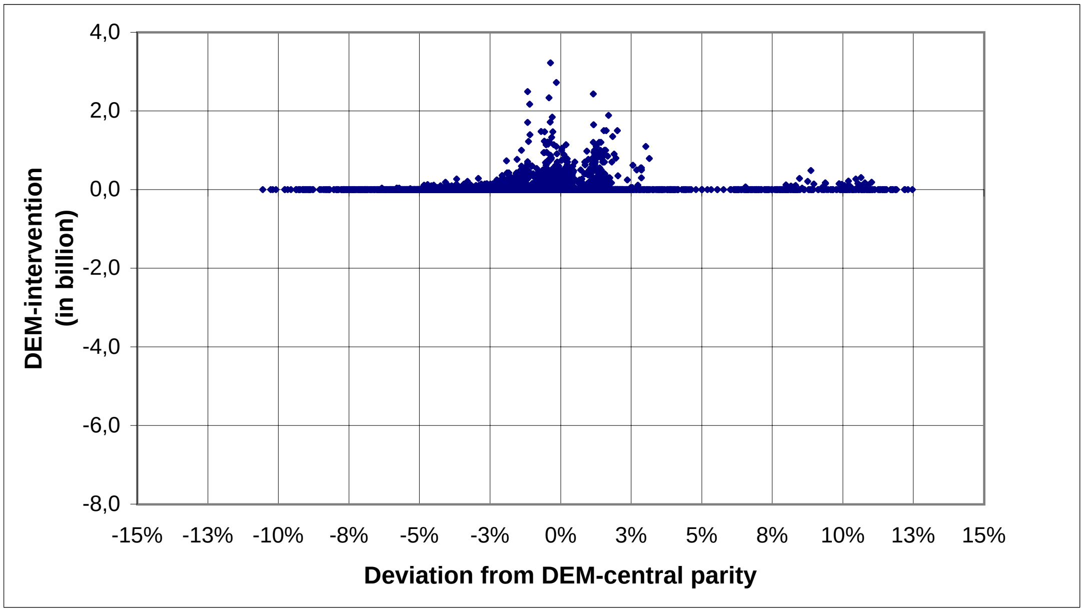


Figure 3: Aggregated daily DEM-interventions and deviation from DEM-central parity

(a) DEM-purchases



(b) DEM-sales

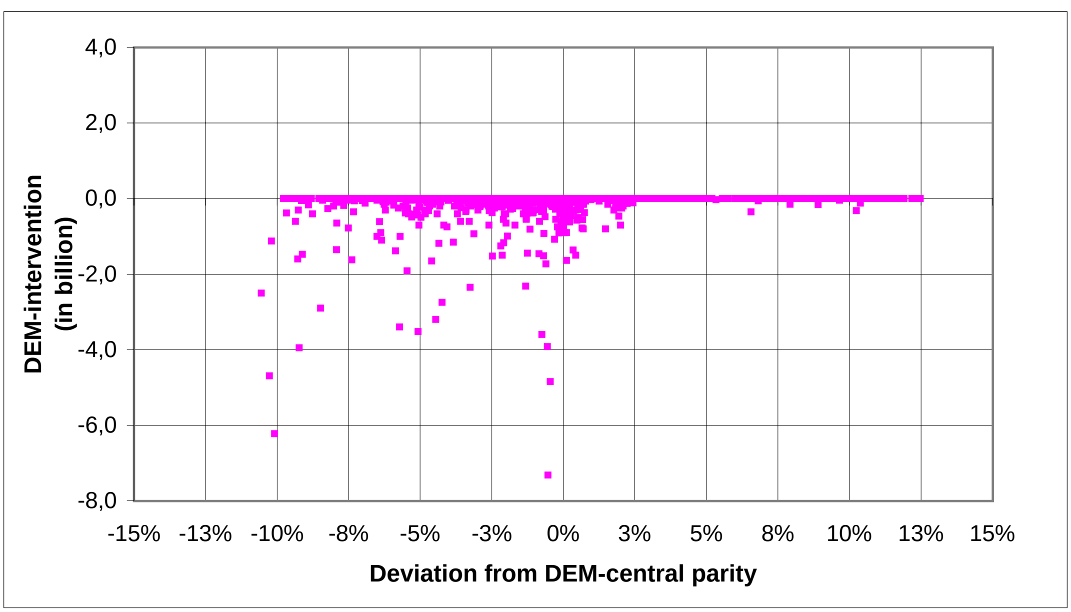


Figure 4: Effective bandwidth of the six currencies in the EMS 2/8/1993 - 30/4/1998

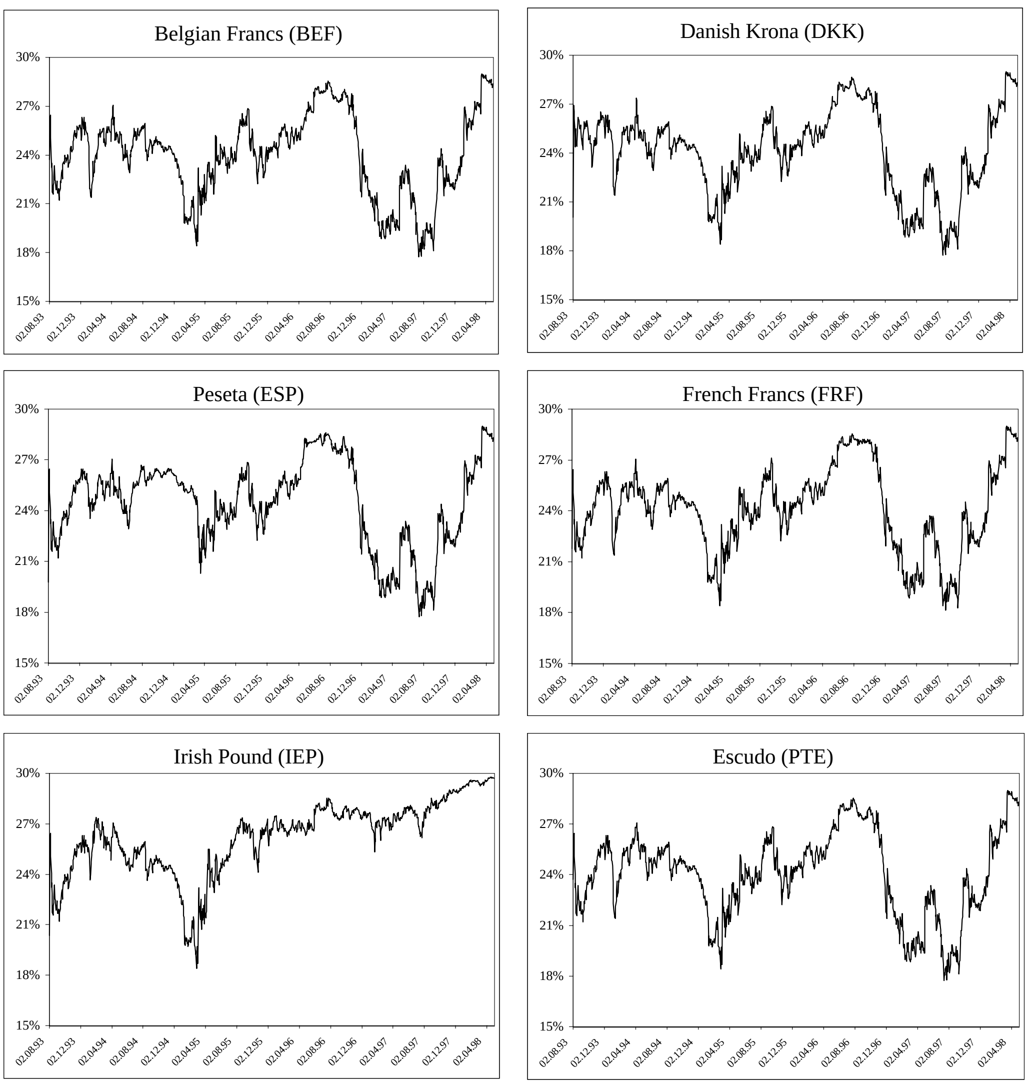


Figure 5: Kernel density estimation of the deviation from DEM-central parity

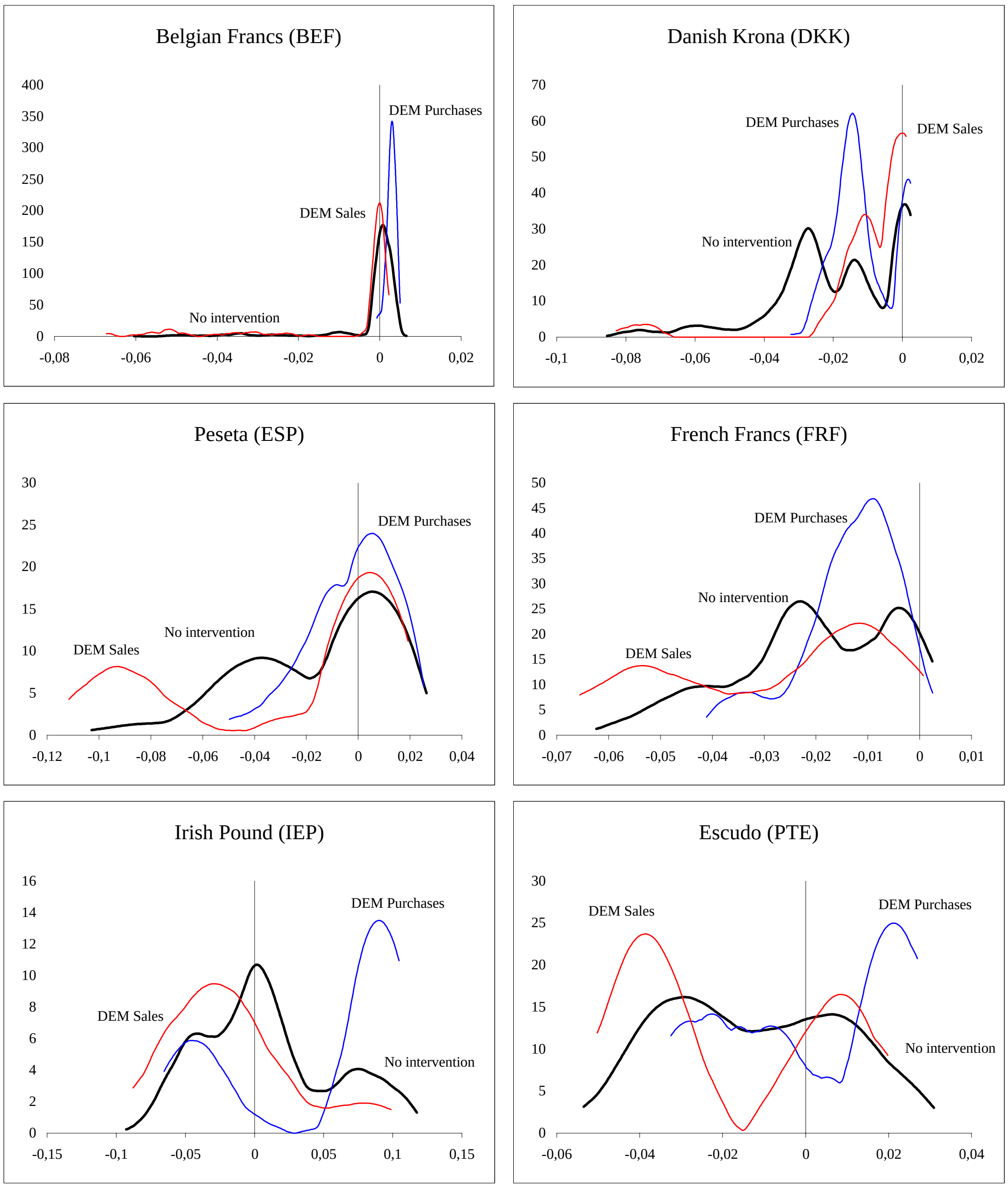


Figure 6: Kernel density estimation of the maximum spot rate deviation from bilateral central rates in the multilateral target zone framework

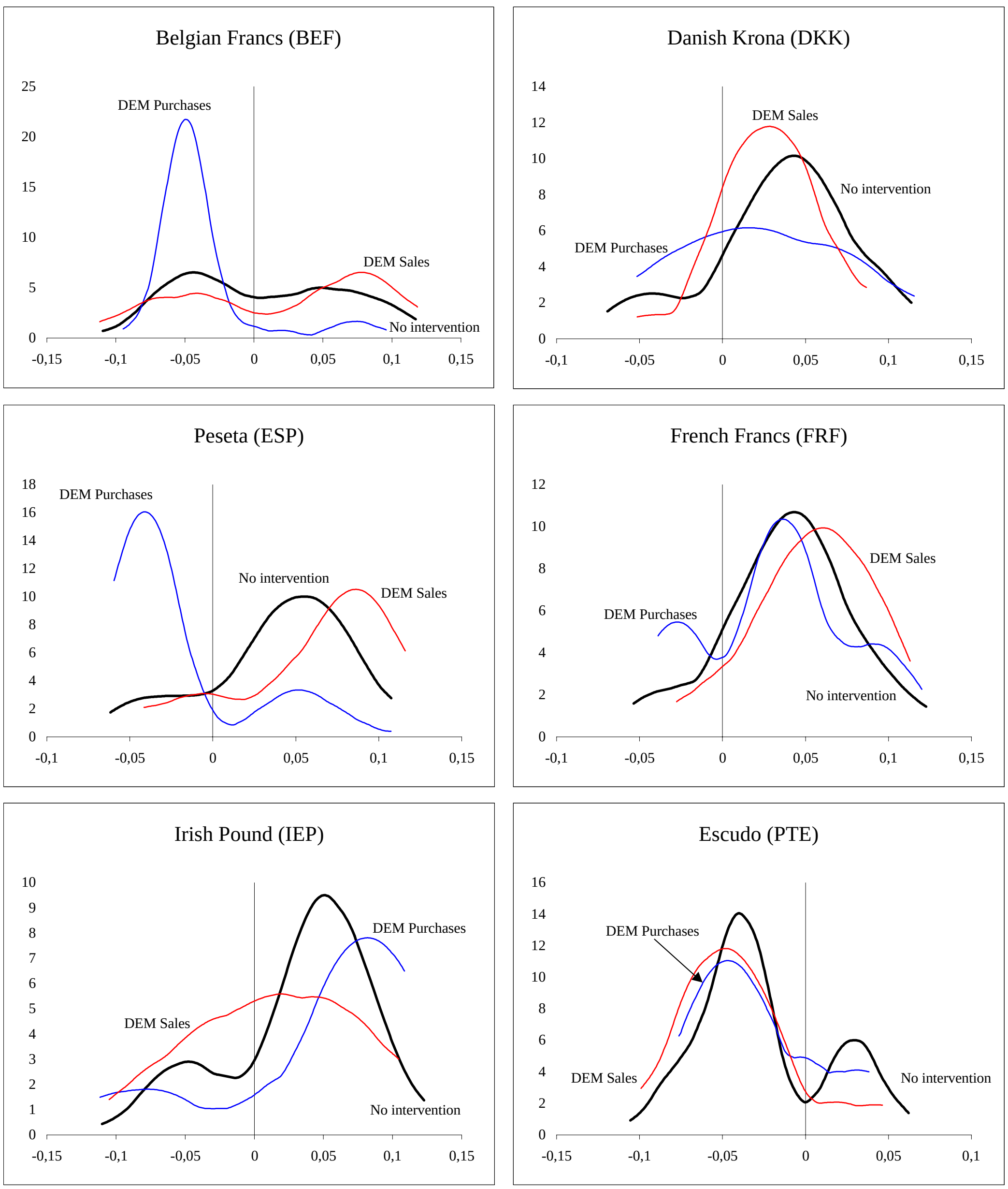


Table 1: Regime specific classification of trading days

	Volatility-specific regime				position in the band	
	high	medium	low		"weak"	"strong"
				in days		
Belgium	128	552	554	*1234*	469	769
Denmark	607	378	235	*1220*	921	317
Spain	582	491	154	*1227*	623	615
France	384	629	206	*1219*	1096	142
Ireland	-	698	539	*1237*	583	655
Portugal	495	640	98	*1233*	795	443
				in percent		
Belgium	10.4	44.7	44.9	*100*	37.9	62.1
Denmark	49.8	31.0	19.3	*100*	74.4	25.6
Spain	47.4	40.0	12.6	*100*	50.3	49.7
France	31.5	51.6	16.9	*100*	88.5	11.5
Ireland	-	56.4	43.6	*100*	47.1	52.9
Portugal	40.1	51.9	7.9	*100*	64.2	35.8

For Ireland, only two volatility regimes have been identified. The total number of trading days is 1238.
Days with regime probabilities below 0.5 have not been assigned to a specific volatility regime.
A "weak" currency regime denotes periods where the spot rate was below the central rate, a "strong" currency regime denotes periods where the spot rate was above the central rate.

Table 2: Simultaneous intervention activity

Number of central banks		Purchasing DEM (in days)							
		0	1	2	3	4	5	6	Total
Selling DEM	0	395	248	161	52	25	2	0	883
	1	162	61	26	6	1	1	0	257
	2	60	12	0	0	0	0	0	72
	3	18	1	0	0	0	0	0	19
	4	6	0	0	0	0	0	0	6
	5	1	0	0	0	0	0	0	1
	6	0	0	0	0	0	0	0	0
	Total	642	322	187	58	26	3	0	1238

Number of central banks		Purchasing DEM (in percent)							
		0	1	2	3	4	5	6	Total
Selling DEM	0	31.9	20.0	13.0	4.2	2.0	0.2	0.0	71.3
	1	13.1	4.9	2.1	0.5	0.1	0.1	0.0	20.8
	2	4.8	1.0	0.0	0.0	0.0	0.0	0.0	5.8
	3	1.5	0.1	0.0	0.0	0.0	0.0	0.0	1.5
	4	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	51.9	26.0	15.1	4.7	2.1	0.2	0.0	100.0

Table 3: Intervention behavior dependent on the position within the band

	DEM-purchases			DEM-sales		
	Regime			**Regime**		
	weak	strong		weak	strong	
			in days			
Belgium	13	253	*266*	91	54	*145*
Denmark	153	55	*208*	37	23	*60*
Spain	92	78	*170*	31	40	*71*
France	263	13	*276*	53	1	*54*
Ireland	18	35	*53*	47	14	*61*
Portugal	8	8	*16*	55	41	*96*
			in percent			
Belgium	4.9	95.1	*100*	62.8	37.2	*100*
Denmark	73.6	26.4	*100*	61.7	38.3	*100*
Spain	54.1	45.9	*100*	43.7	56.3	*100*
France	95.3	4.7	*100*	98.1	1.9	*100*
Ireland	34.0	66.0	*100*	77.0	23.0	*100*
Portugal	50.0	50.0	*100*	57.3	42.7	*100*

A "weak" currency regime denotes periods where the spot rate was below the central rate, "strong" currency regime denotes periods where the spot rate was above the central rate.

Table 4: Volatility-regime specific intervention behavior

	DEM-purchases				DEM-sales			
	Regime				**Regime**			
	high	medium	low		high	medium	low	
				in days				
Belgium	1	220	45	*266*	24	37	83	*144*
Denmark	84	98	26	*208*	6	25	27	*58*
Spain	101	67	2	*170*	33	26	12	*71*
France	76	160	40	*276*	23	29	2	*54*
Ireland		47	6	*53*		33	28	*61*
Portugal	3	13	0	*16*	57	25	14	*96*
				in percent				
Belgium	0.4	82.7	16.9	*100*	16.7	25.7	57.6	*100*
Denmark	40.4	47.1	12.5	*100*	10.3	43.1	46.6	*100*
Spain	59.4	39.4	1.2	*100*	46.5	36.6	16.9	*100*
France	27.5	58.0	14.5	*100*	42.6	53.7	3.7	*100*
Ireland		88.7	11.3	*100*		54.1	45.9	*100*
Portugal	18.8	81.3	0.0	*100*	59.4	26.0	14.6	*100*

For Ireland, only two volatility regimes have been identified.

Table 5: Results of the intervention reaction functions (EGARCH-volatilities) 3/8/1993 - 30/4/1998

	Reaction function of DEM-purchases		***Reaction function of DEM-sales***	
	Deviation from		Deviation from	
	central rate	target volatility	central rate	target volatility
Target volatility measured as conditional volatility				
Belgium	++	.	--	.
Denmark	++	.	++	++
Spain	++	--	--	--
France	++	.	--	--
Ireland	++	--	--	--
Portugal	++	.	.	++
Target volatility measured as 5 day-moving average of the conditional volatility				
Belgium	++	--	--	.
Denmark	++	.	++	--
Spain	++	+	--	++
France	++	.	.	++
Ireland	++	+	--	++
Portugal	++	.	.	--
Target volatility measured as 10 day-moving average of the conditional volatility				
Belgium	++	--	--	.
Denmark	++	.	++	--
Spain	++	++	-	++
France	++	.	-	++
Ireland	++	+	--	++
Portugal	++	.	.	--
Target volatility measured as 20 day-moving average of the conditional volatility				
Belgium	++	--	--	.
Denmark	++	.	++	++
Spain	++	++	.	++
France	++	--	-	++
Ireland	++	++	--	++
Portugal	++	--	.	--

"++" ("+"): An increase in the variable (spot minus central rate, actual minus target volatility) increases the probability of DEM-intervention (purchases/sales), statistically significant at a 5% (10%) marginal significance level.
"--" ("-"): Vice versa.
If too few interventions occured within a regime, no estimation results could be obtained (empty entry).

Table 6: Results of the intervention reaction functions (MS-ARCH-volatilities) 3/8/1993 - 30/4/1998

	Reaction function of DEM-purchases		***Reaction function of DEM-sales***	
	Deviation from		Deviation from	
	central rate	target volatility	central rate	target volatility
Target volatility measured as conditional volatility				
Belgium	++	.	--	.
Denmark	++	.	++	++
Spain	++	++	.	++
France	++	.	.	.
Ireland	++	++	--	.
Portugal	+	.	.	++
Target volatility measured as 5 day-moving average of the conditional volatility				
Belgium	++	.	--	.
Denmark	++	.	++	--
Spain	++	.	--	+
France	++	.	.	.
Ireland	++	.	--	.
Portugal	++	.	-	.
Target volatility measured as 10 day-moving average of the conditional volatility				
Belgium	++	.	--	.
Denmark	++	.	++	--
Spain	++	.	--	+
France	++	.	.	.
Ireland	++	.	--	.
Portugal	++	.	.	--
Target volatility measured as 20 day-moving average of the conditional volatility				
Belgium	++	--	--	.
Denmark	++	.	++	++
Spain	++	++	.	++
France	++	--	.	++
Ireland	++	++	--	++
Portugal	++	.	.	--

"++" ("+"): An increase in the variable (spot minus central rate, actual minus target volatility) increases the probability of DEM-intervention (purchases/sales), statistically significant at a 5% (10%) marginal significance level.
"--" ("-"): Vice versa.
If too few interventions occured within a regime, no estimation results could be obtained (empty entry).

Table 7: Regime specific (weak/strong-criterion) results of the intervention reaction functions (EGARCH-volatilities)

	Reaction function of DEM-purchases				***Reaction function of DEM-sales***			
	Deviation from				Deviation from			
	central rate		target volatility		central rate		target volatility	
	C1	**C2**	**C1**	**C2**	**C1**	**C2**	**C1**	**C2**
Target volatility measured as conditional volatility								
Belgium	--	++	--	++	.	--	.	--
Denmark	++	++	+	++	++	--	++	--
Spain	++	++	--	++	--	-	-	.
France	++	++	.	++	--	--	--	+
Ireland	--	++	--	.	.	.	--	--
Portugal	+	+	.	.	--	.	++	.
Target volatility measured as 5 day-moving average of the conditional volatility								
Belgium	++	++	.	--	--	--	--	++
Denmark	++	++	.	++	++	--	--	+
Spain	++	++	++	.	--	.	++	.
France	++	++	.	--	.		++	
Ireland	--	++	.	.	.	.	++	++
Portugal	++	.	.	--	--	-	--	.
Target volatility measured as 10 day-moving average of the conditional volatility								
Belgium	++	++	--	--	--	--	.	+
Denmark	++	++	.	++	++	--	--	+
Spain	++	++	++	.	--	.	++	.
France	++	++	.	.	.	-	++	++
Ireland	--	++	.	.	.	.	++	++
Portugal	++	+	.	--	--	-	--	.
Target volatility measured as 20 day-moving average of the conditional volatility								
Belgium	++	++	--	--	.	--	.	+
Denmark	++	++	.	.	++	--	++	++
Spain	++	++	++	.	--	-	++	.
France	++	++	--	.	.	.	++	++
Ireland	--	++	.	.	.	.	++	++
Portugal	++	++	--	--	--	-	--	+

"++" ("+"): An increase in the variable (spot minus central rate, actual minus target volatility) increases the probability of DEM-intervention (purchases/sales), statistically significant at a 5% (10%) marginal significance level.
"--" ("-"): Vice versa.
If too few interventions occured within a regime, no estimation results could be obtained (empty entry).
"C1" denotes a regime where the spot rate was below the central rate ("weak" currency regime) and "C2" a regime where the spot rate was above the central rate ("strong" currency regime).

Table 8: Regime specific (weak/strong-criterion) results of the intervention reaction functions (MS-ARCH-volatilities)

	Reaction function of DEM-purchases				***Reaction function of DEM-sales***			
	Deviation from				Deviation from			
	central rate		target volatility		central rate		target volatility	
	C1	**C2**	**C1**	**C2**	**C1**	**C2**	**C1**	**C2**
Target volatility measured as conditional volatility								
Belgium	.	++	-	.	--	--	.	--
Denmark	++	++	.	++	++	--	++	--
Spain	++	++	.	++	--	-	++	++
France	++	++	.	.	.	--	.	.
Ireland	.	++	.	.	.	.	.	.
Portugal	.	++	.	--	--	.	++	.
Target volatility measured as 5 day-moving average of the conditional volatility								
Belgium	++	++	.	.	--	--	.	++
Denmark	++	++	.	++	++	--	--	.
Spain	++	++	+	-	--	.	.	.
France	++	++	.	.	.	--	.	--
Ireland	--	++	.	.	.	.	.	.
Portugal	++	++	.	+	--	--	.	--
Target volatility measured as 10 day-moving average of the conditional volatility								
Belgium	++	++	.	.	--	--	.	++
Denmark	++	++	.	++	++	--	--	.
Spain	++	++	.	.	--	.	.	.
France	++	++	.	.	.	--	.	-
Ireland	--	++	.	.	.	.	.	.
Portugal	++	++	.	.	--	--	--	--
Target volatility measured as 20 day-moving average of the conditional volatility								
Belgium	++	++	++	--	.	--	.	++
Denmark	++	++	--	++	++	--	++	++
Spain	++	++	++	++	--	.	++	++
France	++	++	--	--	.	.	++	++
Ireland	.	++	++	.	.	.	++	++
Portugal	++	++	.	-	--	.	--	.

"++" ("+"): An increase in the variable (spot minus central rate, actual minus target volatility) increases the probability of DEM-intervention (purchases/sales), statistically significant at a 5% (10%) marginal significance level.
"--" ("-"): Vice versa.
If too few interventions occured within a regime, no estimation results could be obtained (empty entry).
"C1" denotes a regime where the spot rate was below the central rate ("weak" currency regime) and "C2" a regime where the spot rate was above the central rate ("strong" currency regime).

Table 9: Regime specific (volatility-criterion) results of the intervention reaction functions (EGARCH-volatilities)

	Reaction function of DEM-purchases						***Reaction function of DEM-sales***					
	Deviation from						Deviation from					
	central rate			target volatility			central rate			target volatility		
	R1	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Target volatility measured as conditional volatility												
Belgium		++	++		.	-	--	--	--	++	--	-
Denmark	++	.	.	++	.	++	++	.	-	++	.	-
Spain	++	++	++	--	++	.	--	++	.	--	.	++
France	++	++	--	.	++	.	--	--	.	--	--	.
Ireland		++	.		--	-		--	--		--	--
Portugal	.	+		.	.		.	.	.	++	.	.
Target volatility measured as 5 day-moving average of the conditional volatility												
Belgium		++	++		--	++	--	--	--	--	.	++
Denmark	++	.	.	.	.	++	++	-	-	--	.	++
Spain	++	++	++	++	.	.	--	++	++	++	.	.
France	++	++	--	++	-	-	--	+	.	.	.	++
Ireland		++	.		++	.		--	--		++	.
Portugal	.	.		.	--		.	++	--	--	.	.
Target volatility measured as 10 day-moving average of the conditional volatility												
Belgium		++	++		--	++	--	--	--	--	.	++
Denmark	++	.	.	.	.	++	++	-	--	--	.	++
Spain	++	++	++	++	.	+	--	++	++	++	.	.
France	++	++	--	.	--	--	--	+	.	++	.	++
Ireland		++	.		++	+		--	--		++	.
Portugal	.	+		-	--		.	++	-	--	.	.
Target volatility measured as 20 day-moving average of the conditional volatility												
Belgium		++	++		--	++	--	--	--	--	.	++
Denmark	++	.	.	--	.	++	++	-	--	+	.	++
Spain	++	++	++	++	.	.	--	++	++	++	.	.
France	++	++	--	.	--	--	--	+	.	++	.	++
Ireland		++	.		++	++		--	--		++	++
Portugal	.	+		--	--		.	++	.	--	-	++

"++" ("+"): An increase in the variable (spot minus central rate, actual minus target volatility) increases the probability of DEM-intervention (purchases/sales), statistically significant at a 5% (10%) marginal significance level.
"--" ("-"): Vice versa.
If too few interventions occured within a regime, no estimation results could be obtained (empty entry).
"R1" denotes a regime with high volatility, "R2" with medium and "R3" with low volatility. For Ireland, only two volatility regimes have been identified.

Table 10: Regime specific (volatility-criterion) results of the intervention reaction functions (MS-ARCH-volatilities)

	Reaction function of DEM-purchases						***Reaction function of DEM-sales***					
	Deviation from						Deviation from					
	central rate			target volatility			central rate			target volatility		
	R1	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Target volatility measured as conditional volatility												
Belgium		++	++		--	++	--	--	--	.	--	.
Denmark	++	.	.	++	.	.	.	.	--	.	++	--
Spain	++	++	++	.	.	.	--	++	++	++	++	.
France	++	++	--	.	.	.	--	++	.	.	++	.
Ireland		++	.		.	.		--	--		.	.
Portugal	-	+		.	.		-	++	--	.	.	-
Target volatility measured as 5 day-moving average of the conditional volatility												
Belgium		++	++		.	++	--	--	--	.	.	.
Denmark	++	.	.	.	.	-	+	-	.	--	.	.
Spain	++	++	++	+	--	--	--	++	++	.	.	.
France	++	++	--	.	.	.	--	++	.	.	++	.
Ireland		++	.		.	-		--	--		.	.
Portugal	.	+		.	.		-	++	--	.	.	++
Target volatility measured as 10 day-moving average of the conditional volatility												
Belgium		++	++		.	++	--	--	--	.	.	.
Denmark	++	.	.	.	.	.	++	-	-	--	.	.
Spain	++	++	++	.	.	-	--	++	++	.	.	+
France	++	++	-	.	.	.	--	++	.	.	++	.
Ireland		++	.		.	.		--	--		+	.
Portugal	.	.		.	.		-	++	--	--	-	++
Target volatility measured as 20 day-moving average of the conditional volatility												
Belgium		++	++		--	++	--	--	--	--	++	--
Denmark	++	.	.	--	.	.	++	--	--	++	++	++
Spain	++	++	++	++	.	.	--	++	++	++	++	.
France	++	++	--	.	--	--	--	.	.	++	++	++
Ireland		++	.		++	++		--	--		++	++
Portugal	.	++		.	-		.	++	--	--	--	.

"++" ("+"): An increase in the variable (spot minus central rate, actual minus target volatility) increases the probability of DEM-intervention (purchases/sales), statistically significant at a 5% (10%) marginal significance level.
"--" ("-"): Vice versa.
If too few interventions occured within a regime, no estimation results could be obtained (empty entry).
"R1" denotes a regime with high volatility, "R2" with medium and "R3" with low volatility. For Ireland, only two volatility regimes have been identified.

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