ANTÓNIO PORTUGAL DUARTE, JOÃO SOUSA
ANDRADE & ADELAIDE DUARTE

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

ESTUDOS DO GEMF
N.º 01 2015
Is There a Trade-off between Exchange Rate and Interest Rate Volatility?

Evidence from an M-GARCH Model

António Portugal Duarte
(portugal@fe.uc.pt)
João Sousa Andrade
(jasa@fe.uc.pt)
Adelaide Duarte
(maduarte@fe.uc.pt)

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.
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 motion\(^1\).

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.

\(^1\) Details of this literature can be found in Magnier (1992), Svensson (1992a), Bertola (1994), Garber and Svensson (1995), Pansard (1997), Kempa and Nelles (1999) and Duarte, Andrade and Duarte (2013).
2. The Portuguese Exchange Rate Target Zone

On April 6 1992, the framework of the Portuguese 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 escudo was allowed to fluctuate within a band of ±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>
<thead>
<tr>
<th>Period / Date</th>
<th>Band</th>
<th>PTE/DM (a)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lower Edge (b)</td>
<td>Central Parity</td>
<td>Upper Edge (b)</td>
<td></td>
</tr>
<tr>
<td>6 April 1992 (c)</td>
<td>±6%</td>
<td>81.9</td>
<td>86.9393</td>
<td>92.336</td>
<td></td>
</tr>
<tr>
<td>23 November 1992 (d)</td>
<td>±6%</td>
<td>87.108</td>
<td>92.488</td>
<td>98.232</td>
<td></td>
</tr>
<tr>
<td>13 May 1993 (e)</td>
<td>±6%</td>
<td>93.197</td>
<td>98.9177</td>
<td>105.042</td>
<td></td>
</tr>
<tr>
<td>2 August 1993 (f)</td>
<td>±15%</td>
<td>85.179</td>
<td>98.9177</td>
<td>114.811</td>
<td></td>
</tr>
<tr>
<td>6 March 1995 (g)</td>
<td>±15%</td>
<td>88.277</td>
<td>102.505</td>
<td>119.033</td>
<td></td>
</tr>
</tbody>
</table>

Source: Banco de Portugal.

Note: (a) Portuguese escudos (PTE) necessary to buy one Deutschmark (DM).
(b) The lower (upper) edge represents the maximum appreciation (depreciation) permitted to the PTE.
(c) Membership of the PTE of the ERM of the EMS with a bandwidth of ±6%.
(d) Realignment in the EMS with a devaluation of 6% of the Spanish’s peseta and the PTE.
(e) Realignment in the EMS with a devaluation of 8% of the Spanish’s peseta and 6.5% of the PTE.
(f) Enlargement of the bands of the ERM to ±15%.
(g) Realignment in the EMS with a devaluation of 7% of the Spanish’s peseta and 3.5% of the PTE.

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 band\(^3\). Besides the target zone period, we simulated, from January 2 1987 to April 5 1992, an unofficial band of ±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 joining\(^4\).

\(^2\) We follow Duarte, Andrade and Duarte (2010: 263-5).
\(^3\) 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 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 realignments. After the widening of the bands, the exchange rate again stabilises, but now within the implicit band of ±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 competition. In comparison to other European countries, the costs of the disinflation process in Portugal seem relatively modest, at least at first. 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 conclusions. 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.

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:

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

where \( s(t) \) is the log of the nominal exchange rate at time \( t \), \( f(t) \) is the fundamental at time \( t \), \( \alpha \) 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 \( \mu \) and instantaneous standard deviation \( \sigma \):

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

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 walk.\(^9\)

\(^9\) We follow closely the presentation in Duarte, Andrade and Duarte (2014).

\(^{10}\) See Merton (1992), Campbell, Lo and Mackinlay (1997), Maddala and Kim (1999) and Demange and Rocher (2005).
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, \( ds(t) = df(t) \).

In a target zone, it is assumed that the intervention rule is based on a specific floating band for the fundamental, \( f_* \leq f(t) \leq f^* \), 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 deviation\(^{11}\):

\[
df(t) = \mu \, dt + \sigma \, dz(t) + dL(t) - dU(t),
\]

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 \( f(t) = f_* \), and \( dU(t) \) represents decreases in the money supply, positive if \( f(t) = f^* \). Under these circumstances, the exchange rate function establishes a non-linear relationship between the exchange rate and its fundamental, as illustrated in Figure 2.

The straight-line FF represents the equilibrium exchange rate in the free floating case. A shock in \( \nu(t) \) 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 \( s_* = s(f_*) \) and \( s^* = s(f^*) \), represented by the curves TZ, non-linear, and S-shape, respectively.

**Figure 2: Exchange Rate in a Perfectly Credible Target Zone**

\(^{11}\) Harrison (1985) and Karatzas and Shreve (1997) provide a formal presentation of these processes.
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 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 stabilising\(^\text{12}\).

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:

\[
V(t)[ds(t)] = \left[s'(f(t))\sigma\right]^2 dt ,
\]

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 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:

\[
i(t) - i^*(t) = E_s[ds(t)]/ dt .
\]

\(^{12}\) 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 \(b\).
Letting $\delta(t)$ denote the interest rate differential, we can combine (6) with equation (1) in order to represent the interest rate differential:

$$\delta(t) = \frac{s(t) - f(t)}{\alpha}.$$  \hfill (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:

$$d\delta(t) = \frac{\delta'(f(t))}{\alpha} dt + \delta'(f(t)) \sigma d\tilde{z}(t),$$ \hfill (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 differential\footnote{See Svensson (1991a, 1994).}.
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) model\textsuperscript{14}, 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:

\[ y_t = x_t \beta + u_t, \quad (9) \]

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

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

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

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:

\[ h_t = c_0 + a_1 u_{t-1}^2 + a_2 u_{t-2}^2 + \ldots + a_q u_{t-q}^2 + b_1 h_{t-1} + b_2 h_{t-2} + \ldots + b_p h_{t-p} = \]

\[ = c_0 + \sum_{i=1}^{q} a_i u_{t-i}^2 + \sum_{j=1}^{p} b_j h_{t-j}. \quad (12) \]

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)\(^{15}\).

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:

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

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 matrix\(^{16}\):

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

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 \( i \neq j \)\(^{17}\).

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 problem\(^{18}\).

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 period\(^{19}\).

---


\(^{16}\) See Baba et al. (1990) and Engle and Kroner (1993).

\(^{17}\) See Bollerslev et al. (1988).

\(^{18}\) See Bollerslev (1990).

\(^{19}\) See Table A.1 in Appendix III for the interest rates with a maturity of 28 to 32 days.
Table 2: Correlation between CVr_TxV_PTE/DM and CVr_(i-i*)_O  
(Variant 1; Whole Period)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>T statistic</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Constant</td>
<td>1.9783e-06</td>
<td>1.1429e-05</td>
<td>0.17310</td>
<td>0.863</td>
</tr>
<tr>
<td>2- Constant</td>
<td>6.2772e-03</td>
<td>4.7366e-04</td>
<td>13.25257</td>
<td>0.000</td>
</tr>
<tr>
<td>3- Trend</td>
<td>-1.9301e-06</td>
<td>1.3781e-07</td>
<td>-14.00585</td>
<td>0.000</td>
</tr>
<tr>
<td>4- (i-i*)_O {1}</td>
<td>0.9567</td>
<td>4.7862e-03</td>
<td>199.88852</td>
<td>0.000</td>
</tr>
<tr>
<td>5- C (1, 1)</td>
<td>-5.7192e-11</td>
<td>0.0000</td>
<td>0.00000</td>
<td>0.000</td>
</tr>
<tr>
<td>6- C (2, 1)</td>
<td>-2.2643e-08</td>
<td>7.6961e-09</td>
<td>-2.94210</td>
<td>0.003</td>
</tr>
<tr>
<td>7- C (2, 2)</td>
<td>9.5160e-08</td>
<td>1.7838e-08</td>
<td>5.33458</td>
<td>0.000</td>
</tr>
<tr>
<td>8- A (1, 1)</td>
<td>0.0556</td>
<td>5.5260e-03</td>
<td>10.06433</td>
<td>0.000</td>
</tr>
<tr>
<td>9- A (2, 1)</td>
<td>9.2753e-03</td>
<td>0.0206</td>
<td>0.44953</td>
<td>0.653</td>
</tr>
<tr>
<td>10- A (2,2)</td>
<td>0.2894</td>
<td>0.0280</td>
<td>10.31747</td>
<td>0.000</td>
</tr>
<tr>
<td>11- B (1, 1)</td>
<td>0.9528</td>
<td>3.6375e-03</td>
<td>261.93571</td>
<td>0.000</td>
</tr>
<tr>
<td>12- B (2, 1)</td>
<td>-0.2363</td>
<td>0.5336</td>
<td>-0.44279</td>
<td>0.658</td>
</tr>
<tr>
<td>13- B (2, 2)</td>
<td>0.8041</td>
<td>0.0129</td>
<td>62.17371</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Note: GARCH Model – BFGS Estimation; Observations used 2117; Convergence in 632 iterations; Final criterion was 0.0000005 < 0.0000100; Log Likelihood 19183.473.

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.

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

The use of both variant 2 and the interest rate differential with a maturity of 28 to 32 days, led to similar results\(^{20}\). 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.

### 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.

\(^{20}\) 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).
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 fifteen years of EMU, winner members have to conduct solid real convergence policies. Overappreciation currencies can be fatal for new members.

Acknowledgments

The authors are grateful for the financial support by Fundação para a Ciência e Tecnologia to Grupo de Estudos Monetários e Financeiros. Special thanks are due to Pedro Bação (FEUC) and Marta Simões (FEUC) for their helpful comments and suggestions.

References


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:

<table>
<thead>
<tr>
<th>Regime</th>
<th>Dates (Sub-periods)</th>
<th>Description</th>
<th>Potential Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>06:04:1992-31:12:1998</td>
<td>Whole Period in the ERM of the EMS</td>
<td>1759</td>
</tr>
<tr>
<td>5</td>
<td>06:03:1995-31:12:1998</td>
<td>3rd Realignment - EMU membership</td>
<td>999</td>
</tr>
<tr>
<td>6</td>
<td>06:04:1992-01:08:1993</td>
<td>Narrow band Period</td>
<td>345</td>
</tr>
<tr>
<td>7</td>
<td>02:08:1993-31:12:1998</td>
<td>Wide band Period</td>
<td>1414</td>
</tr>
<tr>
<td>10</td>
<td>02:01:1987-30:09:1990</td>
<td>Portuguese Escudo Crawling Peg</td>
<td>976</td>
</tr>
<tr>
<td>10’</td>
<td>02:01:1989-30:09:1990</td>
<td>Portuguese Escudo Crawling Peg</td>
<td>455</td>
</tr>
<tr>
<td>11</td>
<td>01:10:1990-05:04:1992</td>
<td>Pegging of the PTE to the DM</td>
<td>395</td>
</tr>
</tbody>
</table>

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 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 6.2\textsuperscript{21}.

**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 ±6%  
No_LS_PTE_DM_6: Unofficial upper edge for PTE/DM and an unofficial exchange rate band of ±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 \((i-i^*)_28\)

\textsuperscript{21} See www.estima.com, for RATS 6.2.
Appendix III – Tables

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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>T statistic</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Constant</td>
<td>2.0383e-06</td>
<td>1.1434e-05</td>
<td>0.17826</td>
<td>0.859</td>
</tr>
<tr>
<td>2- Constant</td>
<td>3.3537e-03</td>
<td>4.9228e-04</td>
<td>6.81266</td>
<td>0.000</td>
</tr>
<tr>
<td>3- Trend</td>
<td>-1.0155e-06</td>
<td>1.4691e-07</td>
<td>-6.91256</td>
<td>0.000</td>
</tr>
<tr>
<td>4- (i-i*)_28</td>
<td>0.9707</td>
<td>4.3473e-03</td>
<td>223.28392</td>
<td>0.000</td>
</tr>
<tr>
<td>5- C (1, 1)</td>
<td>-5.8879e-11</td>
<td>1.1600e-10</td>
<td>-5.05756</td>
<td>0.612</td>
</tr>
<tr>
<td>6- C (2, 1)</td>
<td>-4.7243e-08</td>
<td>2.7780e-08</td>
<td>-1.70059</td>
<td>0.089</td>
</tr>
<tr>
<td>7- C (2, 2)</td>
<td>3.8869e-08</td>
<td>9.8079e-09</td>
<td>3.96301</td>
<td>0.000</td>
</tr>
<tr>
<td>8- A (1, 1)</td>
<td>0.0554</td>
<td>4.0697e-04</td>
<td>136.15167</td>
<td>0.000</td>
</tr>
<tr>
<td>9- A (2, 1)</td>
<td>-2.1731e-03</td>
<td>1.2178e-03</td>
<td>-1.78441</td>
<td>0.074</td>
</tr>
<tr>
<td>10- A (2, 2)</td>
<td>0.1518</td>
<td>0.0144</td>
<td>10.53108</td>
<td>0.000</td>
</tr>
<tr>
<td>11- B (1, 1)</td>
<td>0.9530</td>
<td>1.0848e-03</td>
<td>878.46365</td>
<td>0.000</td>
</tr>
<tr>
<td>12- B (2, 1)</td>
<td>-0.9873</td>
<td>8.4243e-04</td>
<td>-1172.00597</td>
<td>0.000</td>
</tr>
<tr>
<td>13- B (2, 2)</td>
<td>0.8768</td>
<td>8.8324e-03</td>
<td>99.26874</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Note: i) All Observations; ii) GARCH Model – BFGS Estimation; iii) Convergence in 119 iterations. Final Criterion was 0.0000072 < 0.0000100; iv) Observations used 2117; v) Log Likelihood 20279.110.

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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>T statistic</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Constant</td>
<td>6.1536e-06</td>
<td>1.2324e-05</td>
<td>0.49932</td>
<td>0.618</td>
</tr>
<tr>
<td>2- Constant</td>
<td>5.4842e-03</td>
<td>4.8619e-04</td>
<td>11.28016</td>
<td>0.000</td>
</tr>
<tr>
<td>3- Trend</td>
<td>-1.6746e-06</td>
<td>1.4168e-07</td>
<td>-11.81932</td>
<td>0.000</td>
</tr>
<tr>
<td>4- (i-i*)_O</td>
<td>0.9604</td>
<td>4.8173e-03</td>
<td>199.36618</td>
<td>0.000</td>
</tr>
<tr>
<td>5- C (1, 1)</td>
<td>9.7106e-06</td>
<td>4.8309e-06</td>
<td>2.01009</td>
<td>0.044</td>
</tr>
<tr>
<td>6- C (2, 1)</td>
<td>-2.5792e-04</td>
<td>3.5794e-05</td>
<td>-7.20576</td>
<td>0.000</td>
</tr>
<tr>
<td>7- C (2, 2)</td>
<td>6.7666e-09</td>
<td>1.2683e-04</td>
<td>5.33520e-05</td>
<td>0.999</td>
</tr>
<tr>
<td>8- A (1, 1)</td>
<td>-0.1972</td>
<td>0.0100</td>
<td>-19.68569</td>
<td>0.000</td>
</tr>
<tr>
<td>9- A (1, 2)</td>
<td>-0.2280</td>
<td>0.0344</td>
<td>-6.62200</td>
<td>0.000</td>
</tr>
<tr>
<td>10- A (2, 1)</td>
<td>0.0135</td>
<td>3.1292e-03</td>
<td>4.31864</td>
<td>0.001</td>
</tr>
<tr>
<td>11- A (2, 2)</td>
<td>-0.5225</td>
<td>0.0262</td>
<td>-19.95680</td>
<td>0.000</td>
</tr>
<tr>
<td>12- B (1, 1)</td>
<td>0.9821</td>
<td>1.4145e-03</td>
<td>694.32568</td>
<td>0.000</td>
</tr>
<tr>
<td>13- B (1, 2)</td>
<td>-0.0319</td>
<td>5.7684e-03</td>
<td>-5.52804</td>
<td>0.000</td>
</tr>
<tr>
<td>14- B (2, 1)</td>
<td>4.4883e-03</td>
<td>8.3214e-04</td>
<td>5.39371</td>
<td>0.000</td>
</tr>
<tr>
<td>15- B (2, 2)</td>
<td>0.9026</td>
<td>6.7621e-03</td>
<td>133.47746</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Note: i) M-GARCH Model, BEKK – BFGS Estimation; ii) Observations used 2117; iii) Convergence in 94 iterations; iv) Final Criterion was 0.0000044 < 0.0000100; v) Log Likelihood 19141.904.
<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015-01</td>
<td>Is There a Trade-off between Exchange Rate and Interest Rate Volatility? Evidence from an M-GARCH Model</td>
<td>António Portugal Duarte, João Sousa Andrade &amp; Adelaide Duarte</td>
</tr>
<tr>
<td>2014-21</td>
<td>Estado Social, Quantis, Não-Linearidades e Desempenho Económico: Uma Avaliação Empírica</td>
<td>Adelaide Duarte, Marta Simões &amp; João Sousa Andrade</td>
</tr>
<tr>
<td>2014-19</td>
<td>Business Cycle Synchronization and Volatility Shifts</td>
<td>Pedro André Cerqueira</td>
</tr>
<tr>
<td>2014-16</td>
<td>Determinants of Subjective Well-Being in Portugal: A Micro-Data Study</td>
<td>Sara Ramos &amp; Elias Soukiazis</td>
</tr>
<tr>
<td>2014-13</td>
<td>Drivers for Household Electricity Prices in the EU: A System-GMM Panel Data Approach</td>
<td>Patricia Pereira da Silva &amp; Pedro Cerqueira</td>
</tr>
<tr>
<td>2014-11</td>
<td>Dealing with Technological Risk in a Regulatory Context: The Case of Smart Grids</td>
<td>Paulo Moisés Costa, Nuno Bento &amp; Vítor Marques</td>
</tr>
<tr>
<td>2014-10</td>
<td>Stochastic Volatility Estimation with GPU Computing</td>
<td>António Alberto Santos &amp; João Andrade</td>
</tr>
<tr>
<td>2014-09</td>
<td>The Impact of Expectations, Match Importance and Results in the Stock Prices of European Football Teams</td>
<td>Pedro Godinho &amp; Pedro Cerqueira</td>
</tr>
<tr>
<td>2014-07</td>
<td>The Role of Gender in Promotion and Pay over a Career</td>
<td>John T. Addison, Orgul D. Ozturk &amp; Si Wang</td>
</tr>
<tr>
<td>2014-06</td>
<td>Output-gaps in the PIIGS Economies: An Ingredient of a Greek Tragedy</td>
<td>João Sousa Andrade &amp; António Portugal Duarte</td>
</tr>
</tbody>
</table>
2014-04 Agriculture in Portugal: Linkages with Industry and Services
- João Gaspar, Gilson Pina & Marta C. N. Simões

2014-03 Effects of Taxation on Software Piracy Across the European Union
- Nicolas Dias Gomes, Pedro André Cerqueira & Luís Alçada Almeida

2014-02 A Crise Portuguesa é Anterior à Crise Internacional
- João Sousa Andrade

2014-01 Collective Bargaining and Innovation in Germany: Cooperative Industrial Relations?
- John T. Addison, Paulino Teixeira, Katalin Evers & Lutz Bellmann

2013-27 Market Efficiency, Roughness and Long Memory in the PSI20 Index Returns: Wavelet and Entropy Analysis
- Rui Pascoal & Ana Margarida Monteiro

- Carlos Carreira & Filipe Silva

2013-25 A Política Orçamental em Portugal entre Duas Intervenções do FMI: 1986-2010
- Carlos Fonseca Marinheiro

- Pedro Brinca

2013-23 Learning, Exporting and Firm Productivity: Evidence from Portuguese Manufacturing and Services Firms
- Carlos Carreira

2013-22 Equity Premia Predictability in the EuroZone
- Nuno Silva

2013-21 Human Capital and Growth in a Services Economy: the Case of Portugal
- Marta Simões & Adelaide Duarte

2013-20 Does Voter Turnout Affect the Votes for the Incumbent Government?
- Rodrigo Martins & Francisco José Veiga

2013-19 Determinants of Worldwide Software Piracy Losses
- Nicolas Dias Gomes, Pedro André Cerqueira & Luís Alçada Almeida

2013-18 Despesa Pública em Educação e Saúde e Crescimento Económico: Um Contributo para o Debate sobre as Funções Sociais do Estado
- João Sousa Andrade, Marta Simões & Adelaide P. S. Duarte

2013-17 Duration dependence and change-points in the likelihood of credit booms ending
- Vítor Castro & Megumi Kubota

2013-16 Job Promotion in Mid-Career: Gender, Recession and ‘Crowding’
- John T. Addison, Orgul D. Ozturk & Si Wang

- Jorge Marques

2013-14 The Effects of Internal and External Imbalances on Italy’s Economic Growth. A Balance of Payments Approach with Relative Prices No Neutral.
- Elías Soukiazis, Pedro André Cerqueira & Micaela Antunes

2013-13 A Regional Perspective on Inequality and Growth in Portugal Using Panel Cointegration Analysis
- Marta Simões, João Sousa Andrade & Adelaide Duarte

2013-12 Macroeconomic Determinants of the Credit Risk in the Banking System: The Case of the GIPSI
- Vítor Castro

2013-11 Majority Vote on Educational Standards
- Robert Schwager

- Adelaide Duarte, Marta Simões & João Sousa Andrade

2013-09 What Determines the Duration of a Fiscal Consolidation Program?
- Luca Agnello, Vítor Castro & Ricardo M. Sousa
Minimum Wage Increases in a Recessionary Environment
- John T. Addison, McKinley L. Blackburn & Chad D. Cotti

The International Monetary System in Flux: Overview and Prospects
- Pedro Bação, António Portugal Duarte & Mariana Simões

Are There Change-Points in the Likelihood of a Fiscal Consolidation Ending?
- Luca Agnello, Vítor Castro & Ricardo M. Sousa

The Dutch Disease in the Portuguese Economy
- João Sousa Andrade & António Portugal Duarte

Is There Duration Dependence in Portuguese Local Governments’ Tenure?
- Vítor Castro & Rodrigo Martins

Testing for Nonlinear Adjustment in the Portuguese Target Zone: Is there a Honeymoon Effect?
- António Portugal Duarte, João Soares da Fonseca & Adelaide Duarte

Portugal Before and After the European Union
- Fernando Alexandre & Pedro Bação

The International Integration of the Eastern Europe and two Middle East Stock Markets
- José Soares da Fonseca

Are Small Firms More Dependent on the Local Environment than Larger Firms? Evidence from Portuguese Manufacturing Firms
- Carlos Carreira & Luís Lopes

Macroeconomic Factors of Household Default. Is There Myopic Behaviour?
- Rui Pascoal

Can German Unions Still Cut It?
- John Addison, Paulino Teixeira, Jens Stephani & Lutz Bellmann

Financial Constraints: Do They Matter to R&D Subsidy Attribution?
- Filipe Silva & Carlos Carreira

Worker Productivity and Wages: Evidence from Linked Employer-Employee Data
- Ana Sofia Lopes & Paulino Teixeira

Slovak Economic Growth and the Consistency of the Balance-of-Payments Constraint Approach
- Elias Soukiazis & Eva Muchova

The Importance of a Good Indicator for Global Excess Demand
- João Sousa Andrade & António Portugal Duarte

Measuring Firms’ Financial Constraints: A Rough Guide
- Filipe Silva & Carlos Carreira

Convergence and Growth: Portugal in the EU 1986-2010
- Marta Simões, João Sousa Andrade & Adelaide Duarte

Where Are the Fragilities? The Relationship Between Firms’ Financial Constraints, Size and Age
- Carlos Carreira & Filipe Silva

An European Distribution of Income Perspective on Portugal-EU Convergence
- João Sousa Andrade, Adelaide Duarte & Marta Simões

Financial Crisis and Domino Effect
- Pedro Bação, João Maia Domingues & António Portugal Duarte

Non-market Recreational Value of a National Forest: Survey Design and Results
- Paula Simões, Luís Cruz & Eduardo Barata

Growth rates constrained by internal and external imbalances and the role of relative prices: Empirical evidence from Portugal
- Elias Soukiazis, Pedro André Cerqueira & Micaela Antunes

Is the Erosion Thesis Overblown? Evidence from the Orientation of Uncovered Employers
- John Addison, Paulino Teixeira, Katalin Evers & Lutz Bellmann

Explaining the interrelations between health, education and standards of living in Portugal. A simultaneous equation approach
- Ana Poças & Elias Soukiazis
2012-05  Turnout and the Modeling of Economic Conditions: Evidence from Portuguese Elections  
   - Rodrigo Martins & Francisco José Veiga

2012-04  The Relative Contemporaneous Information Response. A New Cointegration-Based Measure of Price Discovery  
   - Helder Sebastião

   - Elias Soukiazis, Pedro Cerqueira & Micaela Antunes

2012-02  As Ações Portuguesas Seguem um Random Walk? Implicações para a Eficiência do Mercado e para a Definição de Estratégias de Transação  
   - Ana Rita Gonzaga & Helder Sebastião

2012-01  Consuming durable goods when stock markets jump: a strategic asset allocation approach  
   - João Amaro de Matos & Nuno Silva

2011-21  The Portuguese Public Finances and the Spanish Horse  
   - João Sousa Andrade & António Portugal Duarte

2011-20  Fitting Broadband Diffusion by Cable Modem in Portugal  
   - Rui Pascoal & Jorge Marques

2011-19  A Poupança em Portugal  
   - Fernando Alexandre, Luís Aguiar-Conraria, Pedro Bação & Miguel Portela

2011-18  How Does Fiscal Policy React to Wealth Composition and Asset Prices?  
   - Luca Agnello, Vitor Castro & Ricardo M. Sousa

2011-17  The Portuguese Stock Market Cycle: Chronology and Duration Dependence  
   - Vitor Castro

2011-16  The Fundamentals of the Portuguese Crisis  
   - João Sousa Andrade & Adelaide Duarte

2011-15  The Structure of Collective Bargaining and Worker Representation: Change and Persistence in the German Model  
   - John T. Addison, Paulino Teixeira, Alex Bryson & André Pahnke

2011-14  Are health factors important for regional growth and convergence? An empirical analysis for the Portuguese districts  
   - Ana Poças & Elias Soukiazis

2011-13  Financial constraints and exports: An analysis of Portuguese firms during the European monetary integration  
   - Filipe Silva & Carlos Carreira

2011-12  Growth Rates Constrained by Internal and External Imbalances: a Demand Orientated Approach  
   - Elias Soukiazis, Pedro Cerqueira & Micaela Antunes

2011-11  Inequality and Growth in Portugal: a time series analysis  
   - João Sousa Andrade, Adelaide Duarte & Marta Simões

2011-10  Do financial Constraints Threat the Innovation Process? Evidence from Portuguese Firms  
   - Filipe Silva & Carlos Carreira

2011-09  The State of Collective Bargaining and Worker Representation in Germany: The Erosion Continues  
   - John T. Addison, Alex Bryson, Paulino Teixeira, André Pahnke & Lutz Bellmann

2011-08  From Goal Orientations to Employee Creativity and Performance: Evidence from Frontline Service Employees  
   - Filipe Coelho & Carlos Sousa

2011-07  The Portuguese Business Cycle: Chronology and Duration Dependence  
   - Vitor Castro

2011-06  Growth Performance in Portugal Since the 1960’s: A Simultaneous Equation Approach with Cumulative Causation Characteristics  
   - Elias Soukiazis & Micaela Antunes

2011-05  Heteroskedasticity Testing Through Comparison of Wald-Type Statistics  
   - José Murteira, Esmeralda Ramalho & Joaquim Ramalho
2011-04  Accession to the European Union, Interest Rates and Indebtedness: Greece and Portugal
- Pedro Bação & António Portugal Duarte

2011-03  Economic Voting in Portuguese Municipal Elections
- Rodrigo Martins & Francisco José Veiga

2011-02  Application of a structural model to a wholesale electricity market: The Spanish market from January 1999 to June 2007
- Vítor Marques, Adelino Fortunato & Isabel Soares

2011-01  A Smoothed-Distribution Form of Nadaraya-Watson Estimation
- Ralph W. Bailey & John T. Addison

A série Estudos do GEMF foi iniciada em 1996.