

Is There a Trade-off between Exchange Rate and Interest Rate Volatility? Evidence from an M-GARCH Model

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1 – Introduction

The functioning of the Exchange Rate Mechanism (ERM) of the European Monetary System (EMS) remains one of the best examples of an exchange rate target zone. The currencies could fluctuate more or less freely within an exchange rate band, committing the central banks to intervene whenever the target zone was threatened, which happened whenever the exchange rate reached one of the edges of the band.

After some initial theoretical research, with major contributions from McKinnon (1984), Williamson (1985) and Williamson and Miller (1987), the literature on the subject has known a revival with the introduction by Krugman (1991) of the first model of a nominal exchange rate target zone in continuum time with rational expectations and flexible prices, using the structure of regulated Brownian motion².

The basic target zone model has quite interesting implications for the behaviour of the exchange rate and the interest rate differential. The model predicts that the exchange rate is much less variable the closer it is to the edges of the band and that there is a negative relationship between the exchange rate and the interest rate differential. Therefore, we should find evidence of a trade-off between the volatility of the exchange rate and the volatility of the interest rate differential. These predictions can be tested against real world data in order to confirm the validity of the model and the credibility of the bands.

In this work we examine the functioning of the Portuguese exchange rate target zone in the context of the ERM of the EMS. Our main aim is to study the behaviour and volatility of exchange rate and interest rate differential based on the predictions of Krugman (1991) model. Our contribution to the literature stems from the fact that we are analysing a currency from the periphery of the system, the Portuguese escudo, while most previous work has focused on the Nordic countries and on fluctuation bands of the ERM of the EMS considered to be more stable and credible.

The paper is structured as follows. Section 2 examines the functioning of the Portuguese exchange rate target zone during the participation of the Portuguese escudo in the ERM of the EMS. Section 3 explores the existence of a trade-off between exchange rate volatility and interest rate differential volatility under an M-GARCH model. Finally, Section 4 draws some conclusions.

² Details of this literature can be found in Magnier (1992), Svensson (1992a), Bertola (1994), Garber and Svensson (1995), Pansard (1997) and Kempa and Nelles (1999).

2 – The Portuguese Exchange Rate Target Zone

On April 6 1992, the framework of the Portuguese monetary and foreign exchange policy changed when the Portuguese escudo joined the ERM of the EMS. This was made possible by the better convergence of the Portuguese inflation rate with the EU's average level and, in particular, with the values recorded by Germany. The central parity was fixed at 178,735 and 86,9393 escudos for the ECU and for the Deutschmark, respectively, and the Portuguese escudo was allowed to fluctuate within a band of $\pm 6\%$.

As there was a formal commitment to keep the Portuguese escudo within the band from this date, the credibility of the disinflation policy increased, facilitating the pursuit of the price stability goal. This foreign exchange policy course was maintained until the end of 1998, in spite of the disturbances that affected the EMS. Table 1 summarizes these events, allowing us to identify the main features of the Portuguese exchange rate target zone while the Deutschmark was the reference currency.

Table 1: Bands for the Portuguese Target Zone (PTE/DM)

Period / Date	Band	PTE/DM ^(a)		
		Lower Edge ^(b)	Central Parity	Upper Edge ^(b)
6 April 1992 ^(c)	$\pm 6\%$	81,9	86,9393	92,336
23 November 1992 ^(d)	$\pm 6\%$	87,108	92,488	98,232
13 May 1993 ^(e)	$\pm 6\%$	93,197	98,9177	105,042
2 August 1993 ^(f)	$\pm 15\%$	85,179	98,9177	114,811
6 March 1995 ^(g)	$\pm 15\%$	88,277	102,505	119,033

Source: Banco de Portugal.

Note: (a) Portuguese escudos necessary to buy one Deutschmark.

(b) The lower (upper) edge represents the maximum appreciation (depreciation) permitted to the Portuguese escudo.

(c) Membership of the Portuguese escudo of the ERM of the EMS with a bandwidth of $\pm 6\%$.

(d) Realignment in the EMS with a devaluation of 6% of the Spanish's peseta and the Portuguese escudo.

(e) Realignment in the EMS with a devaluation of 8% of the Spanish's peseta and 6,5% of the Portuguese escudo.

(f) Enlargement of the bands of the ERM to $\pm 15\%$.

(g) Realignment in the EMS with a devaluation of 7% of the Spanish's peseta and 3,5% of the Portuguese escudo.

In Figure 1 we depict the behaviour of the Portuguese escudo exchange rate against the Deutschmark and the evolution of the overnight interest rate differential between Portugal and Germany as part of the PTE/DM band³. Besides the target zone period, we simulated, from January 2 1987 to April 5 1992, an unofficial band of $\pm 6\%$, with an unofficial central parity (No_C_PTE_DM) and unofficial intervention edges (No_LI_PTE_DM_6 and No_LS_PTE_DM_6) equal to that adopted on joining⁴.

³ See Appendix I for a description of the data used.

⁴ See Appendix II for a complete list of variables and their description.

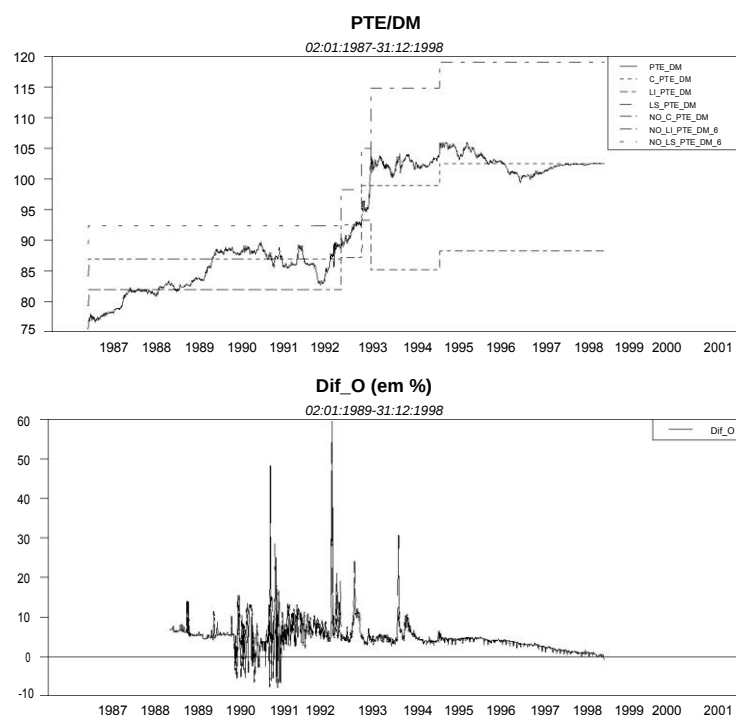
Figure 1: PTE/DM Exchange Rate and Overnight Interest Rate Differential

Figure 1 shows that the PTE/DM exchange rate had been relatively stable since the beginning of the 1990s. This was the result of the pegging of the Portuguese escudo to the Deutschmark, which allowed the Portuguese currency to benefit from the credibility, stability and discipline associated with the tacit acceptance of the anti-inflationary stance of the Bundesbank's monetary policy.

Concentrating on the target zone period, it is possible to confirm that after joining the ERM, the Portuguese escudo registered a significant nominal appreciation and an almost immediate decline to a value near the lower edge of its band. Furthermore, everything seems to indicate that the realignments were anticipated, given the high interest rate differential before the realignments⁵. After the widening of the bands, the exchange rate again stabilises, but now within the implicit band of $\pm 6\%$.

The effectiveness of the nominal stabilisation policy of the escudo allowed the Portuguese economy to substantially reduce inflation deviation against Germany. From 1992 onwards there was a gradual disinflation process in Portugal, expressed on a continuous decline in the inflation rate which coincided with the participation of the Portuguese escudo in the exchange rate target zone.

⁵ The use of interest rates with longer maturity times does not change these results.

Nevertheless, despite the fact that Portugal has made great strides in its European integration process, it should also be mentioned that disinflation brought about a drop in competitiveness due to the real appreciation of the escudo. This affected output growth and, consequently, employment, particularly in the sectors more open to international competition⁶. In comparison to other European countries, the costs of the disinflation process in Portugal seem relatively modest, at least at first⁷. However, the more aggressive effects of the exchange rate appreciation policy are felt in the long run, even if everything seems to indicate that in the short run the costs of the disinflation are relatively low. The findings of Rebelo and Végh (1995), European Commission (2004) and Abreu (2006) pointed in this direction. The main issue seems to lie in the fact that Portugal has joined the ERM of the EMS with a currency too appreciated.

The issues recently raised by the Bruegel policy brief seem to support these conclusions⁸. The first seven years of participation in the euro zone show that some countries, such as Ireland, have been successful, but others, such as Portugal, have faced some adjustment costs. In the case of Ireland, the appreciation of the real exchange rate was quickly adjusted by substantial improvements in terms of productivity and by upward movements in the value of tradable goods. In Portugal, however, the slow growth of productivity and the composition of exports, based on traditional sectors with low added-value, made the country more vulnerable to international competition from countries with low production costs, especially China and new European Union member states.

It was nevertheless possible to begin a cycle of exchange rate stability. Thus, improved competitiveness must be based on structural adjustments. Competitiveness requires productivity gains, which will depend to a great extent on the modernisation of the tradable goods sector and also to a depreciation of the real exchange rate and a tighter budgetary discipline, which may require an extended period of wage moderation. Careful monitoring of credit expansion is also essential to prevent an overshooting of domestic prices, especially because Portugal has to adjust to lower interest rates that it hasn't historically been accustomed to.

⁶ See Duarte (2001, 2002), Macedo (2006) and Duarte, Andrade and Duarte (2008). ⁷ For suggestive evidence see Barbosa and Machado (1996).

⁸ See Ahearne and Pisani-Ferry (2006).

3 – Trade-off between Exchange Rate Volatility and Interest Rate Differential Volatility

According to the basic target zone model proposed by Krugman (1991), the behaviour of the exchange rate within the band depends on an aggregate fundamental and its expected rate of change, as can be described by the following equation:

$$s(t) = f(t) + \alpha E_t [ds(t)] / dt, \quad \forall t \text{ and } \alpha \geq 0, \quad (1)$$

where $s(t)$ is the log of the nominal exchange rate at time t , $f(t)$ is the fundamental at time t , α is the absolute value of the semi-elasticity of the exchange rate with respect to its expected rate of change and E_t is the expectations operator conditional on the available information at time t according to the rational expectations hypothesis.

The fundamental is the sum of two components,

$$f(t) = m(t) + v(t), \quad (2)$$

the domestic money supply, $m(t)$, and a term representing a composite money demand shock, usually referred to in the literature on target zones as “velocity”, $v(t)$. The model assumes that “velocity” is an exogenous stochastic process, whereas the money supply is a stochastic process controlled by the monetary authorities. The question is then how the presence of a credible floating band may affect the behaviour of the exchange rate.

In the absence of any intervention, a situation common in a free floating regime, it is assumed that the money supply $m(t)$ is kept constant. As a consequence, the fundamental is simply equal to “velocity”, $f(t) = v(t)$. It is thus assumed that “velocity” follow a Brownian motion with drift μ and instantaneous standard deviation σ :

$$dv(t) = \mu dt + \sigma dz(t), \quad \mu \text{ and } \sigma \text{ positive parameters and } v(0) > 0, \quad (3)$$

where $z(t)$ is a Wiener process with $E_t [dz(t)] = 0$ and $E_t [(dz(t))^2] = dt$, that is, $f(t)$ is the equivalent of a continuous random walk⁹.

This assumption implies that the exchange rate under a free floating regime is also a Brownian motion. Therefore, changes in the fundamental will translate into equal changes in the exchange rate, $ds(t) = df(t)$.

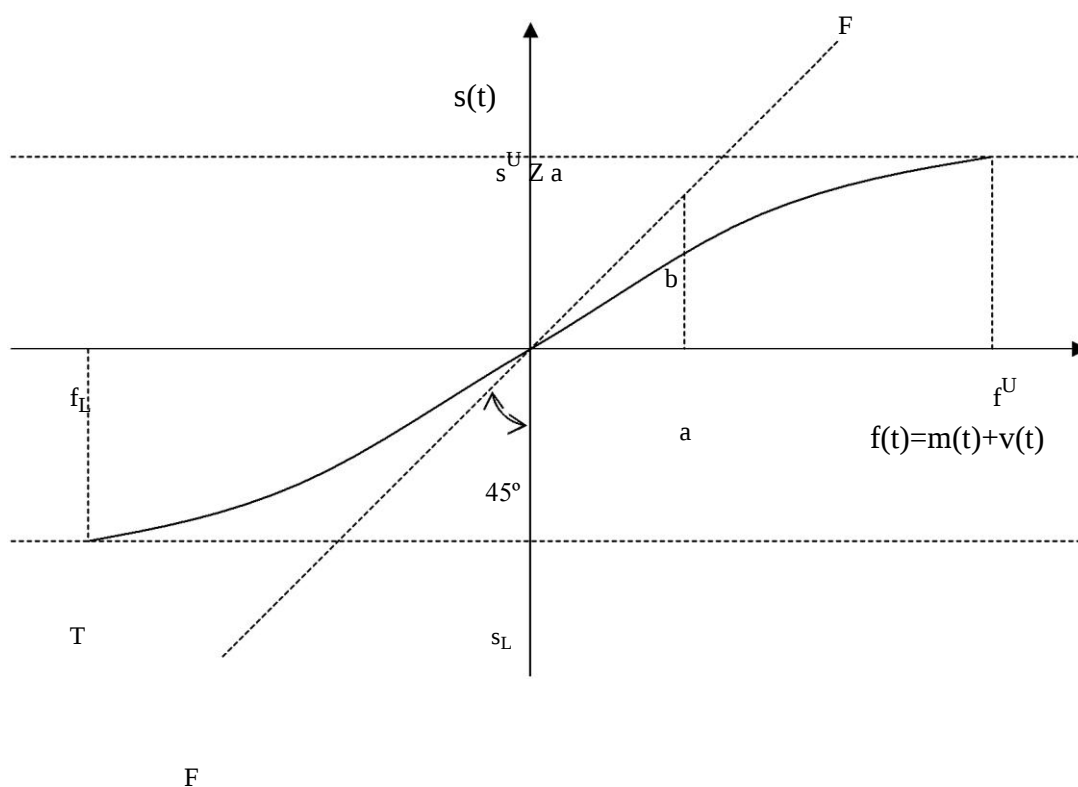
⁹ See Merton (1992), Campbell, Lo and Mackinlay (1997), Maddala and Kim (1999) and Demange and Rocher (2005).

In a target zone, it is assumed that the intervention rule is based on a specific floating band for the fundamental, $f_L \leq f(t) \leq f^U$, and that, if necessary, the fundamental will be regulated to remain within the band. This implies that the fundamental follows a regulated Brownian motion with constant drift and instantaneous standard deviation¹⁰:

$$df(t) = \mu dt + \sigma dz(t) + dL(t) - dU(t), \quad (4)$$

where $L(t)$ and $U(t)$ are the lower and upper regulators, defined as continuous and increasing functions of t , so that $dL(t)$ represents increases in the money supply, positive only if $f(t)=f_L$ and $dU(t)$ represents decreases in the money supply, positive if $f(t)=f^U$. Under these circumstances, the exchange rate function establishes a non-linear relationship between the exchange rate and its fundamental, as illustrated in Figure 2.

Figure 2: Exchange Rate in a Perfectly Credible Target Zone



The straight-line FF represents the equilibrium exchange rate in the free floating case. A shock in $v(t)$ leads to a proportional change in $f(t)$ and $s(t)$. The exchange rate target zone function is tangent to the edges of its floating band, where $s_L = s(f_L)$ and $s^U = s(f^U)$, represented by the curves TZ, non-linear, and S-shape, respectively.

The behaviour of the exchange rate in a target zone with perfect credibility leads to two main results. First, the slope of the curve TZ is always less than one. This feature is

¹⁰ Harrison (1985) and Karatzas and Shreve (1997) provide a formal presentation of these processes.

called “the honeymoon effect”, a reference by Krugman (1987: 19) to a “target zone honeymoon”. The exchange rate function thus appears less sensitive to changes in the fundamental than the corresponding free floating exchange rate. Moreover, the part of the adjustment supported by the exchange rate in a target zone is not constant, but decreases as the exchange rate moves away from the central parity. The “honeymoon effect” thus implies that a perfectly credible target zone is inherently stabilising¹¹.

Second, the curve TZ becomes flatter, reaching a zero slope at the edges of the band. At the edges of the target zone, the exchange rate function is tangential to the horizontal dashed lines that represent the edges of the exchange rate band. This result is known as “smooth pasting” conditions.

Given these conditions, the model predicts that the exchange rate will be much less variable near the edges of the band. According to the model, the instantaneous variability of $s(t)$ is directly proportional to the slope of the curve TZ:

$$V(t)[ds(t)] = [s'(f(t))\sigma]^2 dt, \quad (5)$$

where $V(t)[ds(t)]$ is the conditional variance of the changes in the exchange rate. The variability of the exchange rate thus reaches a maximum at the centre of the exchange rate band and decreases as the exchange rate gets closer to the edges of the band.

The basic model has also implications for the behaviour of the interest rate differential that emphasize the special features of the adjustment process in a target zone following a monetary shock. Svensson (1991b, 1992a, b) shows that in narrow target zones, with and without devaluation risk, the foreign exchange risk premium is likely to be very small. We thus assume that the foreign exchange risk premium is zero and that uncovered interest rate parity continually holds, that is:

$$i(t) - i^*(t) = E_t[ds(t)]/dt. \quad (6)$$

Letting $\delta(t)$ denote the interest rate differential, we can combine (6) with equation (1) in order to represent the interest rate differential:

¹¹ Returning to Figure 2, if we consider that a positive random shock in $v(t)$ increases the fundamental from the origin to point a , under a free floating regime the exchange rate increases by the same amount. However, in a target zone, agents recognize that there is a high probability of a future contraction in the money supply. Thus, agents expect the future appreciation of the exchange rate. This results in an equilibrium exchange rate that is less than a , at point b .

$$\frac{\delta(t) = S(t) - f(t)}{\alpha} \quad (7)$$

In the case of a free floating regime it follows that the interest rate differential is constant and equal to the drift of the fundamental.

Since under a target zone $s'(f(t)) < 1$, it follows that the interest rate differential will be decreasing in the fundamental, $\delta(f(t)) < 0$. Furthermore, recalling that the exchange rate is an increasing function of the fundamental, the basic model implies a negative deterministic relationship between the exchange rate and the interest rate differential.

We can find here the main difference between a free floating regime and a target zone. In a free floating regime, the exchange rate is responsible for the whole adjustment process. In a target zone, the exchange rate and interest rates “share” that responsibility between them. The volatility spillover from the exchange rate to the interest rates can be analysed through the instantaneous variability of the interest rate differential. The variability of $\delta(t)$ is computed using Ito’s lemma:

$$d\delta(t) = \frac{\delta(f(t))}{\alpha} dt + \delta(f(t)) \sigma dz(t), \quad (8)$$

where $[\delta(f(t))\sigma]^2 dt$ represents the conditional variance of the changes in the interest rate differential. It follows that the interest rate differential’s volatility is minimum at the centre of the band and increases near the edges of the band, replacing here the exchange rate as the main variable in the adjustment process. There is thus a trade-off between the instantaneous variability of the exchange rate and the instantaneous variability of the interest rate differential¹².

We examined the correlation between the estimated values of the conditional variances of the exchange rate and interest rate differential under an M-GARCH (Multivariate Generalized-AutoRegressive Conditional Heteroscedasticity) model¹³, in an attempt to validate the theoretical predictions.

The autoregressive conditional heteroscedasticity (ARCH) was proposed by Engle (1982) in order to explain the evolution of the residuals of financial time series models. A very general form of an ARCH model is given by:

¹² See Svensson (1991a, 1994).

¹³ See Hamilton (1994), Campbell, Lo and MacKinlay (1997), Johnston and DiNardo (1997) and Tsay (2002).

$$y_t = x_t \beta + u_t \quad (9)$$

$$h_t = \text{var}(u_t) = \sigma^2(u_t), \quad (10)$$

in which there is an ARCH (q) process if:

$$h_t = c_0 + a_1 u_{t-1}^2 + a_2 u_{t-2}^2 + \dots + a_q u_{t-q}^2, \quad (11)$$

where, by assumption, in the context of our analysis, the dependent variable is the daily depreciation (appreciation) rate of the Portuguese escudo against the Deutschmark.

Instead, Bollerslev (1986) proposed a GARCH (p, q) model where the variance term depends on the lagged residuals (squared), as well as on the lagged variances. This leads to a greater persistence of volatility but with a relatively smaller number of parameters. The GARCH (p, q) model for the variance is given by:

$$\begin{aligned} h_t &= c_0 + a_1 u_{t-1}^2 + a_2 u_{t-2}^2 + \dots + a_q u_{t-q}^2 + b_1 h_{t-1} + b_2 h_{t-2} + \dots + b_p h_{t-p} = \\ &= c_0 + \sum_{i=1}^q a_i u_{t-i}^2 + \sum_{j=1}^p b_j h_{t-j}. \end{aligned} \quad (12)$$

We used a two equations GARCH model (or multivariate GARCH), M-GARCH (p, q), with $p=1, q=1$:

$$Y_t = X_t \beta + \mu_t, \quad (13)$$

where Y_t is a vector with the exchange rate variation and the interest rate differential, and X_t a matrix with the deterministic variables. The exchange rate is always modelled with the constant. In the case of the interest rate differential, in addition to the constant, the model includes a trend and an auto-regressive value (the interest rate differential lagged one day)¹⁴.

In principle we have four variants of the M-GARCH (1, 1) model.

Variant 1 is the separate estimation of the variance for each of the variables in the model:

$$H_{ij}(t) = c_{ij} + a_{ij} u_i(t-1) u_j(t-1) + b_{ij} H_{ij}(t-1), \quad (14)$$

¹⁴ See Engle, Lilien and Robins (1987) and Engle and Kroner (1993).

where $H_{ij}(t)$ represents the conditional matrix of the variances/covariances of the residuals.

Variant 2 takes into account a more important dynamic between the variances. This model requires a positive semi-defined matrix¹⁵:

$$H(t) = C'C + A'u(t-1)u'(t-1)A + B'H(t-1)B. \quad (15)$$

Variant 3 is based on the assumption that the covariance between the conditional variances of the residuals is null, which implies $a_{ij}=0$ and $b_{ij}=0$, with $i \neq j$ ¹⁶.

Finally, the fourth variant of the M-GARCH (1, 1) model is based on the assumption of constant correlation between the conditional variances, which allows to overcome the over-parameterisation problem¹⁷.

In accordance to the purpose of our study, the option was naturally for the use of the first two variants of the M-GARCH (1, 1) model, since we want to find the relationship between the conditional variances.

Table 2 presents the results of the correlation analysis between the estimated values of the conditional variances of the PTE/DM exchange rate and of the overnight interest rate differential, according to variant 1, for the whole period¹⁸.

**Table 2: Correlation between CVr_TxV_PTE/DM and CVr_(i-i*)_O
(Variant 1; Whole Period)**

Variable	Coefficient	Standard Error	T statistic	Significance
1- Constant	1,9783e-06	1,1429e-05	0,17310	0,863
2- Constant	6,2772e-03	4,7366e-04	13,25257	0,000
3- Trend	-1,9301e-06	1,3781e-07	-14,00585	0,000
4- (i-i*)_O 1	0,9567	4,7862e-03	199,88852	0,000
5- C (1, 1)	-5,7192e-11	0,0000	0,00000	0,000
6- C (2, 1)	-2,2643e-08	7,6961e-09	-2,94210	0,003
7- C (2, 2)	9,5160e-08	1,7838e-08	5,33458	0,000
8- A (1, 1)	0,0556	5,5260e-03	10,06433	0,000
9- A (2, 1)	9,2753e-03	0,0206	0,44953	0,653
10- A (2,2)	0,2894	0,0280	10,31747	0,000
11- B (1, 1)	0,9528	3,6375e-03	261,93571	0,000
12- B (2, 1)	-0,2363	0,5336	-0,44279	0,658
13- B (2, 2)	0,8041	0,0129	62,17371	0,000

Note: GARCH Model – BFGS Estimation; Observations used 2117; Convergence in 632 iterations;

Final criterion was 0,0000005 < 0,0000100; Log Likelihood 19183,473.

¹⁵ See Baba et al. (1990) and Engle and Kroner

(1993). ¹⁶ See Bollerslev et al. (1988).

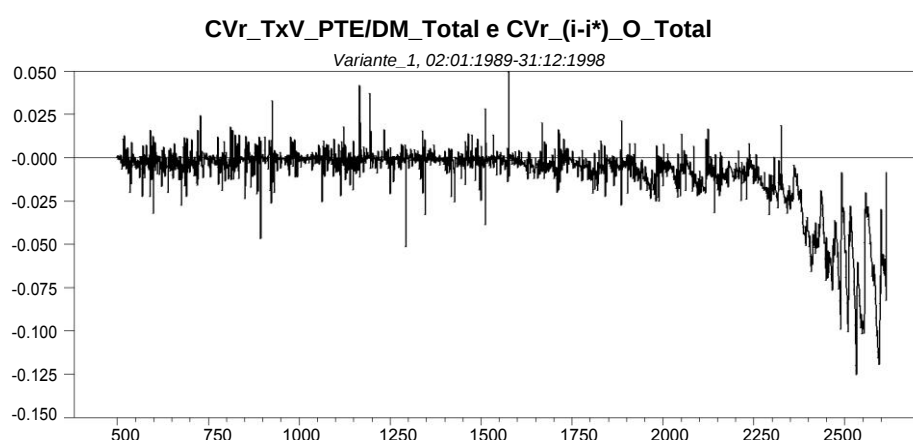
¹⁷ See Bollerslev (1990).

¹⁸ See Table A.1 in Appendix III for the interest rates with a maturity of 28 to 32 days.

The first constant relates to the PTE/DM exchange rate. The second constant and trend concern the overnight interest rate differential, followed by the values of the lagged coefficient of the interest rate differential. The constant in the variance equation is designated by C . The “ARCH” parameters (lagged squared residuals), in increasing lag order, are designated by A . The “GARCH” parameters (lagged variance), in increasing lag order, are designated by B .

The results of this analysis allow us to conclude that in at least one period there is a negative correlation between the estimated values of the conditional variances of the Portuguese escudo rate of change against the Deutschmark and the overnight interest rate differential. It is also worth mentioning that there is a trade-off between the PTE/DM exchange rate volatility and the overnight interest rate differential volatility. Figure 3 illustrates this.

Figure 3: Correlation between the Conditional Variances of the Exchange Rate and Overnight Interest Rate Differential (Variant 1; Whole Period)



The use of both variant 2 and the interest rate differential with a maturity of 28 to 32 days, led to similar results¹⁹. Possible explanations for this situation are the modernisation of the banking and financial system, and the progress made in terms of disinflation policy, which allowed the interest rate to serve as an alternative variable to the exchange rate in the adjustment process following a monetary shock, thereby facilitating the pursuit of the main objective of price stability. In this context, the participation of the Portuguese escudo in a target zone was crucial to create the conditions of stability, credibility, and confidence, necessary for the adoption of the single currency.

¹⁹ See Table A.2 in Appendix III. The remaining results, and their graphical analysis, may be obtained from the corresponding author on request (e-mail: portugal@fe.uc.pt).

4 – Conclusion

In this study we have analysed the participation of the Portuguese escudo in the ERM of the EMS according to the literature on target zones.

The analysis of the correlation coefficients between the estimated values of the conditional variances of the exchange rate and the interest rate differential under an M-GARCH model allowed the identification of a negative correlation between the two variables. This result reveals the presence of a trade-off between the exchange rate volatility and the interest rate differential volatility. This is particularly interesting given the presence of a negative trend in the interest rate differential which, instead of representing inefficient actions in the foreign exchange market, reveals the high degree of macroeconomic stability achieved in the Portuguese economy. The downward path eventually reflects the increased credibility of the conduct of monetary policy, allowing the continued pursuit of exchange rate stability, in the context of the ultimate objective of price stability.

The integration process of the Portuguese economy should therefore be used as an example by other small open economies in the sense that they may benefit from participating in one of the dominant monetary areas, otherwise they will be more exposed to speculative attacks, especially in the case of real appreciation of their currencies. But from eight years of EMU, winner members have to conduct solid real convergence policies. Overappreciation currencies can be fatal for new members.

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Appendix I – The Data

We used time series data with daily frequency in an attempt to cover the period from January 2, 1987 to December 31, 1998, which gives a total of 3130 potential observations. The observations corresponding to holidays and weekends were left out of the sample. In addition to the period when a target zone was officially functioning, between April 6 1992 and December 31 1998, we extended the analysis to a period in which Portugal adopted a crawling peg and a managed floating system, when the Portuguese escudo was pegged to the Deutschmark.

The exchange rate and interest rates data was taken from the Banco de Portugal (Long Series: Monetary and Financial Statistics of the Banco de Portugal) and the Bundesbank (Bundesbank Time Series Database). We used nominal exchange rates of the Portuguese escudo against the Deutschmark (PTE/DM). This exchange rate is computed by the Banco de Portugal as the average daily currency price. Interest rate data is available from January 2, 1989 and is measured as the average of the daily transactions held in the Money Market. Since we used daily data, we chose overnight interest rates and interest rates with a maturity of 28 to 32 days. Based on the examination of the evolution of the interest rates over time, we left out the outliers, defined as observations with values higher than 25% of the arithmetic average of the previous thirty observations relative to the observation under analysis. This methodology made the analysis of the volatility of the series feasible.

Unless otherwise stated, all the series have been transformed into natural logarithms. In the case of the interest rates, we used the natural logarithm of 1 plus the interest rate (%), divided by 100. In order to maximize the number of available observations, we were forced to extrapolate missing values whenever there were breaks in the series. The breaks occurred mainly in the Portuguese Money Market interest rates series with a maturity of 28 to 32 days. To compute the missing values, we used an extrapolation method based on an AR1 process with trend. The empirical analysis was applied to different sub-periods, also known as exchange rate regimes. We considered eleven exchange rate regimes:

Regime	Dates (Sub-periods)	Description	Potential Number of Observations
1	06:04:1992-31:12:1998	Whole Period in the ERM of the EMS	1759
2	06:04:1992-22:11:1992	Membership of the ERM - 1 st Realignment	165
3	23:11:1992-12:05:1993	1 st Realignment - 2 nd Realignment	123
4	13:05:1993-05:03:1995	2 nd Realignment - 3 rd Realignment	472
5	06:03:1995-31:12:1998	3 rd Realignment- EMU membership	999
6	06:04:1992-01:08:1993	Narrow band Period	345
7	02:08:1993-31:12:1998	Wide band Period	1414
8	06:04:1992-15:12:1992	Restrictions on Capital Mobility	182
9	16:12:1992-31:12:1998	Free Capital Mobility	1577
10	02:01:1987-30:09:1990	Portuguese Escudo Crawling Peg	976
10'	02:01:1989-30:09:1990	Portuguese Escudo Crawling Peg	455
11	01:10:1990-05:04:1992	Pegging of the PTE to the DM	395

Note: Exchange rate regime 10' presents a smaller number of observations since the interest rates database only contains 455 observations. When the analysis focused on the exchange rate we used the sample corresponding to exchange rate regime 10. When the analysis concerned both the exchange rate and the interest rates we used sample 10'.

The five observations immediately before and after the realignments and the date corresponding to the enlargement of the bands were excluded from the sample, in all the analyses. This was to avoid biases in the analysis. Most results were obtained using RATS 6.2²⁰.

²⁰ See www.estima.com, for RATS 6.2.

Appendix II – Variables Used in the Empirical Analysis

PTE/DM: Nominal exchange rate of the Portuguese escudo against the Deutschmark

C_PTE_DM: Official central parity of the Portuguese escudo against the Deutschmark

LI_PTE_DM: Official lower edge for PTE/DM

LS_PTE_DM: Official upper edge for PTE/DM

No_C_PTE_DM: Unofficial central parity of the Portuguese escudo against the Deutschmark

No_LI_PTE_DM_6: Unofficial lower edge for PTE/DM and an unofficial exchange rate band of $\pm 6\%$

No_LS_PTE_DM_6: Unofficial upper edge for PTE/DM and an unofficial exchange rate band of $\pm 6\%$

Dif_O: Differential between the Portuguese overnight interest rate and the German overnight interest rate (%)

Dif_28: Differential between the Portuguese interest rate with a maturity of 28 to 32 days and the German interest rate with a maturity of 28 to 32 days (%)

$(i-i^*)_O$: Differential between the Portuguese overnight interest rate and the German overnight interest rate (log)

$(i-i^*)_{28}$: Differential between the Portuguese interest rate with a maturity of 28 to 32 days and the German interest rate with a maturity of 28 to 32 days (log)

CVr_TxV_PTE/DM: Conditional variance of the rate of change of the Portuguese escudo against the Deutschmark

CVr $(i-i^*)_O$: Conditional variance of $(i-i^*)_O$

CVr $(i-i^*)_{28}$: Conditional variance of $(i-i^*)_{28}$

Appendix III – Tables

**Table A.1: Correlation between CVr_TxV_PTE/DM and CVr_(i-i*)_28
(Variant 1; Whole Period)**

Variable	Coefficient	Standard Error	T statistic	Significance
1- Constant	2,0383e-06	1,1434e-05	0,17826	0,859
2- Constant	3,3537e-03	4,9228e-04	6,81266	0,000
3- Trend	-1,0155e-06	1,4691e-07	-6,91256	0,000
4- (i-i*)_28 1	0,9707	4,3473e-03	223,28392	0,000
5- C (1, 1)	-5,8879e-11	1,1600e-10	-0,50756	0,612
6- C (2, 1)	-4,7243e-08	2,7780e-08	-1,70059	0,089
7- C (2, 2)	3,8869e-08	9,8079e-09	3,96301	0,000
8- A (1, 1)	0,0554	4,0697e-04	136,15167	0,000
9- A (2, 1)	-2,1731e-03	1,2178e-03	-1,78441	0,074
10- A (2,2)	0,1518	0,0144	10,53108	0,000
11- B (1, 1)	0,9530	1,0848e-03	878,46365	0,000
12- B (2, 1)	-0,9873	8,4243e-04	-1172,00597	0,000
13- B (2, 2)	0,8768	8,8324e-03	99,26874	0,000

Note: All Observations

GARCH Model – BFGS Estimation

Convergence in 119 iterations. Final Criterion was 0,00000072 < 0,0000100

Observations used 2117

Log Likelihood 20279,110

**Table A.2: Correlation between CVr_TxV_PTE/DM and CVr_(i-i*)_O
(Variant 2; Whole Period)**

Variable	Coefficient	Standard Error	T statistic	Significance
1- Constant	6,1536e-06	1,2324e-05	0,49932	0,618
2- Constant	5,4842e-03	4,8619e-04	11,28016	0,000
3- Trend	-1,6746e-06	1,4168e-07	-11,81932	0,000
4- (i-i*)_O 1	0,9604	4,8173e-03	199,36618	0,000
5- C (1, 1)	9,7106e-06	4,8309e-06	2,01009	0,044
6- C (2, 1)	-2,5792e-04	3,5794e-05	-7,20576	0,000
7- C (2, 2)	6,7666e-09	1,2683e-04	5,33520e-05	0,999
8- A (1, 1)	-0,1972	0,0100	-19,68569	0,000
9- A (1, 2)	-0,2280	0,0344	-6,62200	0,000
10- A (2,1)	0,0135	3,1292e-03	4,31864	0,001
11- A (2, 2)	-0,5225	0,0262	-19,95680	0,000
12- B (1, 1)	0,9821	1,4145e-03	694,32568	0,000
13- B (1, 2)	-0,0319	5,7684e-03	-5,52804	0,000
14- B (2, 1)	4,4883e-03	8,3214e-04	5,39371	0,000
15- B (2, 2)	0,9026	6,7621e-03	133,47746	0,000

Note: M-GARCH Model, BEKK – BFGS Estimation; Observations used 2117; Convergence in 94 iterations; Final Criterion was 0,0000044 < 0,0000100; Log Likelihood 19141,904.

Abstract

One of the main implications of the basic target zone model developed by Krugman (1991) is that there is a trade-off between exchange rate volatility and interest rate differential volatility. Using an M-GARCH model we find evidence that such a trade-off existed, prior to the introduction of the euro, between the exchange rate and the interest rate differential among Portugal and Germany. This result reflects the increased credibility of the Portuguese monetary policy, due mainly to the modernisation of the banking and financial system and to the progress made in the disinflation process under an exchange rate target zone.

JEL Classification: C32, C51, F31, F41, G15.

Key Words: Credibility, disinflation, M-GARCH, volatility and target zones.