Nonlinear Exchange Rate Dynamics in Target Zones: A Bumpy Road Toward a Honeymoon
Some Evidence from the ERM, ERM II and Selected New EU Member States

Jesús Crespo-Cuaresma[1]
Balázs Égert[2]
Ronald MacDonald[3]

This study investigates exchange rate movements in the Exchange Rate Mechanism (ERM) of the European Monetary System (EMS) and in the Exchange Rate Mechanism II (ERM II). On the basis of the variant of the target zone model proposed by Bartolini and Prati (1999) and Bessec (2003), the authors set up a three-regime self-exciting threshold autoregressive model (SETAR) with a non-stationary central band and explicit modeling of the conditional variance. This modeling framework is employed to model daily Deutsche mark-based and median currency-based bilateral exchange rates of countries participating in the original ERM and also for the exchange rates of the Czech Republic, Hungary, Poland and Slovakia from 1999 to 2004. Our results confirm the presence of strong nonlinearities and asymmetries in the ERM period, which, however, seem to differ across countries and diminish during the last stage of the run-up to the euro. Important nonlinear adjustments are also detected for Denmark in ERM II and for our group of four CEE economies.

1 Introduction

The seminal paper of Krugman (1991) focused on explaining the exchange rate behavior of a currency with a central parity rate and upper and lower exchange rate bands, the so-called target zone model. The existence of the Exchange Rate Mechanism (ERM) of the European Monetary System (EMS) gave researchers an ideal opportunity to test the target zone model because it provided ample data for empirical analysis. Since the early 1990s, numerous papers have been written on the period preceding the ERM crisis of 1993,[4] while the period in the run-up to the euro has received less limelight.[5] However, further analysis of the post-1993 experience would appear to be fruitful for at least two reasons. First, Flood, Rose and Mathieson (1990) and Rose and Svensson (1995) reported only limited nonlinearity in the period prior to 1993. However, the widening of the fluctuation bands from 2.25% to 15% in the post-1993 period may have introduced additional nonlinear behavior to exchange rates. Second, the recent enlargement of the European Union to 25 countries implies that the new Member States will participate, at some point in time, in an ERM II arrangement prior to their adoption of the euro. For them, the behavior of ERM currencies prior to the introduction of the euro in 1999 may contain useful information.

The empirical literature on target zones suffers from a number of problems. First, most studies use monthly or weekly frequencies, which may aggregate "out" the true dynamics of the exchange rate. Second, the frequent jumps in the central parity in the ERM are not adequately accounted for in the pre-1993 period. Finally, either the mean[6] or variance equation[7] is investigated in a more sophisticated way instead of being modeled jointly.

[1] *University of Vienna. E-mail: jesus.crespo-cuaresma@univie.ac.at.*

[2] *Oesterreichische Nationalbank; University of Paris X-Nanterre and the William Davidson Institute. E-mail: balazs.egert@oenb.at and begert@u-paris10.fr.*

[3] *University of Strathclyde. E-mail: r.r.macdonald@strath.ac.uk.**The authors would like to thank Marie Bessec, Harald Grech, Peter Mooslechner, Thomas Reininger, Timo Teräsvirta and an anonymous referee for helpful comments and suggestions. The paper benefited from comments from participants at an internal seminar at the Oesterreichische Nationalbank. We are grateful to André Verbanck from the European Commission (DG ECFIN) for providing us with the data series for the median currency.*

[4] *Examples are Anthony and MacDonald (1998), Bessec (2003), Bekaert and Gray (1998), Chung and Tauchen (2001), and Rose and Svensson (1995).*

[5] *See e.g. Anthony and MacDonald (1999), Bessec (2003), and Brandner and Grech (2002).*

[6] *E.g. Bessec (2003) models the mean equation by means of a SETAR model.*

[7] *Brandner and Grech (2002) use a simple autoregressive (AR) process for the mean equation and use different Generalized Autoregressive Conditional Heteroscedasticity (GARCH) models for the variance equation.*

The aim of this study is to shed additional light on exchange rate behavior in ERM, ERM II and CEE (Central and Eastern European) countries. Our modeling framework is based on the target zone models set out in Bartolini and Prati (1999) and Bessec (2003). These models predict the presence of soft bands within the officially announced large bands. More specifically, these models assume that the monetary authorities do not intervene in the proximity of the central parity. In this area, the exchange rate behaves like a random walk. However, the monetary authorities take policy action when the exchange rate is about to leave this corridor. Thus, the exchange rate exhibits mean reversion toward the soft band. However, it should be noted that in reality, such band mean reversion could be the outcome of a number of factors, such as direct and indirect central bank interventions, moral persuasion, communication with the markets and stabilization of market expectations in the face of increased credibility of the monetary authorities or because of an increased stability of the underlying fundamentals. This type of behavior is best captured by a three-regime Self-Exciting Threshold Autoregressive (SETAR) model in which we model conditional variance by means of a GARCH (1,1). The application of this model for daily data from the post-1993 ERM and ERM II not only indicates the presence of a three-regime threshold model but also of considerable asymmetries for the detected upper and lower bounds that delimit the soft band within the announced target zone.

The remainder of the paper is structured as follows: Section 2 overviews the target zone literature and summarizes the principal features of this class of models. Section 3 sets out the econometric framework. Section 4 provides a description and a first analysis of the data used in the paper. Section 5 analyzes the empirical results, and section 6 provides some concluding remarks.

2 Target Zone Models

2.1 The Krugman Model: Perfect Credibility with Marginal Interventions

The baseline target zone model presented in Krugman (1991) is based on a continuous-time representation of the flexible-price monetary model in which the exchange rate (e) is assumed to be a linear function of a set of fundamental variables (f) and the expected change of the exchange rate ($E(de)/dt$):[8]

$$e = f + \delta E(de)/dt \tag{1}$$

The fundamentals explicitly considered by Krugman (1991) are money supply and velocity. Money supply is controlled by the monetary authorities, whereas velocity is exogenous. First, it is assumed that market participants perceive the announced fluctuation band around the central parity as fully credible. Perfect credibility implies that neither the fluctuation bands nor the central parity will be altered and that the exchange rate will remain inside the fluctuation band. Second, it is assumed that the monetary authorities only intervene when the exchange rate hits the upper or lower bound of the officially announced fluctuation band. The implication of the second assumption is that within the fluctuation band the exchange rate behaves like under a free float. Because

[8] *Recall that under the assumption of uncovered interest parity, the standard discrete-time form of the monetary model can be written as follows:* $e_t = m_t - m_t^* - \alpha(y_t - y_t^*) + \beta\triangle e_{t+1}^e$, *$m$ and m^* denoting domestic and foreign money supply, y and y^* standing for domestic and foreign output and $\triangle e_{t+1}^e$ representing the expected change in the nominal exchange rate in period t for period $t+1$.*

velocity is assumed to follow a standard Wiener, or Brownian motion, process without drift[9] and because the money supply is considered constant under a free float (with the expected change in the exchange rate being equal to zero), the nominal exchange rate also follows a Brownian motion process and depends proportionally on the fundamentals, i.e. velocity.

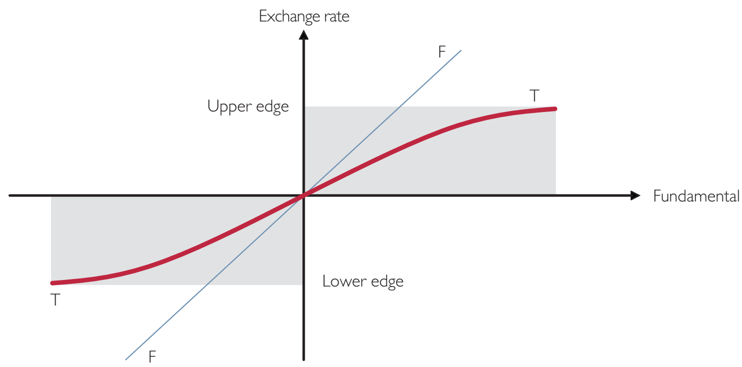
Under the assumptions sketched out above, the general solution of the model becomes the following:

$$e = f + A \cdot exp(\mu \cdot f) + B \cdot exp(-\mu \cdot f) \qquad (2)$$

where A and B are constants, $\mu = \sqrt{2/\lambda \cdot \sigma_f^2}$, σf is the standard deviation of the fundamentals and λ denotes the elasticity of real money supply to the interest rate in the structural form of the monetary model. Equation (2) is composed of a linear and a nonlinear part. The linear part, f, represents the solution for a free float. However, the main results of the model, which came to be known as the *honeymoon effect* and *smooth pasting* are reflected in the nonlinear part, $A \cdot exp(\mu \cdot f) + B \cdot exp(-\mu \cdot f)$. The honeymoon effect refers to the phenomenon that if the exchange rate is close to the weaker (stronger) edge of the band, the probability increases that the exchange rate will hit the edge, which automatically leads to interventions by the monetary authorities. As a consequence, the probability that the exchange rate appreciates (depreciates) is higher than the probability that it depreciates (appreciates). This is depicted in chart 1. From this it follows that the exchange rate will be less depreciated (appreciated), given by the line TT, than the one that would be given by the fundamentals alone (linear component of equation 2) under a free float (45-degree line FF). Thus, this type of target zone model stabilizes the exchange rate relative to its fundamentals within the fluctuation band. *Smooth pasting* refers to the phenomenon that the path of the exchange rate smoothes out on its way to the boundaries of the band and that its slope becomes zero when it eventually hits the edge.

Chart 1

The Krugman Model



Source: Based on Krugman (1991).

A crucial implication of the baseline Krugman model is that the exchange rate will spend more time close to the boundaries than inside the target zone. Consequently, the distribution of the exchange rate will be U-shaped between

[9] *This is indeed the continuous-time representation of a random walk.*

the upper and lower bounds. Lundbergh and Teräsvirta (2003) demonstrate for the case of Norway from 1986 to 1988 that, provided the two main assumptions are satisfied, i.e. the target zone is perfectly credible and the monetary authorities intervene only at the edges of the target zone, the Krugman model is able to describe surprisingly well the exchange rate behavior in Norway in the period considered.

2.2 Extensions of the Krugman Model[10]

Target zone exchange rate regimes may not be fully credible because the central parity may be realigned and the fluctuation bands widened. If realignment causes a shift in the band which does not overlap with the previous band, the exchange rate will jump. This may or may not be the case if there is an overlap between the old and new bands. Numerous realignments took place, for instance, within the ERM[11] and also in transition countries such as Poland and Hungary.[12]

Given such discontinuities, a number of attempts have been made to relax the assumption of perfect credibility and to allow for jumps in the central parity. Table 1 summarizes the main features of the different extensions, and chart 2 gives the distribution of the exchange rate within the officially announced fluctuation bands.

Table 1

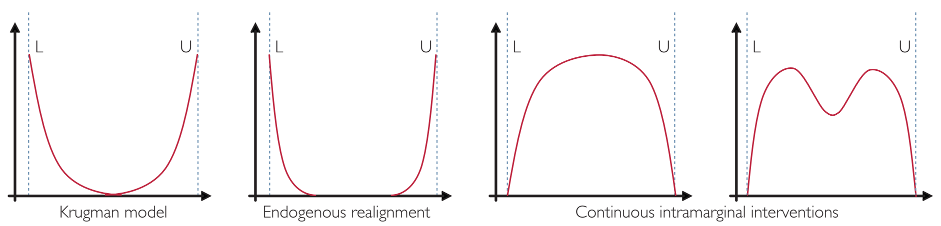
Overview of Different Models and Their Implications

	Prices	Credibility	Intervention	HM	SP	Distribution
Krugman (1991)	flexible	perfect	marginal	K	K	U-shaped
Bertola and Caballero (1992)	flexible	exogenous realignment risk	marginal			
Tristani (1994)						
Werner (1995)	flexible	endogenous				
Realigment risk	marginal	FF	FF	U-shaped		
Delgado and Dumas (1992)	flexible	perfect	continuous intramarginal	K	K	hump-shaped
Beetsma and Ploeg (1994)	sticky	perfect	continuous intramarginal	K	K	hump-shaped
Bessec (2003)	flexible	perfect	two regimes			twin peak

*Notes: HM = honeymoon effect. K denotes the honeymoon effect and smooth pasting (SP) under the Krugman solution.
K (FF) signals that the respective effects are smaller than in the Krugman model (free float).*

Chart 2

The Distribution of the Exchange Rate within the Target Zone



Source: Compiled by authors.

[10] *For a very detailed presentation of the extensions, see e.g. Svensson (1992) and Kempa and Nelles (1999).*

[11] *Note that no realignment took place for Greece and Denmark in the ERM II.*

[12] *In Hungary, the central parity was devalued 23 times between 1990 and 1995 (prior to the introduction of the crawling peg system). Within the framework of the crawling band regime in Poland, the central parity was devalued three times between 1991 and 1993 and was revalued in 1996 (independently from the ongoing daily devaluations).*

2.2.1 Imperfect Credibility with Exogenous Realignment Risk

Bertola and Caballero (1992) allow for exogenous realignment risk. The central parity (c), set to zero in the Krugman model, is now considered to become part of the aggregate fundamental variable: $f = v - \Gamma + c$, where v is a stochastic term and Γ is the fundamental. The monetary authorities will defend the currency with probability (1-p) when it reaches the edges of the band and will proceed with realignment of the central parity with probability p. Realignment is assumed to be reflected in a shift of the band. The general solution of the model is now as follows:

$$e = f + A \cdot exp(\mu \cdot (f - c)) + B \cdot exp(-\mu \cdot (f - c)) \qquad (3)$$

The model with exogenous realignment risk implies that under certain circumstances ($p \geqq 0.5$) both the honeymoon effect and smooth pasting disappear.

2.2.2 Imperfect Credibility with Endogenous Realignment Risk

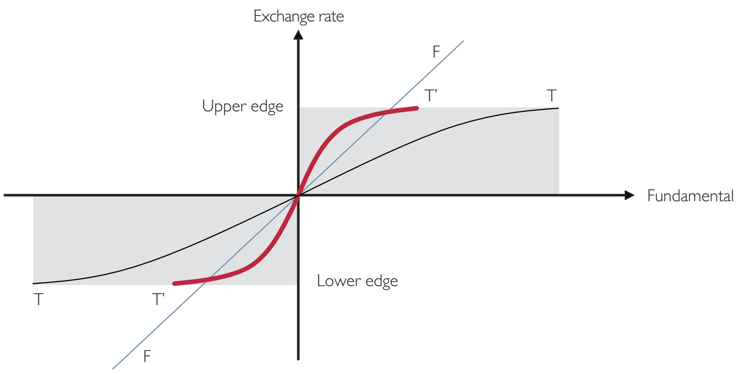
Clearly, the fact that realignment risk is modeled as exogenous and that realignment only takes place when the exchange rate is at the edges of the band may be too restrictive and need not apply in reality. Tristani (1994) and Werner (1995) set out to model realignment risk as endogenous by assuming that the probability of realignment is a positive function of how far the exchange rate is located from the central parity – the larger the distance, the higher the probability of realignment. The general solution of their model is given by:

$$e - c = (f - c) \cdot (1 \frac{\lambda \eta p}{w} + A \cdot exp(\mu \cdot (f - c)) + B \cdot exp(-\mu \cdot (f - c)) \qquad (4)$$

where η, p and w stand for the size of realignment, the probability of a realignment (which is a function of the deviation from the central parity) and the width of the target zone, respectively. Chart 3 shows that a result of the model is that the S curve becomes steeper (line T'T') when compared to the S curve obtained from the Krugman model (chart 1). This in turn implies an even stronger U-shaped distribution of the exchange rate within the band.

Chart 3

Endogenous Misalignment Risk



Source: Compiled by authors.

2.2.3 Perfect Credibility with Intramarginal Interventions

The second main assumption of the Krugman model could fail because the monetary authorities may wish to intervene within the band (i.e intramarginal intervention) and not just in case the exchange rate hits the upper or lower edges of the band (marginal intervention). Mastropasqua et al. (1988) and Delgado and Dumas (1992) argue that about 85% to 90% of total interventions took the form of intramarginal intervention in the ERM before the crises in 1992 and 1993. Regarding the post-crisis period, the exchange rate never hit the upper or lower bound of any of the participating countries, which implies that all interventions were necessarily intramarginal.[13] As a result, it comes as no surprise that the distribution of the exchange rate is usually found to be hump-shaped for currencies participating in ERM and ERM II, suggesting that the exchange rate spends most of the time in the middle of the band rather than close to the boundaries of the target zone.

Considerable effort has been made to build target zone models that are able to account for intramarginal interventions. For example, Delgado and Dumas (1992) modify the Krugman model so as to account for intramarginal interventions, which are assumed to take place continuously inside the target zone if the exchange rate deviates from the central parity. The solution provided by Delgado and Dumas (1992) is:

$$e = \frac{f + \alpha p f_0}{1+\alpha p} + AM\left(\frac{1}{2\alpha p}, \frac{1}{2}, \frac{p(f_0 - f)^2}{\sigma_v^2}\right) + PM\left(\frac{1+\alpha p}{2\alpha p}, \frac{3}{2}, \frac{p(f_0 - f)^2}{\sigma_v^2}\right)\sqrt{\frac{p(f_0-f)}{\sigma_v}} \quad (5)$$

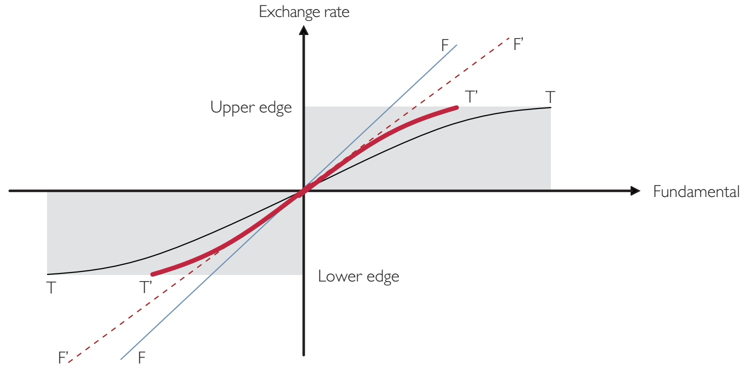
where M is the hypergeometric function and f_0 is the fundamental's value when the exchange rate is equal to the central parity. Chart 4 shows the main result of the model: although the honeymoon effect diminishes considerably (line T'T') when compared to the honeymoon effect under perfect credibility and marginal intervention, the exchange rate is nonetheless less volatile than under a free float.[14] Similarly, smooth pasting is also substantially reduced in this setup because market agents know that monetary authorities have already intervened. If A and B are set to zero, the Delgado and Dumas solution collapses to $e = \frac{f+pf_0}{1+\alpha p}$, which happens to be the case of managed floating without fixed boundaries. In such a setting, all interventions would qualify as intramarginal. The solution shows that the exchange rate is stabilized compared to the free-float position and that interventions induce a mean reversion of the exchange rate toward the central parity (line F'F'). Put differently, even in the absence of a formal target zone-type of exchange rate arrangement, central bank interventions can stabilize the exchange rate relative to the case of a free float.

[13] *Brandner and Grech (2002) provide some summary statistics on the intervention activity of the participating countries' central banks after 1993.*

[14] *Note that this is not necessarily the case in a multilateral target zone with intramarginal interventions. For example, Serrat (2000) shows that in such a setting, exchange rate volatility can be larger than under a free float.*

Chart 4

Intramarginal Interventions



Source: Compiled by authors.

2.2.4 Sticky Prices with Intramarginal Interventions

A major drawback of the models presented above is that they are based, without exception, on the flexible-price monetary model, which assumes that purchasing power parity (PPP) holds continuously. However, it is a well-established fact that PPP does not hold continuously;[15] therefore some kind of rigidity should be introduced into the modeling framework. Following the example of the Dornbusch overshooting model, Miller and Weller (1991) introduce sticky prices into the Krugman model. Beetsma and Ploeg (1994) complete the sticky price model with intramarginal interventions and show that sticky prices coupled with intramarginal interventions lead to a hump-shaped distribution of the exchange rate within the target zone.

2.2.5 Unofficial Bands within the Target Zone

Bessec (2003) proposes that it is unlikely that monetary authorities would be willing to intervene continuously, independently of the distance of the exchange rate from the central parity. She argues that it is more likely instead that monetary authorities do not intervene in the immediate neighborhood of the central parity and that they allow the exchange rate to fluctuate in a given corridor around the central parity. Only if the exchange rate exits this corridor do the monetary authorities step in to intervene. This kind of regime can be described by the combination of the Krugman model with the Delgado and Dumas model. For example, consider e_U and e_L, which denote, respectively, the upper and lower bounds within the band beyond which the monetary authorities intervene in order to bring back the exchange rate to the central parity. The solution is thus a combination of the free-float Krugman solution, if $e_L \leq e \leq e_U$, and the Delgado and Dumas solution in case the exchange rate is below the lower bound ($e < e_L$) or above the upper bound ($e > e_U$):[16]

[15] *See e.g. Rogoff (1996) and MacDonald (1995, 2004).*

[16] *Bartolini and Prati (1999) develop a different model that may be able to capture such behavior. In particular, they argue that there is a narrow, unofficial band within the officially announced band. The narrow band is soft in that its boundaries are not only not publicly announced but also in that they change given that a moving average rule based on past values of the exchange rate is assumed. This setup is indeed very close to reality given that the European Monetary Institute and the ECB evaluated the criterion on exchange rate stability on the basis of a 10-day moving average.*

$$e = \begin{cases} DELGADO-DUMAS \ solution & \text{if } e > e_U \\ KRUGMAN \ free-float \ solution & \text{if } e_L \le e \le e_U \\ DELGADO-DUMAS \ solution & \text{if } e < e_L \end{cases} \quad (6)$$

Note that the upper and lower regimes need not have equal parameters because the monetary authorities may have asymmetric preferences. Table 1 summarizes the main features of the different models, and the corresponding exchange rate distributions are plotted in chart 2.

Although the theoretical model suggests that it is only intramarginal intervention by the monetary authorities that creates a band of inaction, it is worth noting that in practice, a large number of other factors may also be responsible. Such factors are the ability of the monetary authority to stabilize the national currency by other policy actions. Second, moral persuasion and appropriate communication towards the markets are also likely to influence the exchange rate. More particularly, market expectations and the credibility of the monetary authorities are likely to play a big role. If the monetary authorities are credible, it may suffice to intervene in very small amounts in the market to persuade agents that the exchange rate will remain stable. Or, even better, the possibility of market intervention and a well-established track record of the monetary authorities may bring about relative exchange rate stability. Finally, expectations may also be stabilized because fundamentals become increasingly stable or because of expected future developments of the fundamentals. This may have played a special role in the run-up to the euro in the late 1990s, when the markets expected a high degree of macroeconomic convergence to occur across countries. Therefore, the band of inaction could be viewed as a band where the exchange rate dynamics resemble a random walk process whereas outside the band, the above factors can result in the exchange rate mean reverting. In the remainder of the paper, when using the expression "band of inaction," we have this broader interpretation in mind.

3 Econometric Issues: The SETAR-GARCH Model

In this section, we propose a simple nonlinear time series model with local nonstationary behavior but overall ergodic characteristics, which is a discrete-time representation of the mixed-solution model proposed by Bessec (2003). The model aims to detect the nonstationary behavior of the exchange rate within an official band (ψ_2, ψ_1) when it stays within the band of inaction[17] around the officially announced central parity while allowing for global mean reversion toward the band of inaction contemplated by the monetary authorities. The specification we propose is a simple three-regime Self-Exciting Threshold Autoregressive (SETAR) model with a central band in which the variable behaves like a unit root process.[18] The errors in the specification have a simple GARCH (1,1) structure in order to account for the time-varying variance and volatility clustering observed in the data.

[17] *In practice, there are a number of factors that may lead to the emergence of a band of inaction, as explained in section 2.*

[18] *The SETAR-GARCH model proposed presents a more parsimonious specification than the STAR (smooth transition autoregression) parametrization in Lundbergh and Teräsvirta (2003), and appears as a special case of the latter if the thresholds correspond to the official target zone bands. In our modeling strategy, however, we allow for an intramarginal band of inaction whose limits need not correspond to the officially stated ones, and that is actually estimated.*

The specification of the model is the following:

$$\triangle y_t = \begin{cases} \chi_0 + \lambda_1 y_{t-1} + \sum_{k=1}^{K} \chi_k \triangle y_{t-k} + \varepsilon_t & \text{if } \ y_{t-1} \geq \phi_1 \\ \delta - 0 + \sum_{k=1}^{K} \delta_k \triangle y_{t-k} + \varepsilon_t & \text{if } \ \phi_1 \geq y_{t-1} \geq \phi_2 \\ \pi_0 + \lambda_2 y_{t=1} + \sum_{k=1}^{K} \pi_k \triangle y_{t-k} + \varepsilon_t & \text{if } \ \phi_2 \geq y_{t=1} \end{cases} \quad (7)$$

where the error term, ε_t, is assumed to follow a GARCH (1,1) process, $\varepsilon_t \,|\, I_t \quad N(0, \sigma_t)$,

$$\sigma_t^2 = \gamma + \alpha \cdot \varepsilon_{t-1}^2 + \beta \cdot \sigma_{t-1}^2, \quad (8)$$

where I_t refers to the information set available in period t. Note that if $\lambda_i \in (-1{,}0), i = 1{,}2$ for suitable values of χ_0 and π_0, y_t will present overall mean reverting features to the band (ϕ_1, ϕ_2) which is assumed to be contained in the official band (ψ_2, ψ_1). Inside the band, however, the variable behaves as a unit root process with GARCH errors. A homoscedastic version of this model is used in Bessec (2003) to assess the dynamics of the exchange rate of selected countries within ERM.

We intend to estimate the model given by (7) – (8) in the following way. For a given series y_t, the model is estimated setting the values of ϕ_1 and ϕ_2 to actual realizations of y_t in the sample (say starting with the 10th and 90th percentile of the empirical distribution of y_t). The process is repeated for all combinations of ϕ_1 and ϕ_2 corresponding to realized values (after ensuring that a minimal percentage of the observations falls in the central band), and the pair (y_1, y_2) corresponding to the model with a minimal sum of squared residuals is chosen as the estimator of ϕ_1 and ϕ_2. Given the estimates of the threshold values, which are constant over time and which delimit the band, the estimation of the full model is straightforward using maximum likelihood methods.[19]

In our analysis, we obtain the estimates for the thresholds that define the band using a grid search over the realized values of y_t after trimming 10% in the extremes of the empirical distribution of y_t. The grid search was carried out at 5% steps, ensuring that at least 20% of the observations fall in the nonstationary regime defined by the band.[20]

An important issue that needs to be taken into account explicitly is how to test the significance of the simple unit root against the nonlinear model.[21] Due to the fact that the threshold parameters ϕ_1 and ϕ_2 are not identified under the null hypothesis of a linear unit root process with GARCH errors, the usual likelihood ratio test statistic for testing this hypothesis against the alternative of a SETAR model such as (7) – (8) does not have a standard limiting distribution (for literature on this problem see Andrews and Ploberger, 1994 and Hansen, 1996, 2000; Caner and Hansen, 2001, consider the problem when the underlying stochastic process has a unit root). We therefore intend to carry out the test using a bootstrap procedure in the spirit of Hansen (2000) and

[19] *The optimal lag length for the autoregressive component is determined using the Schwarz information criterion.*

[20] *This means that for both the lower and the upper bound threshold, the search is performed from the 10th percentile to the 90th percentile of the distribution. This is much more general than what is done, for instance, in Bessec (2003), who searches from the 5th to the 35th percentile of the distribution for the lower bound threshold and from the 70th to the 95th percentile for the upper bound threshold.*

[21] *To a certain extent, the choice of the unit root model as the null hypothesis could be considered arbitrary, but it appears as a natural model to which the SETAR-GARCH model should be compared if we consider the time series properties of the exchange rate series.*

Caner and Hansen (2001). Let T be the sample size. First, we compute the standard likelihood ratio (LR) test statistic,

$$LR = 2(\log L_{TAR} - \log L_{UR}),$$

where L_{TAR} is the likelihood of the model given by (7) – (8) and L_{UR} is the likelihood of the linear unit root model given by

$$\triangle y_t = \theta_0 + \sum_{k=1}^{K} \theta_k \triangle y_{t-k} + \varepsilon_t, \qquad (9)$$

where the error term is assumed to follow a GARCH (1,1) process such as the one given in (8). With the estimated parameters of model (9) (including the estimated GARCH parameters), we simulate T observations of y_t under the null of linearity. A linear unit root model and a SETAR model are estimated using these simulated data, and the likelihood ratio test statistic, LR_n^S, is computed.[22] This procedure is repeated N times and the bootstrap p-value for the null of a unit root process against the alternative of a SETAR model such as (7) – (8) is given by

$$p_{LR} = \sum_{n=1}^{N} I(LR > LR_n^S)/N, \qquad (10)$$

where $I(\cdot)$ is the indicator function that takes the value of one if the argument is true and of zero otherwise. That is, the p-value corresponds to the proportion of simulated likelihood ratio test statistics that exceed the value of the test statistic computed with the actual data.[23] The bootstrap test was carried out using $N = 500$ replications.

4 Data Issues

4.1 Data Description

The dataset contains average daily deviations of nominal exchange rates from the prevailing central parity.[24] The currencies considered are of countries which participated in the system: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Portugal and Spain. Although the ECU was the official currency of the ERM, it is widely acknowledged that the ERM was centered around the Deutsche mark. Therefore, we use exchange rate series vis-à-vis the Deutsche mark using data obtained from the Deutsche Bundesbank.[25] In its convergence report of 1998, published in the run-up to the euro, the European Commission used the median currency[26] as the benchmark

[22] *Given that it is not ensured that the replicated data will actually cross the estimated thresholds, the SETAR models for the simulated data are estimated setting the thresholds at the quantiles of the replicated series corresponding to the estimated thresholds obtained with the actual data.*

[23] *Note that the bootstrap test used is a simple example of the nonpivotal bootstrap testing procedures described in Pesaran and Weeks (2001) for nonnested model testing.*

[24] *Note that the central parity of the Spanish and the Portuguese currencies were devalued vis-à-vis the Deutsche mark on March 6, 1995, by 7% and 3.5%, respectively. That is, the deviations from the central parity are obtained using the central parity prevailing prior to March 6, 1995, and the devalued central parity from March 6, 1995, onwards. The Irish pound was revalued by 6% on March 16, 1998. This realignment is, however, beyond the period investigated in this paper.*

[25] *See annex for Datastream codes.*

[26] *"(...) median currency is (the currency) which has an equal number of currencies above and below it within the grid at the official ecu fixing on any given day" (European Commission, 1998, p. 123). In more practical terms, for each participating country, the deviation of the bilateral exchange rate against the ECU from its official ECU central parity is determined. Subsequently, the countries are ranked and the 6th out of the 11 participating currencies is chosen in the ranking. It should be noted that the median currency is chosen on a daily basis, implying that the currency chosen as the median currency could have changed day by day.*

currency for the assessment of the criterion on exchange rate stability. To our knowledge, the median currency has not been used in any previous study aimed at testing target zone models. Thus, we also look at the deviations from the median currency.[27] For the Deutsche mark, the time period is the post-1993 crisis period: it begins on September 1, 1993, and ends on February 28, 1998. Although Austria officially entered the ERM after its entry to the EU in 1995, the period from 1993 is investigated for this country because it maintained a tight peg to the Deutsche mark during this period.[28] Using the extended data for Austria allows us to investigate whether or not ERM entry provoked a change in exchange rate behavior. The series are shorter for Finland and Italy, which joined or reentered ERM, respectively, on October 15 and November 25, 1996. For the median currency,[29] the series runs from March 1, 1996, to February 28, 1998.

For ERM II, only Denmark is considered, and deviations from the central parity against the euro are taken for the period January 4, 1999, to April 28, 2004.[30] The source of the data is the ECB.[31]

Finally, we also analyze the exchange rate behavior of four CEECs. The exchange rate against the euro is studied for the Czech Republic, Hungary, Poland and Slovakia. For the Czech Republic and Slovakia, the period starts on January 1, 1999, when the euro was introduced. For these two currencies, the deviation against the period average is used because they adhere to managed floating. The period begins on March 1, 2000, (close to the outset of free floating on April 12, 2000) for Poland and on May 4, 2001, (the widening of the bands to ±15%) for Hungary. On June 4, 2003, the central parity was devalued by some 2.26%. Similarly to the case of Portugal and Spain, the deviations from the pre- and the post-devaluation parities are determined. For all four countries, the sample runs to April 28, 2004. Data are drawn from the ECB for the Czech Republic and Poland, from Magyar Nemzeti Bank for Hungary and from Datastream for Slovakia.

4.2 A Preliminary Analysis of the Data

The distribution of the exchange rate within the target zone is estimated using the Epanechnikov kernel density function for 1993 to 1998 (and 1996 to 1998 for Finland and Ireland) vis-à-vis the Deutsche mark, for 1996 to 1998 for the median currency and for 1999 to 2004 for the euro. The figures reported in the annex reveal two important features of the data.

First, a considerable part of the distributions exhibit a double-hump shape. This is especially the case for the Austrian schilling, the Danish krone, the Dutch guilder, the French franc, the Irish pound and the Portuguese escudo vis-à-vis the Deutsche mark. With the exception of the Spanish peseta and the Dutch

[27] *In addition to the ECU, the Deutsche mark and the median currency, three other benchmarks could, in theory, be used: (1) the strongest currency of the system, (2) bilateral exchange rates with no benchmark currency, and (3) the synthetic euro.*

[28] *As a matter of fact, Austria had a pegged exchange rate regime vis-à-vis the Deutsche mark from the late 1970s. Austria entered the ERM at the fixed peg exchange rate regime it unilaterally maintained before.*

[29] *We are grateful to André Verbanck from the European Commission (DG ECFIN) for providing us with these data series.*

[30] *Greece is excluded because of its ephemeral stay in the ERM and ERM II.*

[31] *See annex for Datastream code.*

guilder, all currencies have a hump-shaped distribution vis-à-vis the median currency.

Brandner and Grech (2002)[32] report kernel density estimations for Deutsche mark purchases and sales for six countries, namely Belgium, Denmark, Spain, France, Ireland and Portugal. Although the period investigated includes some of the turmoil in August 1993,[33] the authors' graphs match remarkably well with our kernel estimates reported in the annex for the period from 1993 to 1998. For Belgium, they show increased Deutsche mark sales at the central parity, whereas Deutsche mark purchases occurred at a deviation of about 0.2% to 0.3% from the stronger side of the fluctuation band. For Denmark, the monetary authorities proceeded with increased Deutsche mark purchases at 2% from the central parity at the weaker side and sold Deutsche mark at the central parity. For France, Deutsche mark purchases and sales are reported to have taken place respectively at about 5% and 1% away from the parity on the weaker side. The Irish monetary authorities reportedly sold Deutsche mark at 5% from the parity on the weaker side and bought Deutsche mark at 10% from the parity on the stronger side. For Portugal, the interventions at about 4% from the central parity on the weaker side and at 2% from the parity on the stronger side are also broadly in line with exchange rate developments. Spain made Deutsche mark sales mostly at 10% from the central parity on the weaker side. A reason for this finding is that Brandner and Grech (2002) start the period in August 1993 during the crisis.

For the series against the euro, a marked twin peak distribution is to be observed for the Czech koruna and a somewhat less pronounced twin peak distribution for the Danish and Slovak currencies. This provides us with some preliminary evidence on the presence of nonlinearity of the type described by the SETAR model.

The second characteristic of the data is the asymmetric distribution. For the ERM, a large part of the distribution of the Austrian, Danish, French and Portuguese currencies is located on the weaker side of the band. By contrast, the exchange rate was most often on the stronger side of the band for Denmark, Finland and the Netherlands. This holds true, in particular, for the end of the period under study. Regarding the euro series, both countries with formal target zone arrangements, namely Denmark and Hungary, had their currencies predominantly on the stronger side of the band.

5 Empirical results

The SETAR-GARCH (1,1) model described earlier was applied first to the exchange rate series vis-à-vis the Deutsche mark for countries participating in the ERM. We first took the whole post-1993 period (after the ERM crisis) up to the announcement of the final conversion rates in early 1998. Then, the estimations were repeated by decreasing the period by one year in each step until the beginning of the reference period taken for the convergence report of the European Commission and the European Monetary Institute is reached.[34]

[32] *Brandner and Grech (2002), p. 23.*

[33] *Their sample covers August 2, 1993, to April 30, 1998, while our period spans September 1, 1993, to February 28, 1998.*

[34] *The following three periods were considered: September 1, 1994, to February 28, 1998; September 1, 1995, to February 28, 1998; March 1, 1996, to February 28, 1998.*

Subsequently, the period was shortened by one-year steps keeping the starting date fixed.[35] Finally, the two subperiods divided by the devaluation of the central parity are analyzed for Portugal and Spain.[36]

From the results reported in tables 2a and 2b, a number of interesting points emerge:

First, the analysis of the estimated upper and lower bounds of the band of inaction shows that there are two groups of countries. The first group consists of countries which have very narrow bands for the entire period. For instance, for the whole period, the absolute bandwidth is 0.05% for Austria, 0.35% for Belgium and 0.15% for the Netherlands.[37] The scale of these ranges remains largely unchanged for the subperiods. This is not surprising given the fact that these countries shadowed very narrowly the monetary policy of the Deutsche Bundesbank and sought to stabilize their currencies relative to the Deutsche mark accordingly. The results for Austria deserve special attention. Notwithstanding the fact that Austria formally joined the ERM only in 1995, the estimated upper and lower bounds are very stable over time, lending support to the fact that exchange rate behavior was not affected by Austria's ERM entry.

The second group comprising the rest of the countries has considerably larger bands. The absolute width of the estimated band was 3.66% for Portugal, 1.28% for France, 3.46% for Denmark, about 4% for Spain and roughly 10% for Ireland for the period from 1993 to 1998. With the exception of Ireland, the estimated bandwidth decreases toward the end of the period to below 1% for Denmark, France and Spain, and close to 2% for Portugal. For Ireland, the estimated bandwidth rises from about 4% from 1993 to 1995 to nearly 8% from 1993 to 1997 and then drops to 2% at the end of the period (1996 to 1998). Note that Italy and Finland, which entered the ERM only in 1996, had bandwidths comparable to those in Belgium and the Netherlands.[38]

Second, the position of the estimated band of inaction relative to the officially announced central parity is analyzed. Regarding the narrow-band countries, the estimated effective fluctuation band is mostly located symmetrically on either side of the central parity for Austria and mainly on the stronger side for Belgium. In the Netherlands, the whole band is always located on the stronger side. Note that the Italian and Finnish currencies are also found to be situated on the stronger side. For the second group of countries, we note that the boundaries of the estimated exchange rate bands are mostly located on the weaker side of the official target zone for Denmark and France. For both countries, the narrowing down of the band manifested itself with the estimated weaker threshold moving closer to the central parity. Although the Portuguese escudo was located on the weaker side at the beginning of the period, the

[35] *The following three periods were considered: September 1, 1993, to September 1, 1997; September 1, 1993, to September 1, 1996; September 1, 1993, to September 1, 1995.*

[36] *September 1, 1993, to March 5, 1995, and March 6, 1995, to February 28, 1998.*

[37] *Note that the estimation method ensures that at least 20% of the observations fall in the band of inaction.*

[38] *Our results can be directly compared with those reported in Bessec (2003), who uses monthly data for the Belgian, Danish, French, Irish and Dutch currencies against the Deutsche mark. Bessec (2003) estimated a time-varying threshold model for the period from 1979 to 1998, with the threshold changing in 1993 when the fluctuation band widened. The comparison of the threshold obtained for the post-1993 period shows that our method for searching the thresholds, coupled with the use of daily data, gives more precise threshold values. Although the thresholds are very similar for Belgium, our thresholds differ greatly from the ones reported in Bessec (2003), table 5, for the other countries.*

estimated band had shifted entirely to the stronger side by the last period. For Ireland, Portugal and Spain, the estimated band was on the weaker side of the official parity and had moved to the stronger side of the official fluctuation band by the end of the period.[39]

Third, the estimated autoregressive terms ($\lambda_{upper}, \lambda_{lower}$), indicating mean reversion to the upper and lower edges ($\phi_{upper}, \phi_{lower}$), have the expected negative sign in the majority of cases, but they are not statistically significant in a number of cases. Generally, they are more significant for the entire period and then become less so toward the end of the period. However, a more detailed look at the results indicates considerable heterogeneity across countries. For Austria, the mean reversion to the band detected for the whole period seems to be unstable because the estimated coefficients are systematically insignificant for the subperiods. Similarly, no significant band mean reversion could be found for Italy.

For the Netherlands and Spain, both coefficients are negative and significant for most of the subperiods. With regard to Spain, two different regimes are hidden behind the band mean reversion behavior detected for the whole period if the time of the devaluation of the central parity is considered as the dividing line for the two subperiods. The estimated band is situated from 4.04% to 8.34% away from the official central parity on the weaker side before the devaluation and is located from 0.99% on the stronger side of the official parity to 1.74% on the weaker side of the official parity.

For some countries, the mean reversion to the band seems to be one-sided. For instance, there is mean reversion only toward the estimated upper (stronger) bound in Belgium, Denmark and Finland, and only toward the lower edge of the estimated band for France and Portugal. This could be an indication of the presence of different pressures for different countries. In Belgium and Finland, the estimated upper and lower bounds are mostly on the stronger side. Thus, the market situation may have been one to avoid excessive appreciation. By contrast, in France, the estimated lower boundary to which the mean reversion occurs happens to be on the weaker side. The analysis of the subperiods shows, however, that there is two-sided mean reversion from 1993 to 1997, and one-sidedness is the feature of the period from 1996 to 1998. Hence, counteracting depreciation pressures and bringing the lower bound closer to the central parity may have been typical for these countries. The fact that the coefficients become insignificant for the period from 1996 to 1998 could suggest that by that time, nonlinearity had diminished and the exchange rate had started behaving like a linear process in the face of increased credibility during the run-up to the euro. The decrease in nonlinearity is also confirmed by the p-values, which show that in some cases the three-regime SETAR model is no better than the linear unit root specification.

Fourth, the ARCH and GARCH terms (α and β) of the conditional variance equation are correctly signed ($\beta > 0$ and $\alpha > 0$) and statistically significant at the 1% level for almost all cases. At the same time, the sum of these two parameters is very close to or larger than unity, implying that the error terms are integrated

[39] *Our results are at odds with the findings of Bessec (2003), table 5, since she finds that both the upper and lower mean reversion coefficients are always significant for all countries and because her estimated coefficients are much larger in absolute terms than ours.*

GARCH processes for most of the series. Interestingly, the α coefficient is found to be insignificant for the Austrian schilling against the Deutsche mark for 1996 to 1998 and for the Spanish peseta vis-à-vis the median currency. The fact that β is very close to unity, especially for Spain, may lend support to the hypothesis of constant conditional variance (for insignificant estimates of γ) or linearly changing variance (if γ is significant) in a deterministic fashion.

The results obtained on the basis of the median currency for the period from 1996 to 1998 are reported in table 3. They appear similar to those noted for the Deutsche mark. The estimated upper and lower bounds, the width and the location of the band for the median currency are comparable to those obtained using the Deutsche mark. However, it is possible to detect more nonlinearity than when using the Deutsche mark. This is especially the case for Austria and Belgium. Also, the median currency approach allows us to look at Germany, for which the SETAR model performs remarkably well.

Table 2a

Model Estimates Using the Deutsche Mark

	period	k	ϕ_{upper}	ϕ_{lower}	λ_{upper}	λ_{lower}	α	β	p-values
ATS_DEM	1993–1998	1	0.02%	−0.03%	−0.0703***	−0.0785**	0.0383***	0.9527***	0.002
ATS_DEM	1994–1998	2	0.02%	−0.03%	−0.1307***	−0.0826**	0.0399***	0.9383***	0.000
ATS_DEM	1995–1998	1	0.02%	−0.03%	−0.1235**	−0.1075	0.0505***	0.9131***	0.000
ATS_DEM	1996–1998	1	0.00%	−0.03%	0.0308	−0.1056	0.0341	0.8711***	0.000
ATS_DEM	1993–1995	1	0.04%	0.02%	−0.0036	−0.0118	0.0465*	0.9073***	0.002
ATS_DEM	1993–1996	1	0.04%	0.00%	−0.0276	−0.0544**	0.0582***	0.9074***	0.000
ATS_DEM	1993–1997	1	−0.02%	−0.04%	−0.0101	0.0021	0.0408***	0.9474***	0.000
BEF_DEM	1993–1998	7	0.30%	−0.05%	−0.126***	−0.011	0.0931***	0.903***	0.038
BEF_DEM	1994–1998	1	0.26%	−0.06%	−0.0924***	−0.0016	0.0771***	0.9161***	0.002
BEF_DEM	1995–1998	1	0.29%	−0.07%	−0.0847**	0.0808	0.0172***	0.9711***	0.066
BEF_DEM	1996–1998	1	0.17%	−0.07%	0.0167	0.039	0.0144*	0.9728***	0.078
BEF_DEM	1993–1995	7	0.13%	−1.12%	−0.0667*	0.0423	0.446***	0.5866***	0.004
BEF_DEM	1993–1996	8	0.27%	0.04%	−0.0834**	−0.0001	0.1259***	0.8795***	0.014
BEF_DEM	1993–1997	7	0.27%	−0.04%	−0.1021***	−0.0152	0.1082***	0.8949***	0.058
DKK_DEM	1993–1998	1	0.09%	−3.55%	−0.0856*	0.0193**	0.1323***	0.8794***	0.002
DKK_DEM	1994–1998	1	0.01%	−2.46%	−0.0905**	−0.0736***	0.135***	0.8767***	0.000
DKK_DEM	1995–1998	1	−0.06%	−-1.21%	−0.0703**	−0.0347	0.0649***	0.924***	0.000
DKK_DEM	1996–1998	1	−0.33%	−-1.19%	−0.0723***	−0.0677	0.053***	0.9448***	0.000
DKK_DEM	1993–1995	1	−2.61%	−3.27%	0.0149	0.0011	0.1669***	0.846***	0.018
DKK_DEM	1993–1996	1	−2.06%	−3.55%	−0.0309**	0.0207**	0.1579***	0.8605***	0.004
DKK_DEM	1993–1997	1	−0.03%	−3.27%	−0.1429**	−0.0024	0.136***	0.8767***	0.004
NGL_DEM	1993–1998	3	0.52%	0.37%	−0.0745***	−0.0029	0.073***	0.9307***	0.002
NGL_DEM	1994–1998	1	0.54%	0.31%	−0.0824***	−0.0191**	0.0986***	0.9066***	0.000
NGL_DEM	1995–1998	1	0.57%	0.01%	−0.0675**	−0.1395**	0.1178***	0.8917***	0.008
NGL_DEM	1996–1998	1	0.45%	0.24%	0.0432**	−0.0289***	0.1274***	0.8828***	0.002
NGL_DEM	1993–1995	3	0.60%	0.37%	−0.0988*	−0.1278**	−0.0056	0.9981***	0.006
NGL_DEM	1993–1996	1	0.65%	0.60%	0.0233	−0.0119	0.0577***	0.9302***	0.000
NGL_DEM	1993–1997	1	0.52%	0.25%	−0.0693***	−0.0341	0.0647***	0.9159***	0.002
FRF_DEM	1993–1998	1	−0.69%	−2.01%	0.0016	−0.0219***	0.1014***	0.9066***	0.032
FRF_DEM	1994–1998	1	−0.74%	−-1.88%	−0.0002	−0.0122	0.1048***	0.9058***	0.006
FRF_DEM	1995–1998	1	−0.76%	−2.71%	−0.0009	−0.0599	0.0759***	0.9244***	0.028
FRF_DEM	1996–1998	1	−0.73%	−-1.61%	0.0008	−0.1815**	0.07***	0.9304***	0.004
FRF_DEM	1993–1995	1	−2.22%	−4.33%	−0.003	−0.0831	0.1032***	0.9024***	0.010
FRF_DEM	1993–1996	1	−2.20%	−4.74%	0.0017	−0.1561**	0.0974***	0.9011***	0.010
FRF_DEM	1993–1997	1	−0.90%	−3.86%	−0.0796***	−0.0777***	0.1012***	0.8989***	0.014

*Notes: k is the lag length used in the AR process and represents the upper (stronger) and lower (weaker) limits of the band of inaction, toward which the exchange rate exhibits mean reversion. Positive (negative) figures refer to a position on the stronger (weaker) side of the officially announced band and stand for the autoregressive coefficients, which capture mean reversion and are the ARCH and GARCH coefficients from the conditional variance equation. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively. The p-value stands for the null of an AR against the alternative of a SETAR.*

Table 2b

Model Estimates Using the Deutsche Mark

	period	k	ϕ_{upper}	ϕ_{lower}	λ_{upper}	λ_{lower}	α	β	p-value
IEP_DEM	1993–1998	1	4.75%	−5.35%	−0.0655***	−0.0346	0.1018***	0.8012***	0.000
IEP_DEM	1994–1998	1	5.99%	−4.49%	−0.0756***	−0.0612*	0.132***	0.7986***	0.004
IEP_DEM	1995–1998	1	9.03%	6.60%	0.1883***	0.0059	0.1923***	0.7628***	0.000
IEP_DEM	1996–1998	4	8.90%	6.55%	0.0595	0.0052	0.2956***	0.6569***	1.000
IEP_DEM	1993–1995	1	−0.39%	−4.47%	−0.0055	−0.0828*	0.0545***	0.9239***	0.006
IEP_DEM	1993–1996	1	−0.37%	−3.04%	−0.0114	−0.0336*	0.0541***	0.9321***	0.004
IEP_DEM	1993–1997	1	3.89%	−4.06%	−0.059***	−0.0488*	0.0288***	0.9566***	0.006
ESP_DEM	1993–1998	1	−0.99%	−3.72%	−0.0473***	−0.0805***	0.0942***	0.9186***	0.000
ESP_DEM	1994–1998	1	0.83%	−5.70%	−0.0628***	−0.102***	0.1257***	0.8968***	0.004
ESP_DEM	1995–1998	1	1.04%	0.21%	−0.0223	−0.0103	−0.0017***	0.9986***	0.038
ESP_DEM	1996–1998	1	1.16%	0.84%	−0.024	−0.0125	0.1015***	0.9016***	0.000
ESP_DEM	1993–1995	1	−1.75%	−7.99%	−0.0664	−0.5411***	0.1319***	0.8391***	0.010
ESP_DEM	1993–1996	1	−1.60%	−6.44%	−0.0237*	−0.1449***	0.2226***	0.7174***	0.018
ESP_DEM	1993–1997	1	0.70%	−4.03%	−0.0665***	−0.078***	0.1081***	0.8963***	0.000
ESP_DEM	Pre-devaluation	1	−4.04%	−8.34%	−0.0988***	−0.4876***	0.2962***	0.7747***	0.004
ESP_DEM	Post-devaluation	1	0.99%	−1.74%	−0.0461**	−0.0815***	0.0138***	0.9813***	0.000
PTE_DEM	1993–1998	1	−0.08%	−3.74%	−0.0031	−0.2597***	0.104***	0.9069***	0.002
PTE_DEM	1994–1998	1	−0.32%	−3.32%	−0.0023	−0.1757***	0.1092***	0.9024***	0.008
PTE_DEM	1995–1998	1	1.76%	1.14%	−0.0553	−0.0112*	0.0734***	0.927***	0.018
PTE_DEM	1996–1998	1	1.89%	−0.26%	−0.0694*	0.0016	0.0821***	0.9204***	0.016
PTE_DEM	1993–1995	1	−3.69%	−4.52%	−0.0088	−0.7588***	0.1594***	0.8379***	0.000
PTE_DEM	1993–1996	1	−0.79%	−3.88%	−0.1195	−0.3029***	0.1065***	0.8947***	0.000
PTE_DEM	1993–1997	1	0.09%	−3.88%	−0.0328**	−0.3086***	0.1037***	0.8937***	0.000
PTE_DEM	Pre-devaluation	1	−3.28%	−4.62%	−0.0145	−0.0916	0.209***	0.8215***	0.000
PTE_DEM	Post-devaluation	1	−0.31%	−1.86%	−0.0019	−0.0977***	0.0649***	0.9354***	0.010
ITL_DEM	1996–1998	1	1.37%	0.99%	−0.0615	−0.0306	0.1771***	0.8302***	0.040
FIM_DEM	1996–1998	1	1.97%	1.60%	−0.2884***	−0.005	0.2269***	0.7971***	0.008

Notes: See table 2a.

Table 3

Model Estimates Using the Median Currency, March 1, 1996, to February 28, 1998

	k	ϕ_{upper}	ϕ_{lower}	λ_{upper}	λ_{lower}	α	β	p-value
ATS_MED	2	−0.02%	−0.28%	−0.5608***	−0.0903	0.4342***	0.701***	0.002
BEF_MED	2	0.00%	−0.29%	−0.0712***	−1.2519***	0.3596***	0.4464***	0.004
NLG_MED	2	0.39%	0.00%	−0.55%	0.0005	0.4888***	0.4986***	0.004
DKK_MED	8	−0.29%	−1.23%	0.81%	−0.2593	0.208***	0.8211***	0.000
DEM_MED	3	−0.04%	−0.26%	−0.7665***	−0.3688***	1.0702***	0.3854***	0.000
FRF_MED	1	−0.74%	−1.02%	−0.0186**	−0.0137	0.2769***	0.769***	0.002
ESP_MED	1	1.09%	0.59%	−4.24%	−0.0195	−0.0043	1.0006***	0.000
PTE_MED	1	1.73%	0.58%	−6.33%	−0.0694***	0.1447***	0.8717***	0.002
IEP_MED	1	9.18%	6.80%	0.2163***	0.0001	0.197***	0.7524***	0.000
ITL_MED	1	0.94%	0.35%	−10.91%	−0.0812	0.1682***	0.8416***	0.010
FIM_MED	1	1.28%	0.86%	−0.0866***	−0.0659	0.2005***	0.8262***	0.004

Notes: See table 2a. The period begins on October 4, 1996, for Finland and on November 15, 1996, for Italy.

Finally, we turn to the estimation results for the currencies expressed against the euro for the period 1999 to 2004. During the period when the Danish krone was in ERM II, the estimated bandwidth decreased further from the 0.8% figure, reported above in the original ERM period, to 0.4%. However, the mean reversion coefficient bears the correct sign and is significant only for the lower bound.

For the CEE countries we find the following development against the euro. Hungary is an interesting case because on May 4, 2001, it widened the fluctuation bands around the central parity.[40] From May 2001 to April 2004, the esti-

[40] *Note that the crawling peg system was abandoned only on October 1, 2001. However, at the time of the widening of the fluctuation band from ±2.25% to ±15%, the rate of crawl was already very low, 0.00654% a day, amounting to a total devaluation of the central parity of around 1.12% until October 1, 2001. Therefore, we believe that this did not have an impact on the behavior of the exchange rate within the band.*

mated upper and lower thresholds were located, respectively, 11% and 6.76% away from the central parity (both on the stronger side of the official fluctuation band of ±15%). The mean reversion coefficients have a negative sign and are significant. This would seem to give strong support to the fact that exchange rate policymakers targeted a narrow band which was judged compatible with the inflation target. However, this is only part of the story. On June 4, 2003, the central parity was devalued by some 2.26%, which triggered considerable depreciation of the currency inside the band. Looking at the period from May 4, 2001, to June 3, 2003, reveals that until the devaluation of the central parity, mean reversion was significant only on the upper (stronger) threshold. So, mean reversion to the lower threshold detected for the whole period may refer to the post-devaluation period.

According to the statement of the Monetary Council of Magyar Nemzeti Bank of August 18, 2003, "the Monetary Council puts the equilibrium exchange rate, which fosters rapid economic growth without endangering price stability in the range of 250 to 260 forints per euro.[41]" Relative to the then prevailing central parity of 282.36 forint per euro, this means a band of 7.92% to 11.46% on the stronger side of the official fluctuation margins. Thus, the estimated band for the whole period from 2001 to 2004 (upper bound at 11%, lower bound at 6.76%) is broadly in line with the implicit target of the Hungarian monetary authorities.

Table 4

Model Estimates Using the Euro

	period	ϕ_{upper}	ϕ_{lower}	λ_{upper}	λ_{lower}	α	β	p-value
DKK_EUR	1999–2004	0.38%	−0.01%	0.0051	−0.2474***	0.1368***	0.8464***	0.004
CZK_EUR	1999–2004	1.70%	−5.73%	−0.0109**	−0.0134	0.0808***	0.8599***	0.038
SKK_EUR	1999–2004	2.30%	−4.16%	−0.0025	−0.0779**	0.1678***	0.7223***	0.018
ZTY_EUR	2000–2004	10.26%	−7.14%	−0.0445**	−0.0045	0.1259***	0.8204***	0.006
HUF_EUR	2001–2004	11.00%	6.76%	−0.1165***	−0.3748**	0.4443***	0.5412***	0.000
HUF_EUR	2001–2003	12.35%	11.00%	−0.2249***	0.0125	0.5858***	0.5473***	0.000

Notes: See table 2a.

As shown earlier, a special case of the Delgado-Dumas solution is tantamount to managed floating without officially announced target zones, which could also induce some nonlinear behavior in the exchange rate. In particular, if the monetary authorities are targeting an implicit target zone, the SETAR model should be particularly useful to detect such a zone because in such a case, interventions would be undertaken only if a depreciation or appreciation of the nominal exchange rate exceeded a given pain threshold of the monetary authorities. This may be the case of the Czech Republic and Slovakia, which have de jure and de facto managed floating. Notwithstanding the official free-floating regime of the Polish zloty vis-à-vis the euro, we may still expect some mean reversion behavior toward a band of inaction. Results reported in table 4 confirm our suspicion about the presence of nonlinear behavior. However, the mean reversion appears to be one-sided. There are signs of significant mean reversion only on the strong side for the Czech Republic and Poland, and only on the weak side for Slovakia. The mean reversion of the Czech koruna and the Polish zloty

[41] *Retrieved in August 2004 from http://english.mnb.hu/engine.aspx?page=mnben_monet_kozlem.*

may actually reflect the recent switch from huge nominal appreciation to a large depreciation of the two currencies. The width of the estimated band is close to 7% for the Czech Republic and Slovakia, which is in sharp contrast with the detected wide band of more than 17% for Poland, lending more empirical support to more active exchange rate policies in the two preceding countries.

Like for the period preceding the introduction of the euro, there appears to be strong integrated GARCH effects in the conditional variance for all cases.

7 Conclusions

In this paper, we have applied a three-regime SETAR model with GARCH errors to daily exchange rate data for countries participating in the post-1993 ERM and ERM II and for selected CEE economies. The underlying idea of the theoretical model is that the monetary authorities do not intervene in the proximity of the central parity where the exchange rate behaves like a random walk. However, the exit of the exchange rate from this band of inaction on either side triggers policy action by the monetary authorities, which forces the exchange rate to return to the band. However, it should be noted that mean reversion to the band could be the outcome of a range of factors, such as direct and indirect central bank interventions, moral persuasion, communication with the markets and stabilization of market expectations in the face of increased credibility of the monetary authorities or because of an increased stability of the underlying fundamentals. However, large and coordinated interventions may be able to impact on the market exchange rate.

We have argued that such a modeling framework is better suited to capturing exchange rate dynamics in a target zone, particularly the ERM variant of a target zone, than the frameworks used in previous research because it captures mean reversion to a band of inaction within the official target zone and gives a more realistic description of the behavior of ERM currencies. A further novelty of our work is that in addition to using Deutsche mark-based bilaterals, we also use median currency-based bilaterals for the original ERM period. Given the way in which the ERM was supposed to work, the latter are the more appropriate bilaterals in any target zone modeling of this system.

For the ERM experience we are able to place the countries in two groups depending on the size of the bandwidth. For Austria, Belgium and the Netherlands, we find very narrow and very stable thresholds delimiting the band of inaction. This holds true for Italy and Finland for the period when they reentered or joined the ERM in 1996. Also, for these countries, the estimated bands are usually located on the stronger side of the official band. For the second group of countries – Denmark, France, Ireland, Portugal and Spain – the estimated bandwidth is substantially higher for the whole period but decreases toward the end of the period. Simultaneously, we observe a shift of the bands either toward the central parity or into the stronger part of the official fluctuation bands. Although we find evidence in favor of reversion toward the band, this reversion partly disappears by the end of the period. In the paper, we divide the whole period into subperiods to account for time-varying threshold values. A future avenue for research would be to estimate time-varying break points.

For Hungary, we detect a narrow band of 7% to 11% on the stronger side of the official band. We also show that reversion to the band occurred to the upper threshold before June 4, 2003, when the central parity was devalued, and mean reversion happened to the lower and the upper threshold for the whole period. For the other CEE countries which have not been pursuing a policy of explicit exchange rate bands we find evidence of nonlinear exchange rate behavior, and the observed mean reversion is one-sided.

References

Andrews, D. W. K. and W. Ploberger. 1994. Optimal Tests When a Nuisance Parameter Is Present Only Under the Alternative. Econometrica 62. 1383–1414.

Anthony, M. and R. MacDonald. 1998. On the Mean-Reverting Properties of Target Zone Exchange Rates: Some Evidence from the ERM. European Economic Review 42. 1493–1523.

Anthony, M. and R. MacDonald. 1999. The Width of the Band and Exchange Rate Mean-Reversion: Some Further ERM-based Results. Journal of International Money and Finance 18. 411–428.

Bartolini, L. and A. Prati. 1999. Soft Exchange Rate Bands and Speculative Attacks: Theory and Evidence from the ERM since August 1993. Journal of International Economics 49. 1–29.

Beetsma, R. M. and F. van der Ploeg. 1994. Intramarginal Interventions, Bands and the Pattern of EMS Exchange Rate Distributions. International Economic Review 35(3). 583–602.

Bekaert, G. and S. F. Gray. 1998. Target Zones and Exchange Rates: An Empirical Investigation. Journal of International Economics 45. 1–35.

Bertola, G. and R. J. Caballero. 1992. Target Zones and Realignments. American Economic Review 82(3). 520–536.

Bessec, M. 2003. The Asymmetric Exchange Rate Dynamics in the EMS: a Time-Varying Threshold Test. European Review of Economics and Finance 2(2). 3–40.

Brandner, P. and H. Grech. 2002. Why Did Central Banks Intervene in the EMS? The Post 1993 Experience. Oesterreichische Nationalbank Working Paper 77.

Caner, M. and B. E. Hansen. 2001. Threshold Autoregression with a Unit Root. Econometrica 69. 1555–1596.

Chung, C.-S. and G. Tauchen. 2001. Testing Target-Zone Models Using Efficient Methods of Moments. Journal of Business&Economic Statistics 19(3). 255–271.

Delgado, F. and B. Dumas. 1992. Target Zones Broad and Narrow. In: P. R. Krugman and M. Miller (eds.). Exchange Rate Targets and Currency Bands. Cambridge: Cambridge University Press.

European Commission. 1998. Convergence Report 1998. European Economy 65.

Flood, R. P., A. K. Rose and D. J. Mathieson. 1990. An Empirical Exploration of Exchange Rate Target Zones. NBER Working Paper 3543.

Hansen, B. E. 1996. Inference when a Nuisance Parameter Is Not Identified Under the Null Hypothesis. Econometrica 64. 413–430.

Hansen, B. E. 2000. Sample Splitting and Threshold Estimations. Econometrica 68. 575–603.

Kempa, B. and M. Nelles. 1999. The Theory of Exchange Rate Target Zones. Journal of Economic Surveys 13(2). 173–210.

Krugman, P. R. 1991. Target Zones and Exchange Rate Dynamics. The Quarterly Journal of Economics 106(3). 669–682.

Lundbergh, S. and T. Teräsvirta. 2003. A Time Series Model for an Exchange Rate in a Target Zone with Applications. SEE/EFI Working Paper Series in Economics and Finance 533.

MacDonald, R. 1995. Long-Run Exchange Rate Modeling: A Survey of the Recent Literature. International Monetary Fund Staff Papers 42(3). 437–489.

MacDonald, R. 2004. Exchange Rate Economics: Theories and Evidence. Second Edition. Taylor Francis.

Mastropasqua, C., S. Micossi and R. Rinaldi. 1988. Interventions, Sterilization and Monetary Policy in the European Monetary System Countries, 1979–1987. In: Giavazzi, F., S. Micossi and M. Miller (eds.). The European Monetary System. Cambridge: Cambridge University Press.

Miller, M. and P. Weller. 1991. Exchange Rate Bands with Price Inertia. The Economic Journal 101(409). 1380–1399.

Pesaran, M. H. and M. Weeks. 2001. Non-Nested Hypothesis Testing: An Overview. In: B. H. Baltagi (ed.). Companion to Theoretical Econometrics. Oxford: Basil Blackwell.

Rogoff, K. 1996. The Purchasing Power Parity Puzzle. Journal of Economic Literature 34(2). 647–668.

Rose, A. K. and L. E. O. Svensson. 1995. Expected and Predicted Realignments: The FF/DEM Exchange Rate During the EMS, 1979–1993. Scandinavian Journal of Economics 97. 173–200.

Serrat, A. 2000. Exchange Rate Dynamics in a Multilateral Target Zone. Review of Economic Studies 67(1). 193–211.

Svensson, L. E. O. 1992. An Interpretation of Recent Research on Exchange Rate Target Zones. Journal of Economic Perspectives 6(4). 119–144.

Tristani, O. 1994. Variable Probability of Realignment in a Target Zone. Scandinavian Journal of Economics 96(1). 1–14.

Werner, A. M. 1995. Exchange Rate Target Zones, Realignments and the Interest Rate Differential: Theory and Evidence. Journal of International Economics 39(3–4). 353–367.

Annex

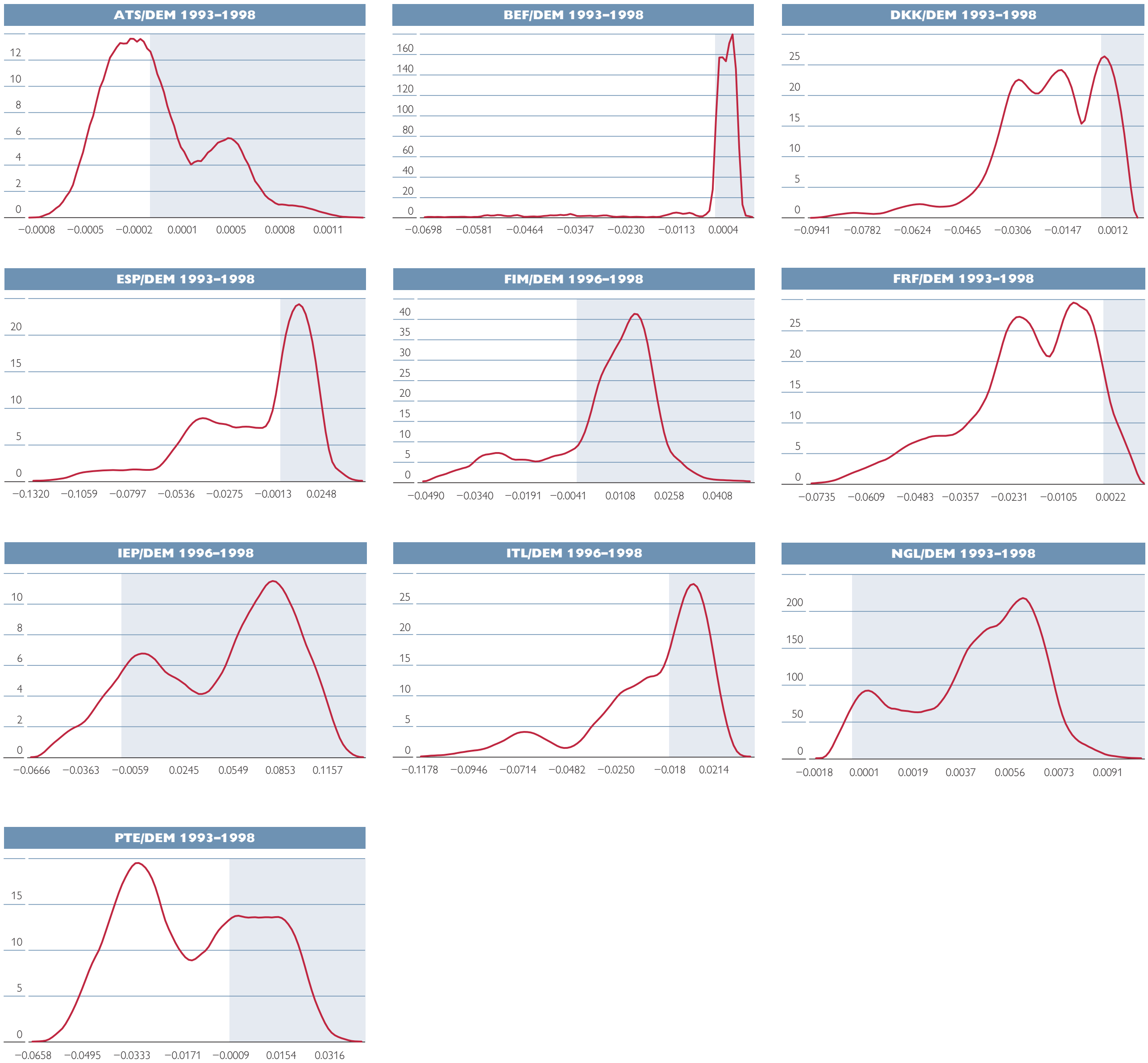
1 Datastream Codes

Datastream Codes

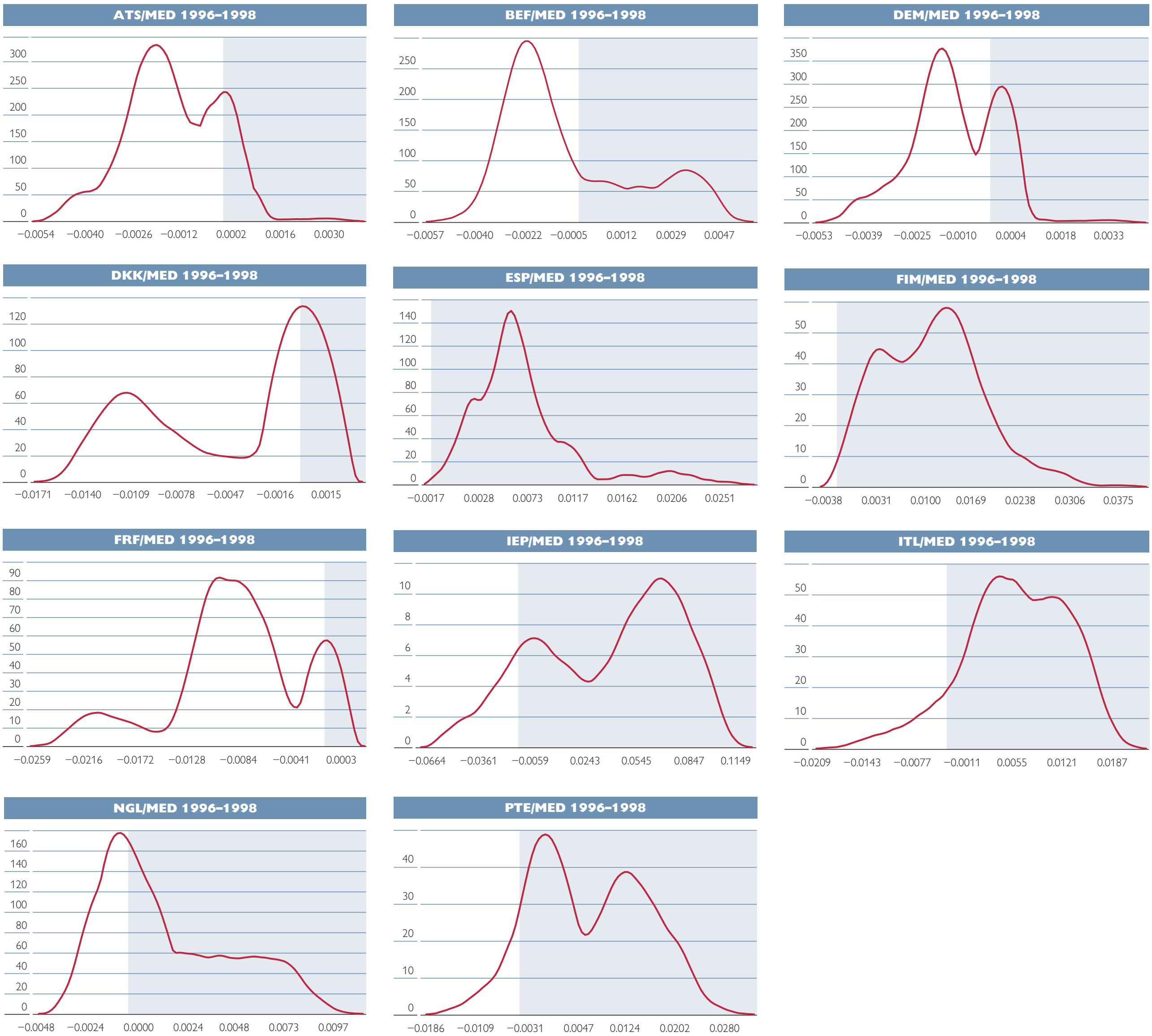
	Source	DEM		Source	EUR
Austria	Deutsche Bundesbank	DMATSSP	Denmark	European Central Bank	DKECBSP
Belgium	Deutsche Bundesbank	DMBECSP	Czech Republic	European Central Bank	CZECBSP
Denmark	Deutsche Bundesbank	DMDKKSP	Hungary	European Central Bank	HNECBSP
Finland	Deutsche Bundesbank	DMFIMSP	Poland	European Central Bank	POECBSP
France	Deutsche Bundesbank	DMFRFSP	Slovakia	Datastream	SXEURSP
Ireland	Deutsche Bundesbank	DMIEPSP			
Italy	Deutsche Bundesbank	DMITLSP			
Netherlands	Deutsche Bundesbank	DMNLGSP			
Portugal	Deutsche Bundesbank	DMPTESP			
Spain	Deutsche Bundesbank	DMESPSP			

II Distribution of Exchange Rate Deviations from the Central Parity

Distribution vis-à-vis the Deutsche Mark, 1993 to 1998



Distribution vis-à-vis the Median Currency, 1996 to 1998



Distribution vis-à-vis the Euro, 1999 to 2004