Empirical Assessment of Target-Zone using a STAR Model

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ABSTRACT

This study is intended to investigate mean reversion and nonlinearity for exchange rates in a target zone system using a Smooth Transition Auto Regressive (STAR) model. We estimate an implicit target zone using daily spot French franc/Deutsche mark exchange rates. Our contribution is to support the exchange-rate nonlinearity, a phenomenon called the honeymoon effect, and to confirm behavior of exchange rates differs when near or distant from the implicit central parity. The estimated implicit band is narrower than the officially announced band, not symmetric around the announced central parity.

1. Introduction

Since the advent of the generalized floating exchange rate system in spring, 1973, the choice of an optimal exchange rate system has remained a central issue in modern international finance. Traditionally, the relative advantages of the two polar cases, fixed and freely floating exchange rate regimes, have remained theoretical and empirical focal points. Both regimes present advantages and disadvantages; tradeoff relationships might exist between them. Therefore, eclectic regimes between two polar regimes seem to be attractive if the exchange rate exhibits flexibility with less variability than a freely floating system would allow. An example of such eclectic systems is proposed in an elegant theoretical framework of a target zone system by Krugman (1991), who derives two key predictions for exchange rate movements: to the extent that the exchange rate is determined by fundamental factors that are subject to a random walk process within a credible target zone, the exchange rate is mean-reverting. That movement is approximated by an S-shaped curve near the boundaries of the target zone. Consequently, the target zone exerts a stabilizing effect on the exchange rate according to the threat of intervention at the boundaries.

Nevertheless, few empirical tests have confirmed the main predictions for the target zone models. Svensson (1992) and Garber and Svensson (1995) attribute the rejection to the following two assumptions imposed by Krugman (1991). The first assumption is that perfect credibility to intervention pertains. The second is that, although central banks actually intervene in the interior of a zone, the central bank is assumed to intervene only at the zone margin. For that reason, empirical studies need to identify intervention time periods accurately. However, because of the lack of reliable data on actual intervention, precedent empirical studies have either failed to examine the stabilizing effect of a target zone or insufficiently tested it.

The purposes of this paper are twofold. First, we investigate mean reversion and nonlinearity for exchange rates in a target zone system using a Smooth Transition Auto Regressive (STAR) model, which is an extension of a non-linear unit root test.

The second purpose is that we estimate an implicit target zone using the daily spot French franc/Deutsche mark exchange rates, similarly using the STAR. This model is employed as regime-switching, to account for existence of an unobservable *implicit target zone* that differs from the announced target zone, but which is perceived by actual investors who are sensitive to intervention[1]. As many studies (Svensson, 1992; Giavazzi and Giovannini, 1989; Klein and Lewis, 1993) point out, intra-marginal intervention is a fact, but few studies have estimated the exchange rate level for the implicit band directly, except for Chung and Tauchen (2001).

We can infer whether or not Krugman's target zone model is empirically supportable under the estimated implicit band if we obtain results for our purposes. We confirm mean reversion for exchange rates under the implicit zone measured using its adjustment speed and transition function of the estimated STAR model to be more specific. The mean-reversion for exchange rates signifies stability that is absent under freely floating rates and a conventional managed float system. In short, if we confirm that exchange rates under a target zone regime follow a globally mean reverting process, the regime would be equally preferable or more preferable to the two polar regimes. Although the property of a target zone has been widely pointed out[2], little effort has been devoted to testing their validity, except for two noteworthy studies by Anthony and MacDonald (1998, 1999).

Our first contribution is to support the nonlinearity of exchange rate, a phenomenon called the honeymoon effect, and to confirm that behavior of the exchange rate is different between the neighborhood of and away from the implicit band: the exchange rate locally follows a diffusion process, whereas the exchange rate globally follows a mean-reverting process. This result contrasts sharply with that of Anthony and MacDonald (1998, 1999), who find mean-reversion without dividing samples by a linear unit root test and variance ratio test. That is, using the same sample period and the same French franc/Deutsche mark exchange rate as Anthony and MacDonald (1998), we obtain different results and conclude that exchange rates behave as though under the managed float system, not as though they are under the target zone system.

The second contribution is that the implicit band estimated by the STAR model is narrower than the officially announced band; moreover, it is not symmetric around the announced central parity. This point roughly concurs with that of Chung and Tauchen (2001). They identify the exchange rate level of the implicit band for the same sample period and the same French franc/Deutsche mark exchange rate using the efficient method of moments, whereas we specify the implicit boundaries as a range that includes the exchange rate level estimated by Chung and Tauchen (2001). This different

[1] As stated in Chung and Tauchen (2001, p255), an implicit band is defined as "a situation in which market participants do not believe the official band and instead base their decisions on a perceived unofficial band with unstated target rates."

[2] See Flood, Rose and Mathieson, 1991; Lindberg and Soderlind, 1991

point poses a question on Krugman's predictions or existence of an implicit target level for the exchange rate by the government.

The remainder of this paper is organized as follows: The next section briefly introduces a target zone model and elucidates its limitations. Section 3 is dedicated to empirical examination of the target zone using a STAR model. Our analysis for the implicit target zone is presented in Section 4. The last section concludes the paper.

2. Target Zone Models

After some earlier works on exchange rate target zones, recent works have been inspired by the elegant model by Krugman (1991)[3].

Krugman (1991) started from the presumption that an exchange rate depends both on some current fundamentals and an expected future change in the exchange rate.

$$s_t = f_t + \alpha \frac{E_t[ds_t]}{dt} \tag{1}$$

Therein, s_t is the logarithm of the spot exchange rate at time t, α represents the sensitivity of the exchange rate to its own expected future change, ds_t is the change in the exchange rate over time, and E_t represents the mathematical expectation operator. Also, f_t denotes the unobservable aggregate fundamentals, which are presumed to consist of two components: *velocity*, which is exogenous and stochastic; and the money supply, which is inferred to be managed by a central bank.

Krugman (1991) assumes that the fundamentals conform to a Brownian motion with the constant instantaneous standard deviation σ,

$$df = \sigma dW_t , \tag{2}$$

where a random variable dW_t is a standard Wiener process.

The assumption of a Brownian motion for fundamentals is plausible because it implies that the movements of the free-float exchange rate would be closely approximated by a random walk process,

[3] For instance, Williamson (1985) and Dumas (1992) are exemplary earlier works.

which inference corresponds to those of some empirical studies[4]. In Krugman (1991), the exchange rate fluctuates within a target zone around a specified central parity by central bank intervention. We denote this band as

$$\underline{s} \le s_t \le \overline{s}\,, \tag{3}$$

where $\underline{s}$ and $\overline{s}$ respectively represent the lower and upper edges of the exchange rate band. Making the zone symmetric around s=0 to simplify the algebra, we assume that $\overline{s} = -\underline{s}$. When the exchange rate strictly satisfies eq.(3), we can obtain the general solution:

$$s_t \equiv G(f_t) = f - A[\exp(\lambda_1 f) - \exp(-\lambda_2 f)]\,, \tag{4}$$

where $\lambda = \sqrt{\dfrac{2}{\alpha\sigma^2}}$. A is an arbitrary constant to be determined by the smooth pasting conditions, which are obtained by continuity of the exchange rate and the expected intervention[5].

Krugman (1991) shows that the exchange rate would follow a nonlinear S-shaped locus and be mean-reverting within the band. In addition, Svensson (1992) suggests that the exchange rate spends most of the time near the edges of the band and that the distribution is U-shaped. However, few researchers have examined the first prediction except for Anthony and MacDonald (1998), and many researchers report that empirical tests of this simple target-zone model have not confirmed the second prediction.

As Garber and Svensson (1995) point out, Krugman (1991) requires two crucial assumptions. First, the exchange rate target zone is perfectly credible, in the sense that market agents believe that the lower and upper edges of the band will remain fixed forever, and that no realignment will occur. However, the assumption of perfect credibility is unrealistic given the frequent realignments that are actually observed. Second, the target zone is defended with marginal interventions only: no intervention occurs as long as the exchange rate does not hit the edges of the target zone. However, numerous empirical findings indicate that central banks in the European Monetary System (EMS) intervened before exchange rates hit the announced edges of the target zone, i.e., intra-marginal

[4] See Meese and Rogoff (1983)

[5] The smooth pasting conditions hold when both marginal and intra-marginal interventions are anticipated. See Flood and Garber (1991) and Delgado and Dumas (1992).

intervention[6].

Therefore, we attribute the failure of most empirical studies of target-zone models to be based on assumptions that the market would base decisions on the official band of central banks. In the following section 3, we empirically examine the predictions of Krugman (1991) using the estimation method, which is different from Anthony and MacDonald (1998) and Chung and Tauchen (2001).

3. Empirical Analysis

3.1 Data

At the Bremen Summit of July 1978, the European Council (EC) endorsed the creation of the EMS, which came into existence in March of 1979. The centerpiece of the EMS was the Exchange Rate Mechanism (ERM), which was designed to limit exchange rate fluctuations. The seven charter members of the ERM were Belgium, Denmark, France, Germany, Ireland, Italy and the Netherlands. The ERM was strengthened greatly in September of 1987 with the signing of the Basle-Nyborg agreement, which effectively stabilized the ERM for nearly five years. Apart from the Lira's *technical* realignment of January 1990, no changes in central parities occurred until the summer of 1992. Notwithstanding, the speculative attack against the currency of the EMS members is well known to have raged in September 1992 and August 1993. Since that time, member countries of the EMS widened the target zone from ±2.25% to ±15% around the central parity.

The purpose of our empirical investigation is to examine the mean-reverting property of the exchange rate and the existence of an S-shaped locus, given a credible target zone.

For that purpose, we select the daily spot exchange rates for French franc/Deutsche mark (FF/DM), from 12 January 1987 to 31 July 1993, simply because it has been relatively stable compared with the other ERM exchange rates, and because it is used by Anthony and MacDonald (1999) and Chung and Tauchen (2001), among others. The central parity is *officially* 3.354 FF/DM, the upper bound is 3.429, and the lower bound is 3.278 during the period. The sample is obtained from the database provided by the University of British Columbia[7]. Figure 1 shows a plot of daily observations on FF/ DM exchange rate in the sample period and Table 1shows descriptive statistics.

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[6] For theoretical examination on intra-marginal intervention, see Bertola and Caballero (1992).

[7] The data set is available from http://fx.sauder.ubc.ca/data.html

The data are expressed as deviations from central parity.

***** Insert Figure 1 and Table 1 around here *****

3.2 Econometric Methodology

The standard means of evaluating the mean-reversion for target zone models, which is known as an Argument Dickey-Fuller unit root test (ADF), is to estimate the following regression equation.

$$\Delta s_t = \kappa_1 s_{t-1} + \sum_{j=1}^{n-1} \kappa_j \Delta s_{t-j} + \upsilon_t \tag{5}$$

A unit root will be present in the exchange rate series if $\kappa_1=0$. The null hypothesis is tested using a standard *t*-ratio of the estimate of κ_1 to its estimated standard error. Although this will engender a non-standard distribution, one must use the percentiles tabulated by Fuller (1976) or Mackinnon (1991). Table 2 reports the results in this *linear* unit root test[8]. The nonstationarity of the FF/DM exchange rate is apparent.

***** Insert Table 2 around here *****

However, as presented in section 2, Krugman (1991) suggests that the exchange rate within the target zone is non-linear for fundamentals. Moreover, if an exchange rate band is credible, the exchange rate within the band should be strongly mean-reverting. In addition, Meese and Rose (1983) and Bekaert and Gray (1998) also indicate the fact that linear models do not well describe higher-frequency exchange rate dynamics. Garratt, Psaradakis and Sola (2001) find evidence of target-zone nonlinearities in the sample period, from 10 October 1990 to 16 September 1992. Therefore, the results for an ADF test are incompatible with target-zone models[9]. We propose an

[8] We also conduct unit root tests with a drift, and with drift and a time trend. Although the results are unreported, they show the nonstationarity of the FF/DM exchange rate as well.

[9] Taylor and Iannizzotto (2001) show that an ADF test has little power.

alternative test using a Smooth Transition Auto Regressive (STAR) model, which extends to a *nonlinear* unit root testing procedure to evaluate target-zone models. Another advantage of using STAR is that it can be interpreted as a regime-switching model and can consequently treat the upper and lower boundaries as unknown parameters in the case that boundaries are unobservable because of intra-marginal intervention.

The STAR is first introduced by Tong (1990) and Granger and Terasvirta (1993); it is popularized by Terasvirta and Anderson (1992), and others. Michael, Nobay and Peel (1997) apply an exponential STAR (ESTAR), which is one of the STAR family, to two data sets: annual and monthly data. They find strong support for mean-reverting dynamic process, which is varying with sizable deviations from Purchasing Power Parity. We apply the method of Michael, Nobay and Peel (1997) to a target zone model and assume that the exchange rate is described by the following ESTAR model:

$$\Delta s_t = \lambda_1 s_{t-1} + \sum_{j=1}^{p-1} \phi_j \Delta s_{t-j} + (\lambda_1^* s_{t-1} + \sum_{j=1}^{p-1} \phi_j^* \Delta s_{t-j}) F(y_t;\gamma,c) + \varepsilon_t, \quad \varepsilon_t \sim i.i.d.(0,\sigma^2), \tag{6}$$

where $F(y_t;\gamma,c)$ is a continuous transition function and y_t is a transition variable; γ denotes the speed of transition and c indicates central parity in a target zone. In an ESTAR model, $F(y_t;\gamma,c)$ is substituted into the following exponential function.

$$F(y_t;\gamma,c) = 1 - \exp\{-\gamma(y_t - c)^2\} \qquad \gamma > 0, \quad 0 \le F \le 1 \tag{7}$$

Figure 2 shows that the transition function (7) switches smoothly from an inner regime to two symmetric outer regimes, so that the ESTAR model implies a non-linear unit root test weighted by the transition function. The inner regime corresponds to $y_t = c$. That is, when $F(y_t;\gamma,c) = 0$ and eq. (6) becomes a tractable AR (p) model, then

$$\Delta s_t = \lambda_1 s_{t-1} + \sum_{j=1}^{p-1} \phi_j \Delta s_{t-j} + \varepsilon_t' . \tag{8}$$

The outer regimes correspond to $y_t = \pm\infty$ when $F(y_t;\gamma,c) = 1$ and eq. (6) becomes a different AR (p) model:

$$\Delta s_t = (\lambda_1 + \lambda_1^*) s_{t-1} + \sum_{j=1}^{p-1} (\phi_j + \phi_j^*) \Delta s_{t-j} + \varepsilon_t'' . \tag{9}$$

The crucial parameters are λ_1 in (11) and $\lambda_1 + \lambda_1^*$ in (9), indicating the adjustment speed. In our discussion, the effect of expected intervention suggests that the larger the deviation from central parity, the stronger the tendency to move back. This means that, whereas $\lambda_1 \geq 0$ is possible, we must have $\lambda_1^* < 0$ and $\lambda_1 + \lambda_1^* < 0$. Consequently, if these sign conditions are satisfied, it implies that eq. (6) with eq. (7) is globally mean-reverting.

***** Insert Figure 2 around here *****

3.3 Estimation and Results

For estimation of the ESTAR model, we first need to specify a linear autoregressive model AR (*p*), in which *p* denotes the order of the lag. The order *p*=2 is selected from SBIC statistics[10]. Next, for each linear AR (*p*) model for the FF/DM exchange rate, we test linearity (*F* test) for a certain transition variable, y_t. It is common to select a single lagged endogenous s_{t-d} (*d* is called a delay parameter) as y_t. We test *d*=1, 2, and 3 using the following auxiliary equation[11].

$$s_t = \beta_{00} + \sum_{j=1}^{p} (\beta_{1j} s_{t-j} + \beta_{2j} s_{t-j} s_{t-d} + \beta_{3j} s_{t-j} s_{t-d}^2) + \xi_t \qquad \xi_t \sim n.i.d(0, \sigma_\varepsilon^2) \tag{10}$$

The null hypothesis of linearity for s_t is

$$H_0 : \beta_{2j} = \beta_{3j} = 0 .$$

As reported in Table 3, it is concluded that the linearity in eq. (10) is rejected strongly for *d*=1;

[10] If the order is determined by the AIC for a finite sample, it is known that it has a positive probability of overfitting, but it is not consistent for a large sample. In contrast, it is known that the SBIC is consistent. The sample size of our data is relatively large. Therefore, we adopt the SBIC. We also validate the selected order of lag with the Ljung-Box (Q) statistics.

[11] See Terasvirta and Anderson (1992).

therefore, a nonlinear stochastic process is accepted in the FF/DM. This fact suggests that a *honeymoon effect* exists in the exchange rates within a band[12].

Taylor and Iannizzotto (2000) show that nonlinearity is present, but that it only applies in regions that are very close to the tangency point at the edges of the band. That is, the honeymoon effect is much smaller. Jong (1994) reports that no nonlinearities exist for the three currencies (Dutch guilder, Irish punt and Italian lira) on the six EMS exchange rates. The two results seem to conflict with our evidence at first sight, but might indeed be consistent. The reason is explained in the next section.

*****Insert Table 3 around here*****

Finally, we use a nonlinear least-squares method to estimate eq. (6). Terasvirta (1994) points out that the estimation of parameters might cause some problems (e.g., slow convergence, overestimation and so on) [13]. We therefore follow his recommendation in scaling the argument of the transition function $F(s_{t-d})$ by dividing it by the variance of s_t. We set γ at 1 and use zero for all parameters other than γ as the initial value. The estimation results are listed in Table 4.

*****Insert Table 4 around here*****

Terasvirta (1994) suggests that the estimate of the parameter c be within the observed range of s_t. Our estimated $\hat{c}$ (=0.007) satisfies this criterion for the FF/DM and is actually positive, as reported in Table 4. The positive $\hat{c}$ means that observations for the FF/DM scatter above the announced central parity (see Fig. 1). According to Table 5, the reduction in the residual variances relative to the linear model is 2%, as shown by the variance ratio, and the possibility of autocorrelation is low, although we should be cautious of heteroscedasticity[14].

Most of the estimated coefficients are statistically significant at the 5% level by the t test and the

[12] Krugman (1991) assumes that the exchange rate is non-linear for fundamentals. Nevertheless, it is impossible to test nonlinearity of the daily exchange rate for fundamentals because daily data for fundamentals are not available.

[13] A precise estimate of γ by STAR estimations is well known to be difficult to obtain. However, an apparently non-significant estimate of γ should not be interpreted as indicating the non-significance of regime switching (see, Terasvirta and Anderson (1992)).

[14] For the ratio of residual variances, the best ratio is 0.766 and the worst is 0.967 in Michael, Nobay and Peel (1997), the best ratio is 0.883 and the worst is 0.962 in Chen and Wu (2000), respectively.

sign conditions are satisfactory. Hence, we confirm that, whereas the exchange rates around the estimated central parity ($=\hat{c}$) mark a diffusion process, the exchange rates that are distant from the parity follow a mean-reverting process. To reinforce this, we additionally perform a test of mean-reversion by examining the conditions from eqs. (9) and (11). The hypotheses to be tested are formally stated as

$$H_0^{inside} : \lambda_1 = 0,$$

and

$$H_0^{outside} : \lambda_1 + \lambda_1^* = 0.$$

We confirmed that the exchange rate is global stationary and is mean-reverting toward the estimated central parity. The ones near the parity follow a diffusion process using both the Wald test and the Likelihood ratio test (see Table 6).

*****Insert Tables 5 and 6 around here*****

These results yield an informative suggestion into the behavior of exchange rates within the target zone. Krugman (1991) points out that if a target zone is credible, the exchange rate within the zone should exhibit mean-reversion strongly, even without intervention. However, the evidence of diffusion process we find is clearly the property of free-float system or managed float with a target central parity, rather than that of target zone, as Svensson (1992) argued.

Surprisingly, these rejections might support the two results of Anthony and MacDonald (1998). It indicates little evidence of mean reversion using the ADF test, but it confirms that the exchange rates within the target zone are mean-reverting using the variance ratio test. That is, the two conflicting results are consistent with our findings that exchange rates are globally mean-reverting, but which locally show diffusion. In addition, Taylor and Iannizzotto (2000) and Jong (1994), suspecting a nonlinearity process in exchange rates, are probably compatible with our findings, allowing for partial existence of the random walk process within the target zone[15]. In other words, our findings indicate that exchange rates have nonlinearity, but Taylor and Iannizzotto (2000) and Jong (1994) could only slightly observe the property because the

[15] Jong (1994) also suggests that nonlinearities be explained by the presence of an implicit band that is narrower than the official band.

mean-reversion range in exchange rates is limited. We are unable to deny that the honeymoon effect is smaller than the supposition of Krugman (1991), as Taylor and Iannizzotto (2000) point out.

4. Suggestion of an Implicit band by Adjustment Speed and Transition function

Rose and Svensson (1995) suggest the existence of an implicit band. Chung and Tauchen (2001) estimate that the upper band is 3.408, the lower is 3.292, and that the central parity is 3.377. They assert that the implicit band is narrower than the official band. In contrast, Labhard and Wypolsz (1996) report that the implicit band is slightly larger than the official band, although they do not identify the bandwidth. Clearly, these affirmations of the implicit band are inconsistent. Does an implicit band really exist? And what ever does the implicit band mean? During this sample period, several studies show that the governments in fact intervene intra-marginally. However, it is impossible for us to accurately determine when the governments intervene, the extent or degree of that putative intervention, and where a target level of band is, unless a government announces it. When we define an implicit band, we are unable to identify whether the governments actually intervene, or investors who are sensitive to intervention sell or buy currency spontaneously without using accurate intervention data. The actual exchange rate level of intra-marginal intervention is not always coincident with the level of the band perceived by investors without announcement. Therefore, we define an implicit band only as an observable band, by which we conjecture the target level of intra-marginal intervention and the band perceived by investors.

In this paper, the estimated transition function and adjustment speed make it possible to identify the observed implicit band. In Fig. 3, the transition function indicates that the transition from the lower outside to the inside of zone starts from around 3.317 FF/DM and arrives at 3.377. The interval between 3.317 and 3.377 is interpreted as a process of regime-change. Therefore, the transition function shows that the implicit lower band must be in this interval. This means that 3.317 is definitely in the lower regime, and 3.377 is the implicit central parity, which is perfectly consistent with the central parity estimated by Chung and Tauchen (2001). Similarly, 3.438 is definitely in the upper regime and the implicit upper band must be in between 3.377 and 3.438.

*****Insert Table 7 around here*****

Figure 3 also depicts the adjustment speed for the FF/DM exchange rates, obtained from our simulation. The adjustment speed is defined with the gradient vector, which means a convergence process (mean-reversion) in the case of negative values and a diffusion process in the case of positive ones. The adjustment speed is the most rapid at 3.377. The slowest is around 3.361 and 3.394, changing from negative to positive. This relationship suggests that exchange rates tend to stay around 3.361 and 3.394 for a long time. This fact seems to be consistent with the humped distribution of exchange rates suggested by some preceding studies. However, 3.361 and 3.394 are near the announced central parity, but it seems to be U-shaped for the estimated central parity, the estimated upper and lower regime. In addition, exchange rates follow a diffusion process between 3.361 and 3.394 FF/DM. This interpretation posits that investors only slightly expected a government to intervene between 3.361 and 3.394 FF/DM because the movement of exchange rates is consistent with that of a free-float system in this range. On the other hand, exchange rates are mean-reverting between 3.317 and 3.361 and between 3.394 and 3.438. All investors might believe a government defense of an announced band in the range less than 3.317 and more than 3.438. But investors expecting an intra-intervention might increase gradually from 3.317 to 3.361, or from 3.394 to 3.438. In summary, our simulation experiment shows that, given perfect credibility, the lower boundary of the implicit zone is identified as below 3.361 and the upper boundary is identified as above 3.394 for the FF/DM exchange rate during our sample period. Consequently, our estimated implicit band differs greatly from the officially announced target zone and is not symmetric around the announced central parity. However, it is impossible to specify the level of implicit boundaries in our research, though it includes the estimation result of Chung and Tauchen (2001). Because the range of the exchange rate transiting a regime is very broad[16]. We suggest two plausible interpretations for the implicit band. One is that each investor expects different target levels and sells or buys currency because of reiteratively intra-marginal intervention without a definite target level, as in a managed float system. The other is that even if a government intervenes intra-marginally with a definite target level and all investors fully forecast that level, exchange rates behave similar to those of a managed float system by the presence of an implicit target zone, not as Krugman (1991) suggests.

[16] This is corresponding to the argument of Labhard and Wypolsz (1996) because our results show that the range of the upper boundary is above the officially announced upper boundary.

*****Insert Figure 3 around here*****

5. Concluding Remarks

This paper presented an empirical examination of the main predictions of Krugman (1991), who concluded that the exchange rate would remain, most of the time, near the edges of the band and be mean-reverting within the band under the perfect credibility for intervention. Through employment of a more elaborate ESTAR model, we confirmed that (1) nonlinearity, (2) mean-reversion, and (3) existence of the implicit band (or intra-marginal intervention). Our salient results are summarized briefly as follows.

First, this paper provides evidence that the FF/DM exchange rates follow a nonlinear process, which suggests the existence of the honeymoon effect. Second, the exchange rates far from the estimated central parity follow a mean-reverting process toward parity, whereas the exchange rate near the estimated parity follows a diffusion process. This is an important result because it can explain the failure in many empirical studies for nonlinearity and mean reversion. The failure in nonlinearity tests might result from two kinds of movement for exchange rates within a target zone. Furthermore, the failure in mean-reversion results from using a linear model and two different movements. Finally, we found the existence of an implicit band that is different from the officially announced target zone and which is asymmetric around the announced central parity by our simulated transition function and the adjustment speed. Moreover, we specified the possible range of the implicit band. Although many precedent studies have suggested the existence of the implicit band, to our knowledge, not one, except for Chung and Tauchen (2001), has directly calculated the range of the lower and upper boundaries for the implicit exchange rate band.

In conclusion, we demonstrated that the key predictions of Krugman (1991) are incorrect for the FF/DM exchange rates during the sample period, even allowing for an implicit band, and exchange rates behaved as in the managed float system, not like a target zone.

Nevertheless, it is important to recall that the exchange rate was stable during the sample period and that the government kept the announced target zone.

After the EMS crisis, the bipolar view on the exchange rate regimes became dominant. However, the Brazilian crisis raised several questions against that view, and Frankel (1999) and Fischer (2001) pointed out that intermediate exchange rate regimes are more likely to be appropriate for many countries than the bipolar view.

If the target zone system or managed float system is more stable under some conditions, as we have concluded, then adopting intermediate exchange rate regimes is supported.

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Table 1: Descriptive Statistics for the FF/DM Exchange Rates

Mean	Median	Maximum	Minimum	Standard Deviation	Skewness	Kurtosis	Observations
3.382	3.387	3.426	3.323	0.024	-0.602	2.539	1658

Table 2: Augmented Dickey-Fuller Test for Unit Roots

	$\hat{\kappa}_1$	S.E.	SBIC	adjR2	Log Likelihood
FF/DM	-0.0035 (0.002)	0.001129	-10.726	0.0236	8910.734

S.E. is standard error of regression, Standard error is in parenthesis, adjR2 is adjusted coefficient of determination for degrees of freedom.

***, **, and * indicate significance at the 1, 5, and 10% level, respectively by Mackinnon(1996).

Table 3: Linearity Test

	d=1	d=2	d=3
FF/DM	3.55 ***	2.30 *	1.84

***, **, and * indicate significance at the 1, 5, and 10% level, respectively, and are determined by the critical value on the basis of the F distribution.

Table 4: The Coefficients for ESTAR Model

	$\hat{\lambda}_1$		$\hat{\phi}$	$\hat{\lambda}_1^*$		$\hat{\phi}^*$		$\hat{\gamma}$	$\hat{c}$	
FF/DM	0.0132	**	-0.0287	-0.0257	***	-0.243	***	1.1327	0.0073	***
	(0.006)		(0.045)	(0.008)		(0.076)		(0.839)	(0.000)	

Standard error is in parenthesis.

***, **, and * indicate significance at the 1, 5, and 10% level, respectively, and are determined by the critical value on the basis of the t distribution.

Note. $\hat{\gamma}^* = \hat{\gamma} \times \sigma_s^2$

Table 5: Diagnostic Test

	ARCH(4)	Q (4)	SBIC	JB	VR	Log likelihood	adjR2	S.E.
FF/DM	178.8***	0.730	-10.72	1811.2***	0.98	8911	0.037	0.0011

JB is the Jarque and Bera (1980) normality test.

VR shows variance ratio $\frac{\sigma_E^2}{\sigma_L^2}$, where σ_E^2 and σ_L^2 are the residual variances from the restricted ESTAR and the linear model, respectively.

ARCH(k) is ARCH test up to order k.

Q(k) is the Ljung-Box statistics for residual autocorrelation up to order k.

Table 6: Target Zone Test

	H_0^{inside}				$H_0^{outside}$			
	W		LR		W		LR	
FF/DM	4.509	**	5.189	**	4.705	**	9.250	***

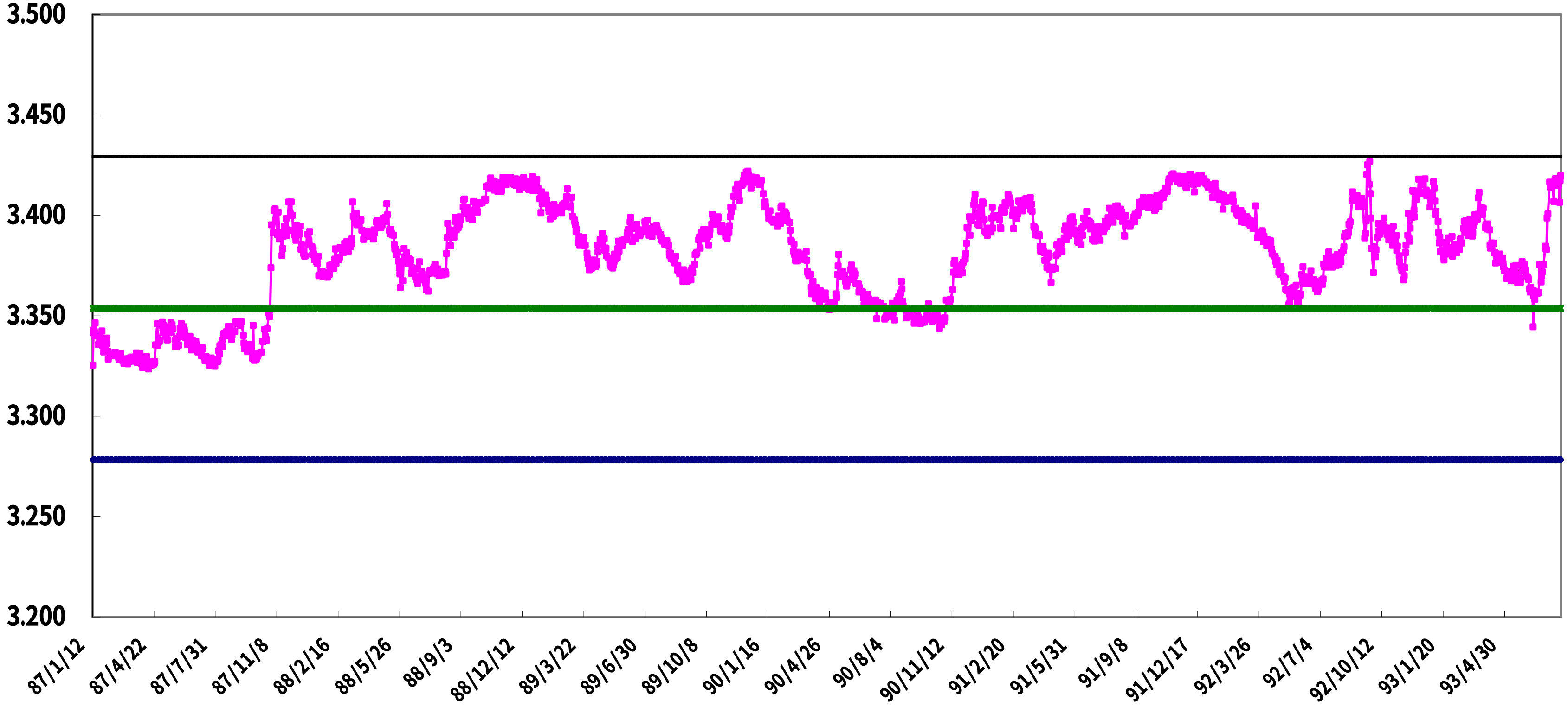
W is the Wald test statistics, and LR is the likelihood ratio test statistics corresponding to H_0. ***, **, and * indicate significance at the 1, 5 and 10% level, respectively, and are determined by the critical value on the basis of the χ^2 distribution.

Table 7: Estimated Boundary Level

	Upper boundary level	Central parity level	Lower boundary level
The Official band	3.429	3.354	3.278
Chung and Tauchen's results	3.408	3.377	3.292
The results in this paper	between 3.377 and 3.438	3.377	between 3.317 and 3.377

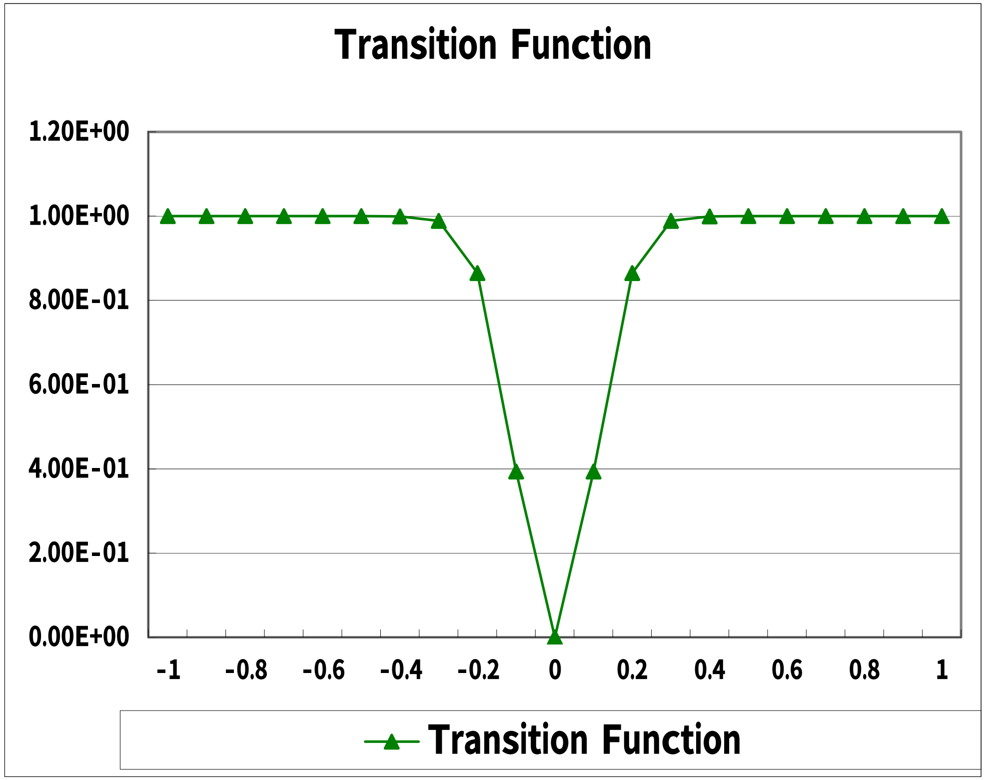
Unit: FF/DM

Figure 1: Daily FF/DM Exchange Rate :1987-1993



The upper, middle, and lower lines are the announced upper edge (3.43FF/DM), the central parity(3.35FF/DM), and lower edge(3.28FF/DM), respectively, of Target-zone.

Figure 2: Exponential Transition Function

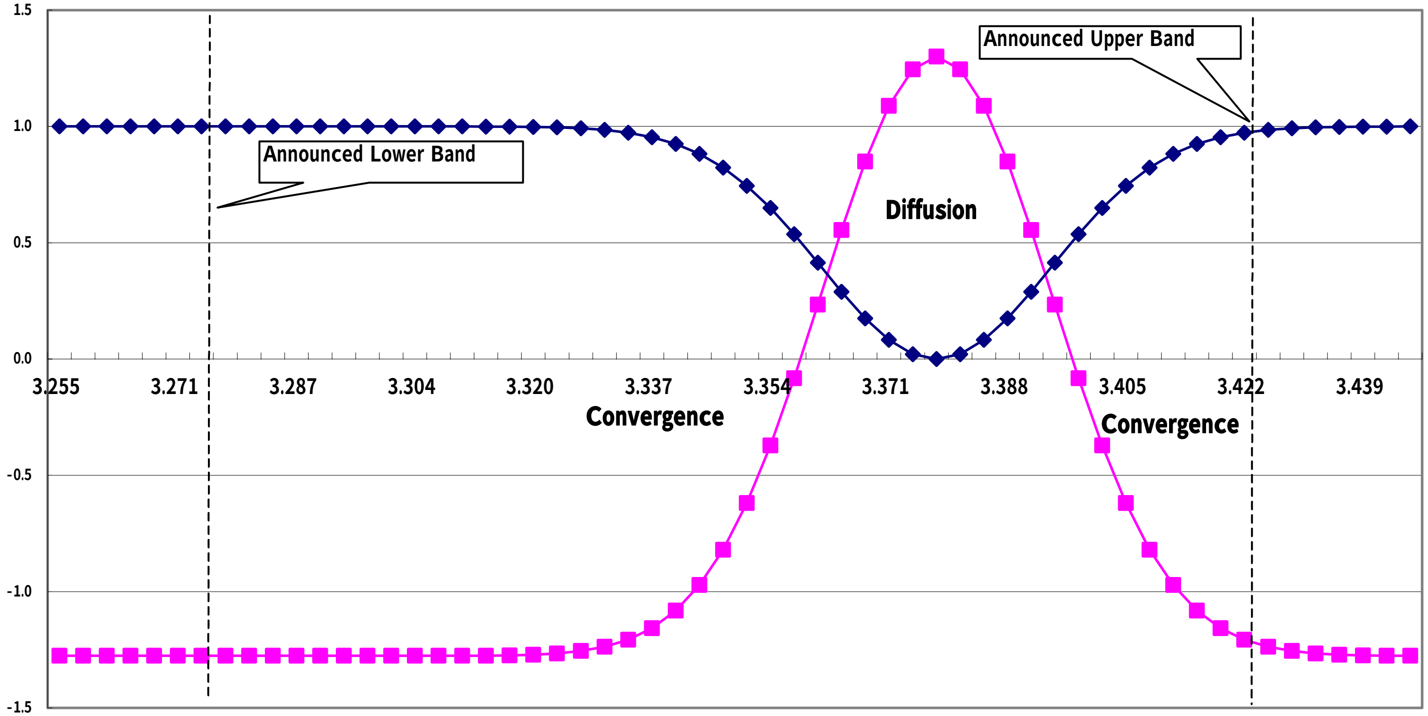


The vertical axis: $F(s_{t-d})$

The horizontal axis: s_{t-d}

c_1=0, γ=20

Figure3 :Implicit Band and Adjustment Speed



Transition function is indicated by blue line, adjustment speed is by red line.

The vertical axis: Adjustment speed (multiplied by10) and the estimated transition function.

The horizontal axis: The level of the FF/DM exchange rates.