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Why Did Central Banks Intervene in ERM I? The Post-1993 Experience

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In this paper, we present stylized facts about exchange rate fluctuations 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 I currencies, explicitly taking the multilateral setting of ERM I into account. In a further analysis, we estimate short-term reaction functions for the central banks of Belgium, Denmark, France, Ireland, Portugal, and Spain by applying a Tobit analysis. The period under review is from August 1993 to April 1998. We use daily exchange rate and intervention data. The exchange rate position in the band (deviation of the deutschemark (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 E58, F31, F33]

The effectiveness of foreign exchange (FX) 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. In general, FX interventions are primarily undertaken to maintain or defend a certain exchange rate commitment. Countering disorderly market conditions or dampening short-term excess volatility are other important driving forces. This type of

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intervention is, for instance, treated in Article IV of the Articles of Agreement of the IMF.[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 a credible commitment to intervene at the edges (marginal intervention) by itself would keep the exchange rate within 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 was the modeling of intramarginal intervention.

More recently, the focus has shifted 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 (e.g., ERM I and II) is different from the economics of bilateral target zones, with one important aspect being endogenous intramarginal intervention that arises from cross-currency constraints. Under ERM I, in particular after the Basel/Nyborg Agreement in 1987, intramarginal 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] (EMS) was recently analyzed in Brandner, Grech, and Stix (2001). Covering the period from August 1993 to April 1998, they tested for the effects of intramarginal DEM intervention of six EMS central banks[3] on the level and volatility of DEM spot rates. The results of that paper, derived by applying EGARCH and Markov Switching ARCH (MS-ARCH) models, show that even in the same institutional framework (ERM I), intervention (DEM purchases and/or sales) did not affect the 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 about exchange rate movements and intervention behavior in 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 ERM I into account. The kernel density estimations were undertaken for intervention days (days of DEM purchases and DEM sales separately) and trading days without intervention. In a further analysis, we estimate short-term reaction functions for the central banks of Belgium, Denmark, France, Ireland, Portugal, and Spain by applying a Tobit analysis. The period under review

[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 synonymous since all currencies in our empirical analysis were part of both the EMS and the ERM.

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

is from August 1993 to April 1998. We use daily exchange rate and intervention data, 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 Three of EMU. Therefore central banks may have preferred the spot rates to remain inside an informal band narrower than the official bandwidth of ±15 percent. Potential candidates for EMU may have also favored stable market conditions with low exchange rate volatility during the runup to Stage Three. 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 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.

I. 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 that 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, to counter erratic short-term exchange rate movements but not to alter the current trend, to reshuffle foreign exchange reserves for portfolio considerations, and/or to assist bi- or unilaterally other central banks in conducting their foreign exchange operations.

In 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 intramarginally to correct exchange rate levels deemed not adequate.[5] In contrast to ERM II (see below), ERM I relied on a "parity grid approach": whenever a country wanted to join ERM I, the ECU central rate was first determined. Then as a second step, the bilateral central rates (including the intervention points) were calculated. Since in ERM I all currencies were formally linked to each other via their bilateral central rates and since intervention obligations existed in a mutual way, ERM I truly was a multilateral target zone. In practice, however, the symmetrically designed ERM I soon evolved as an asymmetric exchange rate system in which the deutschemark 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

[4] The most important basic documents were the "Resolution of the European Council on the establishment of the European Monetary System (EMS) and related matters" (1978) and "The Agreement of 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 domestic monetary policy; (c) changes in central rates; (d) other measures of economic policy." ("Resolution of the European Council on the establishment of the European Monetary System (EMS) and related matters," 1978, Section 3.6).

system. Another consequence was that, already in the 1980s, intervention activity shifted from the U.S. dollar to the deutschemark, with the deutschemark becoming the most important ERM intervention currency.

On December 31, 1998, the EMS (and ERM I) ceased to exist and was replaced by ERM II, which entered into force on January 1, 1999.[6] Compared to its predecessor, ERM II is based on 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-à-vis each other. Fluctuation bands are set at ±15 percent around the euro central rates or narrower, depending on progress toward convergence. Interventions have to be undertaken symmetrically and obligatory at the margins, but 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 ERM I, there are no bilateral central rates between the non-euro area member currencies and no bilateral intervention obligations between the non-euro area member currencies. In addition to obligatory interventions, ERM II also entails provisions for intramarginal interventions.[7] An example of intervention activity in ERM II are the euro interventions undertaken by Danmarks Nationalbank after the Danish EU referendum in September 2000.

There is a lot of empirical research on the effectiveness of foreign exchange intervention analyzing the effects of intervention on the level and volatility of exchange rates.[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 “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 here:

> Almekinders and Eijffinger (1994) find that an increase in the conditional variance of the US$/DEM rate leads to an increase in the volume of DEM intervention. In another paper, Almekinders and Eijffinger (1996) find that the Bundesbank and the Federal Reserve (Fed) appear to have “leaned

[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, for example, Dominguez and Frankel (1993), Edison (1993), Almekinders (1995), Schwartz (2000), and Sarno and Taylor (2001).

against the wind" and reacted to increases in the conditional variance of DEM/US$ returns. Lewis (1995) finds that the intervention probability of the Federal Reserve, 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 US$/DEM and $/¥ markets for the period from August 1985 to March 1990. In the first paper, the authors find that for the US$/DEM rate the deviation from a target level Granger-causes intervention. Excess volatility, however, did not increase the probability of intervention. For the $/¥ market, they find mixed evidence. Increased volatility led to US$ purchases, but there was no evidence for DEM sales. The deviation from a target value, in contrast to the US$/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 $/¥ and US$/DEM exchange rates and rejects the hypothesis that exchange rate volatility Granger-causes central bank intervention. Döpke and Pierdzioch (1999) find that the deviation from a target value as well as a change in volatility in the US$/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. Galati and Melick (1999) show that the Fed intervened to support the U.S. 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 and predominantly analyzes the exchange rate relations between the U.S. dollar, the deutschemark, and the Japanese yen. Estimating reaction functions shows that interventions were mainly driven by attempts to correct spot rate deviations from levels that were regarded as being fundamentally justified. There is mixed evidence that an increase in volatility triggered intervention.

II. Modeling Target Zones

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 will take place since the credible commitment by itself will keep the exchange rate within the band. The linkage between the fundamentals and the exchange rate would be nonlinear ("S-shaped") with a slope in general, and at the margins in particular, less than 1 ("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 sensitively the exchange rate reacts to underlying shocks because of expected stabilizing intervention by the monetary authority. When we combine the "honeymoon effect" and the "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 predominantly moving near the edges of the band, are less sensitive to changes in fundamentals. Therefore, compared with a free float solution, a target zone will 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.

When confronted with data from the EMS, however, 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 hump-shaped rather than U-shaped, which demonstrates that exchange rates show a tendency to gather around bilateral parities (e.g., Flood, Rose, and Mathieson, 1991; Dominguez and Kenen, 1992; and 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 intramarginal intervention (e.g., Lindberg and Söderlind, 1994).

The Multilateral Target Zone Model

More recently, the focus shifted from bilateral target zone to multilateral target zone models. Jørgensen and Mikkelsen (1996), Flandreau (1998), and Serrat (2000) analyze exchange rate behavior and intramarginal intervention in a multilateral target zone context. As already mentioned earlier, in 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. Intramarginal interventions, potentially creating unpleasant externalities for other currencies, cause intramarginal

[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 with a free float regime, where only the fundamentals of two currencies determine the bilateral exchange rate.

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

interventions by other central banks, which ultimately lead to situations where exchange rates fluctuate around the middle of the band. This is clearly opposite from 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, exchange rate volatility is a decreasing monotonic function of the distance from the bilateral central rate to the margins. This does not hold for multilateral target zones: here, exchange rate volatility is no longer a monotonic function of the distance. It might even vanish when the exchange rate is well within the band; see Serrat (2000). Jørgensen and Mikkelsen (1996) reach similar conclusions.

Honohan (1993, 1998) and Pill (1996) point out that in 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 deutschemark. A currency could be around or even at the bilateral central rate against the deutschemark and still be at the margin against a third currency at the same time. 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 intramarginal targets. The higher the externalities, the closer the two humps; ultimately they collapse to a hump-shaped density form. Furthermore, higher externalities result in effective exchange rate bands that are narrower than the formerly agreed nominal bands.

III. Stylized Facts about Exchange Rate Movements and Intervention Behavior

Data

We analyze the period from August 3, 1993, the first day after the widening of the bands to ±15 percent, to April 30, 1998, the day before the start-up Member Countries of Stage Three of the European Economic and Monetary Union were officially announced. Our sample contains daily bilateral deutschemark (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 deutschemark assumed the pivotal role in the ERM I, we focus on bilateral deutschemark spot rates

[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 ERM I.

and interventions denominated in deutschemarks. Interventions in other currencies occurred on rare occasions.

The exchange rate data are US$ exchange rate series from the database of the Bank for International Settlements (BIS), 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.[13] According to the rules of the EMS framework, EMS central banks and a few other central banks met four times a day in telephone conferences to exchange market information, including 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 of the previous day to 16:00 of the next day. Interventions, undertaken on the same day but after 16:00, are reported at the first concertation round of the next day at 9:30 and are therefore included in the next day's total intervention volume.

Exchange Rate Behavior

As already mentioned in Section I, foreign exchange intervention may be triggered not only by deviations of the spot rate from target rates but also by excessive 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.[14] In Figure 1, the very 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 relates to the position in the band.

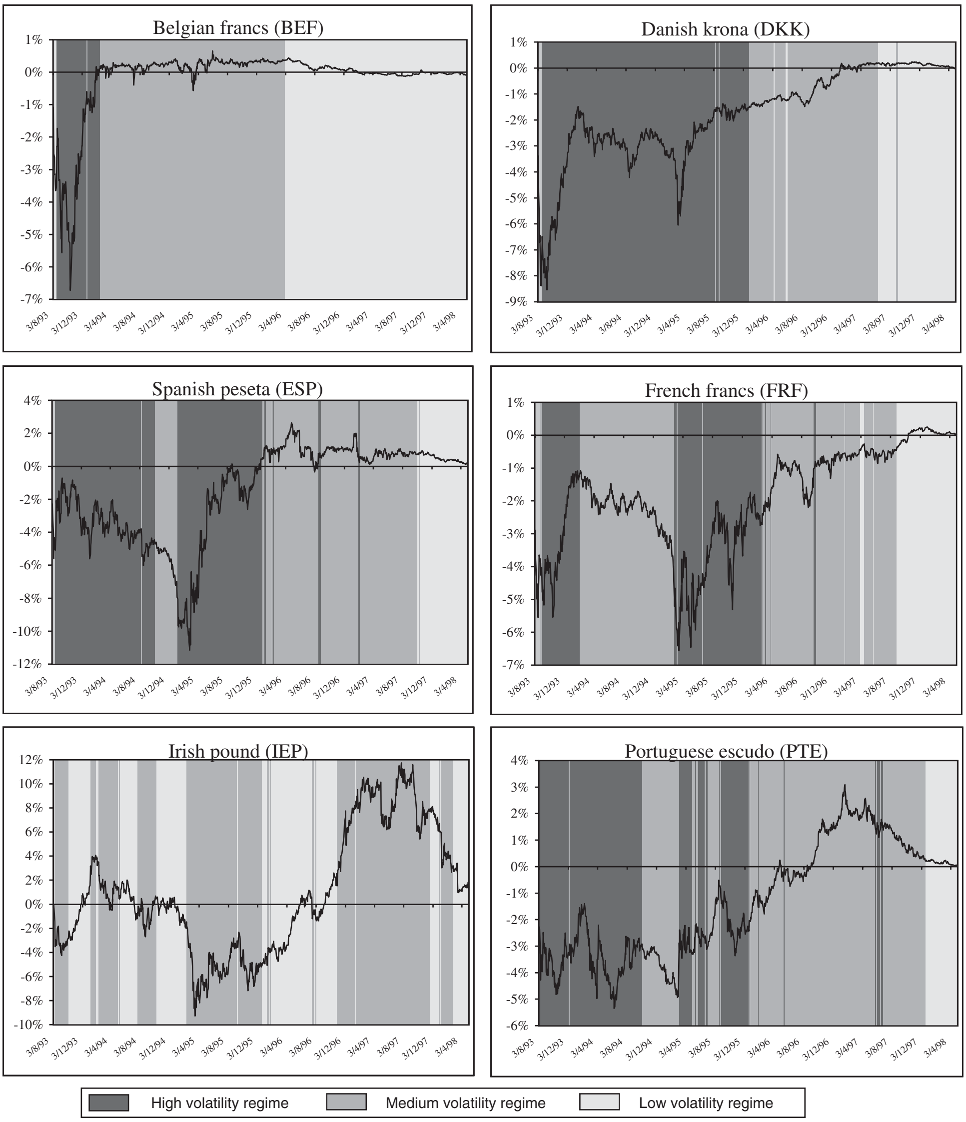
Figure 1 shows deviations of the DEM spot rates from the respective bilateral DEM central parities. All six currencies sharply depreciated after the widening of the bands on August 2, 1993. The depreciation was more pronounced for some currencies (Belgian franc, Danish krona) than for others. All six currencies rebounded at the end of 1993 and, with the exception of the Belgian franc, dropped again by March 1995, partly to levels actually lower than recorded after the bands had been 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

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

[13] Researchers interested in ERM I intervention data are advised to contact the European Central Bank or national central banks, which may release the intervention data upon request.

[14] 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 subperiods, a regime with high, medium, and low volatility. If the regime probability exceeds a value of 0.5, a trading day is assigned to one of the three regimes.

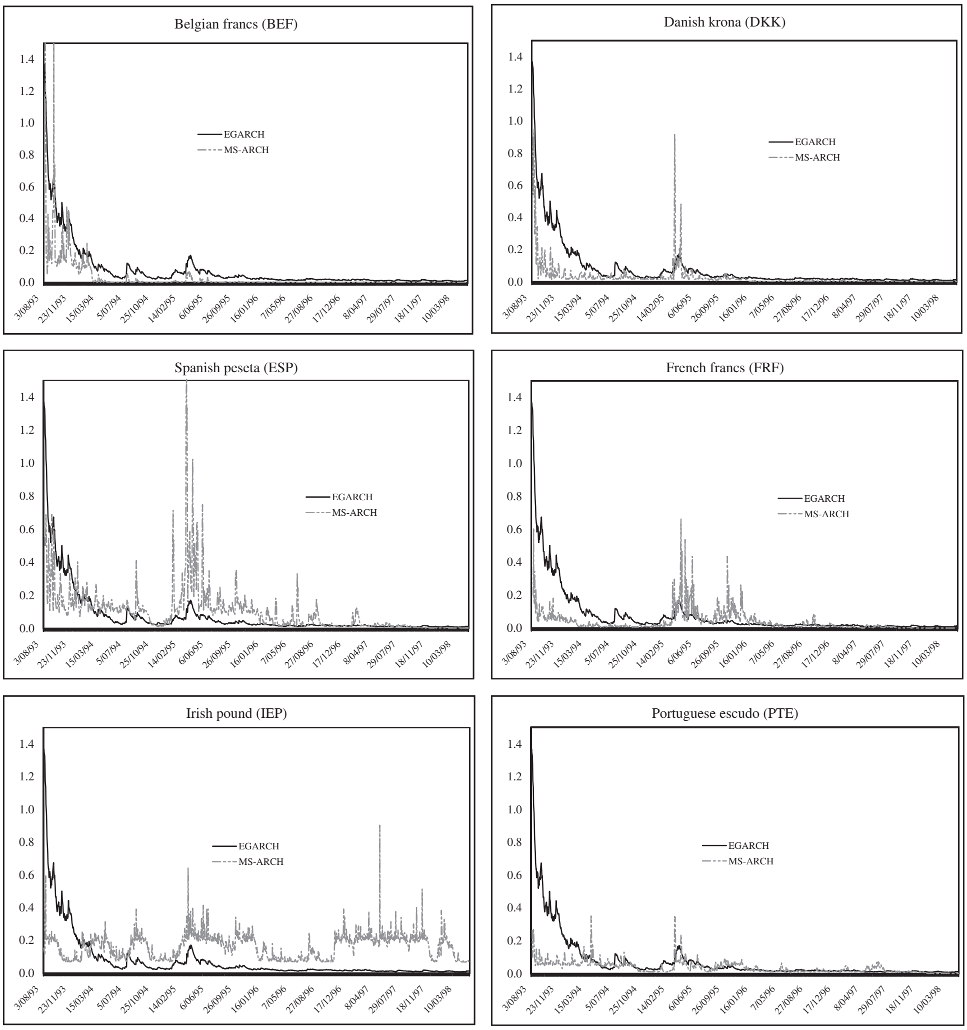
Figure 1. Deviation from Central Parity



of the Spanish peseta and the Portuguese escudo), the Danish krona, Spanish peseta, French franc, Irish pound, and Portuguese escudo appreciated gradually toward the bilateral DEM central rates, but at different speeds. At the end of 1996, the Irish pound started to record significant positive deviations (up to around 10 percent). The Spanish peseta and Portuguese escudo showed modest positive deviations (around 2–3 percent), and the Danish krona and French franc remained around the DEM parities.

In order to see if a currency predominantly stayed above or below the central rate in our sample period, we cumulate the respective trading days (for

Figure 2. Conditional Volatilities



detailed figures see Table 1). The Belgian franc mainly stayed above the central parity (62 percent of all trading days), the Spanish peseta and Irish pound are approximately equally distributed, and the Danish krona, French franc, and Portuguese escudo mainly stayed below the central parity (74, 89, and 64 percent, respectively).

With respect to volatility, the Belgian franc, for instance, remained predominantly in the medium and low volatility regimes, the Danish krona in the high volatility, and the French franc and Portuguese 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.

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
France	384	629	206	*1219*	1096	142
Ireland	—	698	539	*1237*	583	655
Portugal	495	640	98	*1233*	795	443
Spain	582	491	154	*1227*	623	615
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
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
Spain	47.4	40.0	12.6	*100*	50.3	49.7

Notes: 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.

Intervention Behavior

When describing intramarginal DEM intervention activity in 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.[15] All interventions occurred intramarginally.

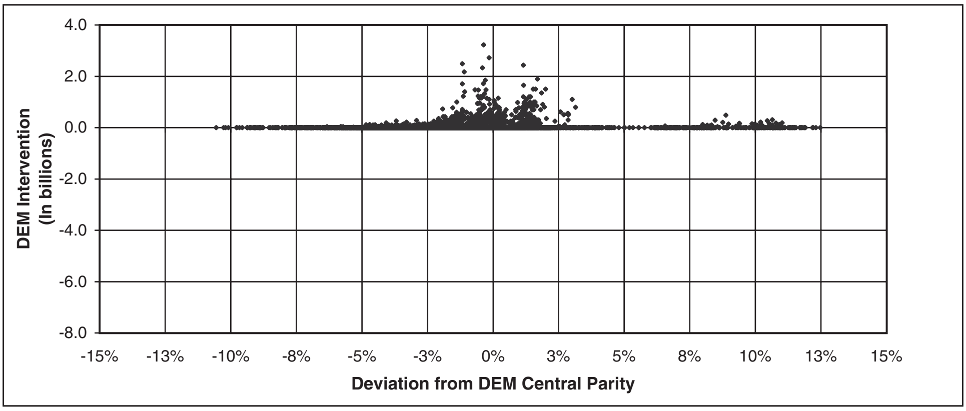
Our sample covers 1,238 trading days. DEM intervention occurred on 843 days (68 percent), DEM purchases on 596 days (48 percent), and DEM sales on 355 days (29 percent). DEM purchases and sales, undertaken on the same day but by different central banks, occurred on 108 trading days (8 percent). Figure 3 presents scatter plots of accumulated daily DEM interventions (Figure 3a: purchases, and Figure 3b: 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 percent around the central parities.

An interesting aspect is to see how many central banks intervened on the same day. Just one central bank bought deutschemarks on 322 days (26 percent of the total number of 1,238 trading days). Two central banks simultaneously purchased deutschemarks on 187 days (15 percent). Five central banks bought deutschemarks on three days. The figures for DEM sales are as follows: only one

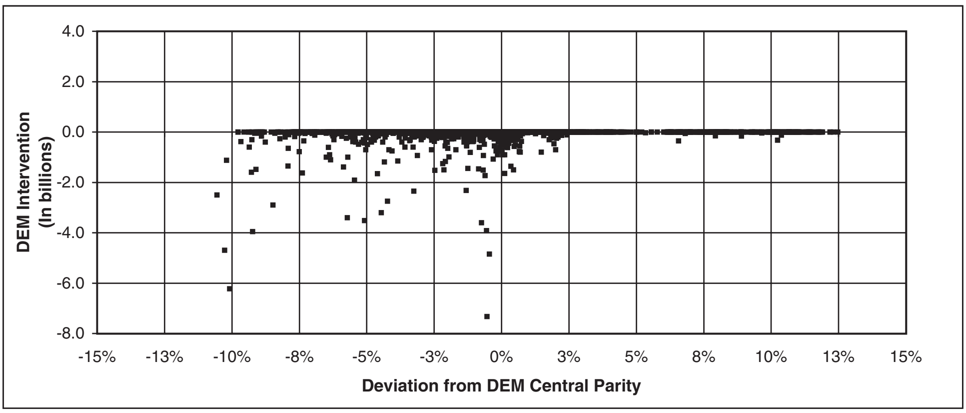
[15] For a description of the 1992/93 ERM turmoil, see, for example, Buiter, Corsetti, and Pesenti (1998).

Figure 3. Aggregated Daily DEM Interventions and Deviation from DEM Central Parity

(A) DEM Purchases



(B) DEM Sales



central bank sold deutschemarks on 258 days (21 percent), two central banks on 72 days (6 percent). Detailed figures are reported in Table 2. Obviously, intervention was conducted on a unilateral basis rather 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, where the spot rate was above the central rate. Surprisingly, a lot of DEM purchases were undertaken in “weak” regime-periods and substantial DEM sales occurred in “strong” regime periods. We take these stylized facts as evidence that obviously motives different from 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 pur-

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 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*
France	263	13	*276*	53	1	*54*
Ireland	18	35	*53*	47	14	*61*
Portugal	8	8	*16*	55	41	*96*
Spain	92	78	*170*	31	40	*71*
In percent						
Belgium	4.9	95.1	*100*	62.8	37.2	*100*
Denmark	73.6	26.4	*100*	61.7	38.3	*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*
Spain	54.1	45.9	*100*	43.7	56.3	*100*

Notes: 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*
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*
Spain	59.4	39.4	1.2	*100*	46.5	36.6	16.9	*100*

Notes: For Ireland, only two volatility regimes have been identified.

chases occurred in periods of medium volatility. DEM sales were undertaken in all three regimes.

Bilateral Exchange Rate Distributions in the Multilateral Framework

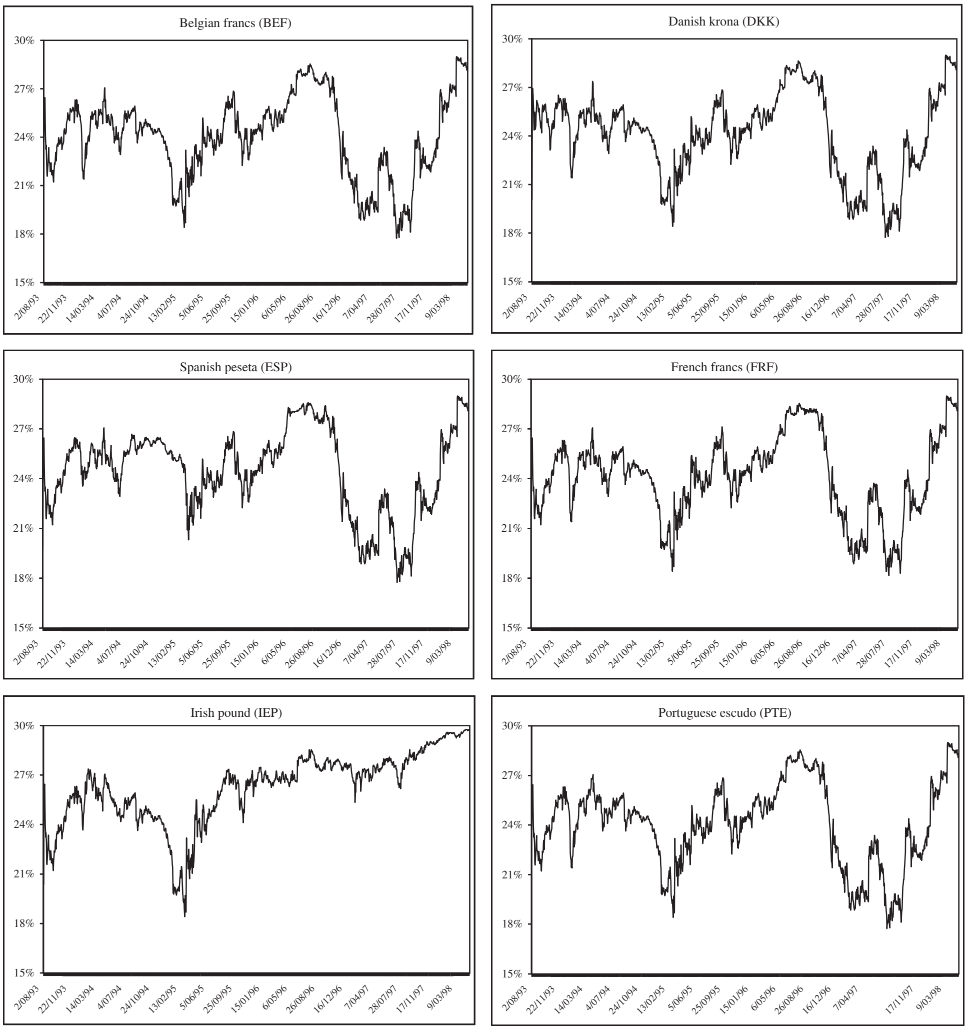
The distribution of exchange rates has been one of the main issues when discussing the empirical implications of target zone models (see also Section II). As already noted, the empirical analysis of exchange rate distributions in ERM I was confined to bilateral relationships against the deutschemark. In particular, the agreement on bilateral fluctuation margins of ±15 percent vis-à-vis more than one currency did not mean that a currency had permanent room for maneuver up to 30 percent 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 were in perfect conformity with the agreed bilateral central rates. Deviations of the spot rates from their central rates result in time-varying effective bandwidths with a floor of 15 percent.

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

$$b_i^{eff}(t) = 0.30 - (\max(s_{ik}(t) - s_{ik}^*) - \min(s_{ik}(t) - s_{ik}^*)),\ k \neq i, \qquad (1)$$

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

Figure 4. Effective Bandwidth of the Six Currencies in the EMS



In order to account for the multilateral setting, we proceed as follows. We estimate bilateral exchange rate distributions of 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

$$d_i^+(t) = \max(s_{ik}(t) - s_{ik}^*), \tag{2a}$$

$$d_i^-(t) = \min(s_{ik}(t) - s_{ik}^*). \tag{2b}$$

The maximum deviation is then given as

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

Figure 5. Kernel Density Estimation of the Deviation from DEM Central Parity

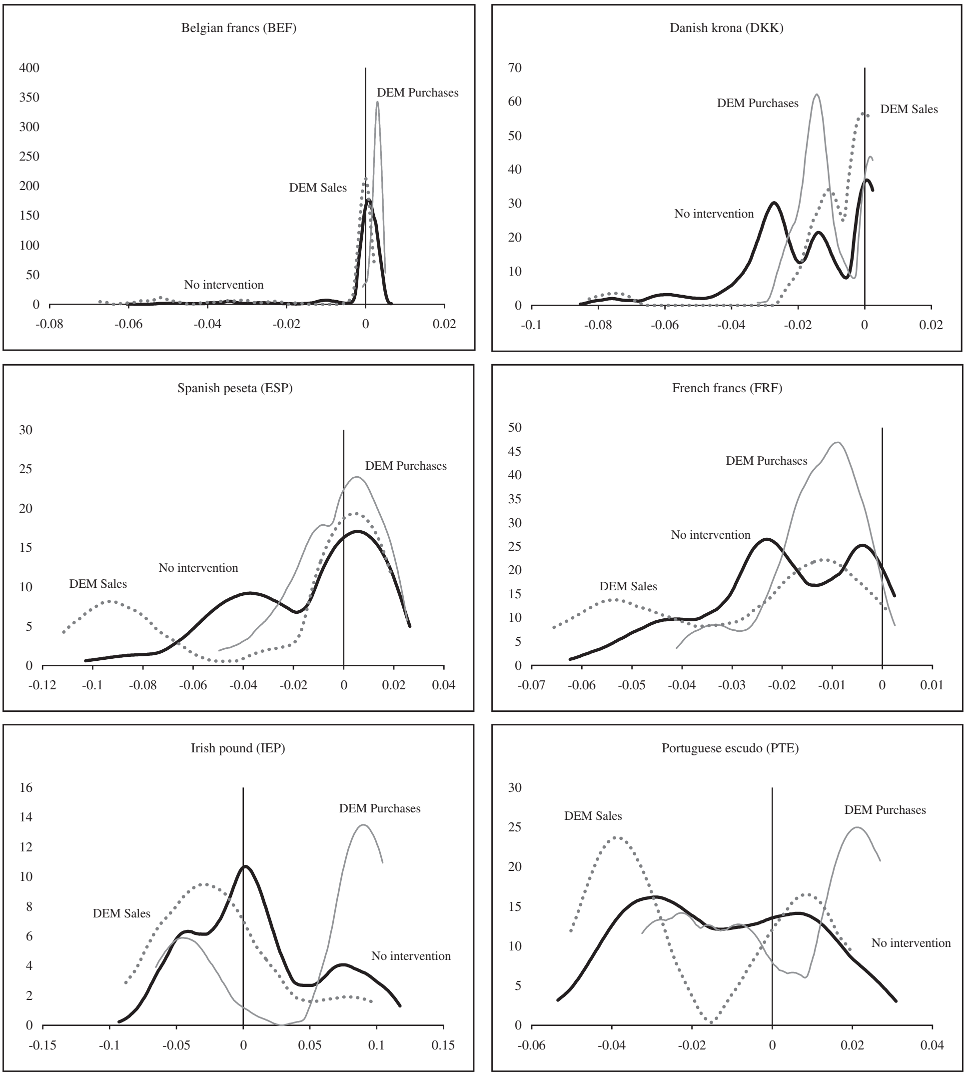
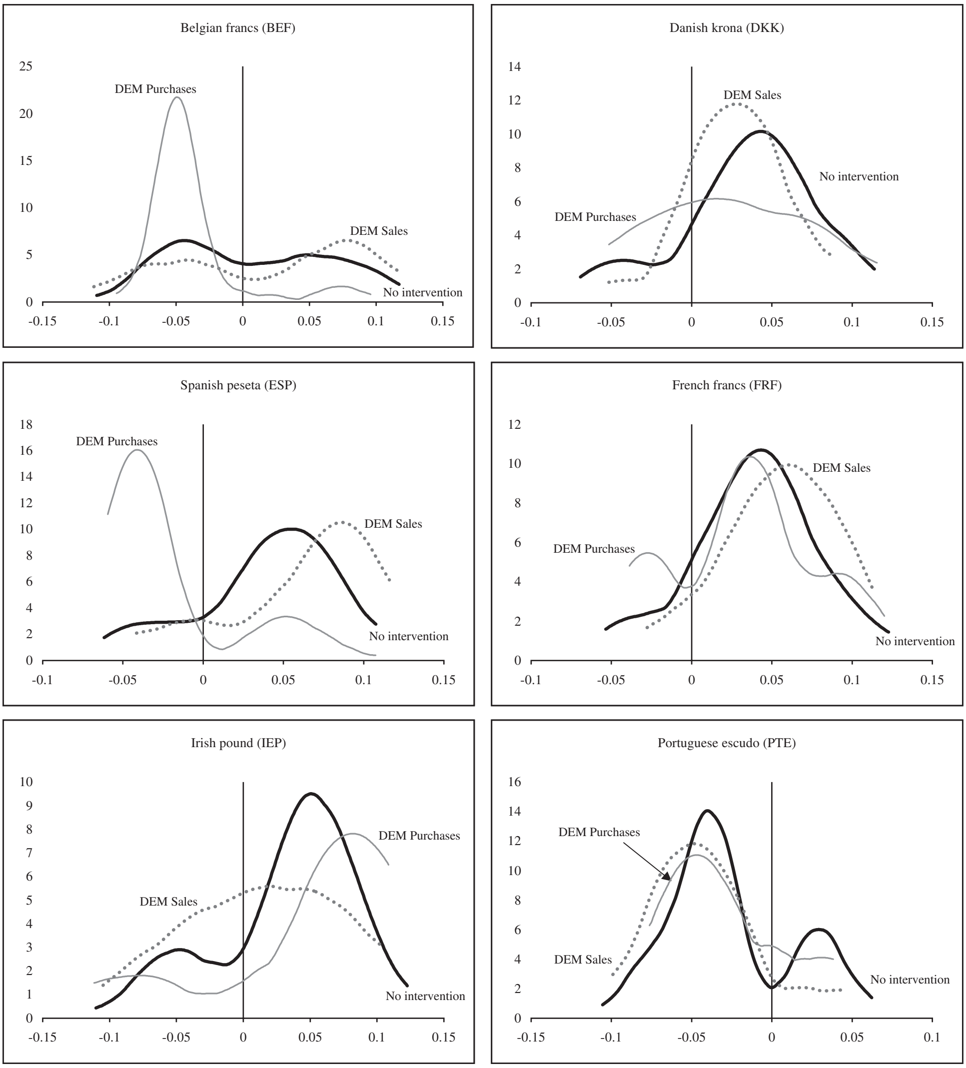


Figure 5 displays the kernel density estimations of the deviations from the DEM central parities, and Figure 6 displays the estimation results of the maximum spot rate deviations from the bilateral central rates in the multilateral target zone framework.[16] The calculations were undertaken for intervention days (days of DEM purchases and DEM sales separately) and days without interventions.

[16] 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.

Figure 6. Kernel Density Estimation of the Maximum Spot Rate Deviation from Bilateral Central Rates in the Multilateral Target Zone Framework



Two aspects deserve special attention:

With respect to intervention behavior (DEM purchases and sales), a remarkable difference emerges by simple visual inspection when we compare Figures 5 and 6. The kernel density estimations of the deviations from the DEM central parities display a more or less "normal" intervention pattern (Figure 5). Deutschemarks are predominantly purchased when spot rates are above the central rates ("DEM-strong currency regime") and deutschemarks 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 when the effective position in the band of one currency was negative ("effective-weak currency regime") and DEM sales vice versa mainly occurred when the effective position in the band was 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 deutschemark than to any other currency in their internal decision making on (intramarginal) 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 subsumed under one objective. As already stated above, central banks obviously did not only have in mind to bring the spot rates back to the levels of the bilateral DEM parities. As central banks also bought deutschemarks in periods of negative spot rate deviations and also sold deutschemarks 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 conditional volatility (or the deviation from a prespecified target volatility) into the intervention reaction functions (see equations (4)–(5) below).

IV. 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 (1997). The authors 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 (1997). 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 to the central parity, the higher the volatility and vice versa. As already mentioned in Section II, these implications need 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 whether 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:[17]

[17]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 will not be a crucial point when using daily data. Brandner, Grech, and Stix (2001) found that DEM interventions were effective on the level and/or volatility only in very few cases.

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

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

where ε_t is an independently and identically distributed error term. The variables are defined in the following way: s_{t-1} is the log of the spot exchange rate (Belgian franc, Danish krona, Spanish peseta, French franc, Irish pound, and Portuguese 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 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).[18]

The empirical specification of the reaction functions also includes the lagged spot rate change as an additional regressor to capture effects not explicitly modeled. The estimation results of all models (coefficients and marginal effects of 96 equations) are presented in nontechnical tables.[19]

V. 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 Section III). The "position-in-the-band" criterion identifies periods of weak and strong currency regimes, that is, 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 and 6 refer to the estimation results for the total period, Tables 7 and 8 show subsample results

[18] The estimations were carried out with the EViews software package.

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

Table 5. 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
Target volatility measured as conditional volatility				
Belgium	++	.	—	.
Denmark	++	.	++	++
France	++	.	—	—
Ireland	++	—	—	—
Portugal	++	.	.	++
Spain	++	—	—	—
Target volatility measured as 5-day moving average of the conditional volatility				
Belgium	++	—	—	.
Denmark	++	.	++	—
France	++	.	.	++
Ireland	++	+	—	++
Portugal	++	.	.	—
Spain	++	+	—	++
Target volatility measured as 10-day moving average of the conditional volatility				
Belgium	++	—	—	.
Denmark	++	.	++	—
France	++	.	-	++
Ireland	++	+	—	++
Portugal	++	.	.	—
Spain	++	++	-	++
Target volatility measured as 20-day moving average of the conditional volatility				
Belgium	++	—	—	.
Denmark	++	.	++	++
France	++	—	-	++
Ireland	++	++	—	++
Portugal	++	—	.	—
Spain	++	++	.	++

Notes: ++ (+): 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 percent (10 percent) marginal significance level.

— (-): Vice versa.

(·): Statistically not significant.

Sample period: August 3, 1993 to April 30, 1998.

following the weak/strong criterion, and Tables 9 and 10 present results of the volatility criterion (high, medium, and low volatility).

Results for the Total Period

An increase in the exchange rate (appreciation of the currency vis-à-vis the deutschemark) raises the volume of DEM purchases of all six central banks (Tables 5 and 6). A depreciation raises the volume of DEM sales or leaves it unchanged in

Table 6. 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
Target volatility measured as conditional volatility				
Belgium	++	.	—	.
Denmark	++	.	++	++
France	++	.	.	.
Ireland	++	++	—	.
Portugal	+	.	.	++
Spain	++	++	.	++
Target volatility measured as 5-day moving average of the conditional volatility				
Belgium	++	.	—	.
Denmark	++	.	++	—
France	++	.	.	.
Ireland	++	.	—	.
Portugal	++	.	-	.
Spain	++	.	—	+
Target volatility measured as 10-day moving average of the conditional volatility				
Belgium	++	.	—	.
Denmark	++	.	++	—
France	++	.	.	.
Ireland	++	.	—	.
Portugal	++	.	.	—
Spain	++	.	—	+
Target volatility measured as 20-day moving average of the conditional volatility				
Belgium	++	—	—	.
Denmark	++	.	++	++
France	++	—	.	++
Ireland	++	++	—	++
Portugal	++	.	.	—
Spain	++	++	.	++

Notes: ++ (+): 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 percent (10 percent) marginal significance level.

— (-): Vice versa.

(·): Statistically not significant.

Sample period: August 3, 1993 to April 30, 1998.

most specifications, Denmark being an exception. The results are more or less insensitive to the choice of the conditional volatility variables.

In contrast to the significant impact of the deviations from the DEM central rates, deviations from the target volatilities exert less influence on the intervention behavior. An increase in the conditional volatility triggers DEM sales more often than DEM purchases. Estimations based on EGARCH volatilities lead to more significant results than estimations based on MS-ARCH volatilities. Market-smoothing

Table 7. Regime-Specific 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	++	++	+	++	++	—	++	—
France	++	++	.	++	—	—	—	+
Ireland	—	++	—	.	.	.	—	—
Portugal	+	+	.	.	—	.	++	.
Spain	++	++	—	++	—	-	-	.
Target volatility measured as 5-day moving average of the conditional volatility								
Belgium	++	++	.	—	—	—	—	++
Denmark	++	++	.	++	++	—	—	+
France	++	++	.	—	.	. . .	++	. . .
Ireland	—	++	.	.	.	.	++	++
Portugal	++	.	.	—	—	-	—	.
Spain	++	++	++	.	—	.	++	.
Target volatility measured as 10-day moving average of the conditional volatility								
Belgium	++	++	—	—	—	—	.	+
Denmark	++	++	.	++	++	—	—	+
France	++	++	.	.	.	-	++	++
Ireland	—	++	.	.	.	.	++	++
Portugal	++	+	.	—	—	-	—	.
Spain	++	++	++	.	—	.	++	.
Target volatility measured as 20-day moving average of the conditional volatility								
Belgium	++	++	—	—	.	—	.	+
Denmark	++	++	.	.	++	—	++	++
France	++	++	—	.	.	.	++	++
Ireland	—	++	.	.	.	.	++	++
Portugal	++	++	—	—	—	-	—	+
Spain	++	++	++	.	—	-	++	.

Notes: ++ (+): 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 percent (10 percent) marginal significance level.

— (-): Vice versa.

(·): Statistically not significant.

If too few interventions occurred within a regime, no estimation results could be obtained (. . .).

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 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	++	++	.	++	++	—	++	—
France	++	++	.	.	.	—	.	.
Ireland	.	++	.	.	.	.	.	.
Portugal	.	++	.	—	—	.	++	.
Spain	++	++	.	++	—	-	++	++
Target volatility measured as 5-day moving average of the conditional volatility								
Belgium	++	++	.	.	—	—	.	++
Denmark	++	++	.	++	++	—	—	.
France	++	++	.	.	.	—	.	—
Ireland	—	++	.	.	.	.	.	.
Portugal	++	++	.	+	—	—	.	—
Spain	++	++	+	-	—	.	.	.
Target volatility measured as 10-day moving average of the conditional volatility								
Belgium	++	++	.	.	—	—	.	++
Denmark	++	++	.	++	++	—	—	.
France	++	++	.	.	.	—	.	-
Ireland	—	++	.	.	.	.	.	.
Portugal	++	++	.	.	—	—	—	—
Spain	++	++	.	.	—	.	.	.
Target volatility measured as 20-day moving average of the conditional volatility								
Belgium	++	++	++	—	.	—	.	++
Denmark	++	++	—	++	++	—	++	++
France	++	++	—	—	.	.	++	++
Ireland	.	++	++	.	.	.	++	++
Portugal	++	++	.	-	—	.	—	.
Spain	++	++	++	++	—	.	++	++

Notes: ++ (+): 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 percent (10 percent) marginal significance level.

— (-): Vice versa.

(·): Statistically not significant.

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 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	++	.	.	++	.	++	++	.	-	++	.	-
France	++	++	—	.	++	.	—	—	.	—	—	.
Ireland	. . .	++	.	. . .	—	-	. . .	—	—	. . .	—	—
Portugal	.	+		.	.	. . .	.	.	.	++	.	.
Spain	++	++	++	—	++	.	—	++	.	—	.	++
Target volatility measured as 5-day moving average of the conditional volatility												
Belgium	. . .	++	++	. . .	—	++	—	—	—	—	.	++
Denmark	++	.	.	.	.	++	++	-	-	—	.	++
France	++	++	—	++	-	-	—	+	.	.	.	++
Ireland	. . .	++	.	. . .	++	.	. . .	—	—	. . .	++	.
Portugal	.	.	. . .	.	—	. . .	.	++	—	—	.	.
Spain	++	++	++	++	.	.	—	++	++	++	.	.
Target volatility measured as 10-day moving average of the conditional volatility												
Belgium	. . .	++	++	. . .	—	++	—	—	—	—	.	++
Denmark	++	.	.	.	.	++	++	-	—	—	.	++
France	++	++	—	.	—	—	—	+	.	++	.	++
Ireland	. . .	++	.	. . .	++	+	. . .	—	—	. . .	++	.
Portugal	.	+	. . .	-	—	. . .	.	++	-	—	.	.
Spain	++	++	++	++	.	+	—	++	++	++	.	.
Target volatility measured as 20-day moving average of the conditional volatility												
Belgium	. . .	++	++	. . .	—	++	—	—	—	—	.	++
Denmark	++	.	.	—	.	++	++	-	—	+	.	++
France	++	++	—	.	—	—	—	+	.	++	.	++
Ireland	. . .	++	.	. . .	++	++	. . .	—	—	. . .	++	++
Portugal	.	+	. . .	—	—	. . .	.	++	.	—	-	++
Spain	++	++	++	++	.	.	—	++	++	++	.	.

Notes: ++ (+): 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 percent (10 percent) marginal significance level.

— (-): Vice versa.

(·): Statistically not significant.

If too few interventions occurred within a regime, no estimation results could be obtained (. . .).

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 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	++	.	.	++	.	.	.	.	—	.	++	—
France	++	++	—	.	.	.	—	++	.	.	++	.
Ireland	. . .	++	.	. . .	.	.	. . .	—	—	. . .	.	.
Portugal	-	+	. . .	.	.	. . .	-	++	—	.	.	-
Spain	++	++	++	.	.	.	—	++	++	++	++	.
Target volatility measured as 5-day moving average of the conditional volatility												
Belgium	. . .	++	++	. . .	.	++	—	—	—	.	.	.
Denmark	++	.	.	.	.	-	+	-	.	—	.	.
France	++	++	—	.	.	.	—	++	.	.	++	.
Ireland	. . .	++	.	. . .	.	-	. . .	—	—	. . .	.	.
Portugal	.	+	. . .	.	.	. . .	-	++	—	.	.	++
Spain	++	++	++	+	—	—	—	++	++	.	.	.
Target volatility measured as 10-day moving average of the conditional volatility												
Belgium	. . .	++	++	. . .	.	++	—	—	—	.	.	.
Denmark	++	.	.	.	.	.	++	-	-	—	.	.
France	++	++	-	.	.	.	—	++	.	.	++	.
Ireland	. . .	++	.	. . .	.	.	. . .	—	—	. . .	+	.
Portugal	.	.	. . .	.	.	. . .	-	++	—	—	-	++
Spain	++	++	++	.	.	-	—	++	++	.	.	+
Target volatility measured as 20-day moving average of the conditional volatility												
Belgium	. . .	++	++	. . .	—	++	—	—	—	—	++	—
Denmark	++	.	.	—	.	.	++	—	—	++	++	++
France	++	++	—	.	—	—	—	.	.	++	++	++
Ireland	. . .	++	.	. . .	++	++	. . .	—	—	. . .	++	++
Portugal	.	++	. . .	.	-	. . .	.	++	—	—	—	.
Spain	++	++	++	++	.	.	—	++	++	++	++	.

Notes: ++ (+): 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 percent (10 percent) marginal significance level.

— (-): Vice versa.

(·): Statistically not significant.

If too few interventions occurred within a regime, no estimation results could be obtained (. . .).

R1 denotes a regime with high volatility, R2 with medium, and R3 with low volatility. For Ireland, only two volatility regimes have been identified.

objectives seem to play a less prominent role for intervention decisions than the spot rate position in the band.

Results for the Subsamples

We start with the discussion of subsample results according to the weak/strong criterion (Tables 7 and 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 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 differ slightly 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 and 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.

VI. Summary and Conclusions

In this paper, we present stylized facts about exchange rate movements and intervention behavior in ERM I, in particular in light of the recent literature on multilateral target zone models. The economics of multilateral target zones differs from the economics of bilateral target zones. An important aspect in this respect is endogenous intramarginal intervention that arises from cross-currency constraints.

We estimate bilateral exchange rate distributions of the maximum spot rate deviations vis-à-vis all central parities to account for the multilateral setting of ERM I. In a further analysis, we estimate short-term reaction functions for the central banks of Belgium, Denmark, France, Ireland, Portugal, and Spain by applying a Tobit analysis. We use 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 bank intervention. These general conclusions are insensitive to the choice of the modeling 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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