Censured Exchange Rates in a Discrete Time Target Zones Model: The Spanish Peseta/Deutsche Mark Case

M. Isabel Campos, Julio Herrera and Zenón Jiménez-Ridruejo[∗][†]
University of Valladolid (Spain)

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Abstract

The literature on "Target Zones" is characterized by a continuous stochastic time modelization, where the exchange rate is a non-censured dependent variable. In this paper we propose a discrete time target zones model, taking into account the censured disposition of the exchange rate, whose parameters will be estimated by the FIML method. The settled theoretical model is a simplified version of Dornbusch´s (1976) model, applied in a two countries environment. It will be tested into a peseta/deutsche mark exchange rate frame, from june 1989 to may 1998. The period is split in two sub-samples thinking over the enlargement of bands decided in august 1993. The estimation procedure of the model is based on the limited dependent rational expectation technique developed by Pesaran and Ruge-Murcia (1999). The results point out weightily differences between the two considered sample periods.

Keywords: Target Zones, LD-RE Models, Credibility, Realignment Probability

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[∗]Departament of Foundations of the Economic Analysis. Economic and Business Faculty (University of Valladolid). Avda Valle Esgueva, 6, 47.011-Valladolid- (Spain). Tf: +34 983 423382. Fax: +34 983 423299. E-mail: maribel@eco.uva.es; jherrera@eco.uva.es; zenon@eco.uva.es

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1 Introduction

The recently developed literature known as "Target Zones" since the initial papers by Flood and Garber (1983), Williamson and Miller (1987), or the well-known Krugman's (1991) paper, models, in continuous time, the exchange rate behavior inside a floating band. The basic idea of these models can be represented in figure 1, and point out the fact that the band, if credible, plays a stabilizing effect [the "honeymoon effect"] on the exchange rate which exhibits less variability than in the free float case [line FF in figure 1]. The stabilizing effect comes from the monetary authority, who will intervene when necessary [with marginal or intramarginal intervention], or from the moderation effect that the band implies on exchange rate expectations. In a simple two countries monetary model, in continuous time,the typical expression for the exchange rate behavior is the following:

$$e_t = e(h_t) = h_t + c\, E_t(de_t/dt) \tag{1.1}$$

where e_t is the log of exchange rate, h_t represents the "fundamentals" or basic variables that determine e_t, c is the semi-elasticity of money demand with respect to interest rate, and $E_t\,(de_t/dt)$ is the expected variation of exchange rate in period t. The fundamentals are given by the following stochastic process:

$$dh_t = dm_t + d\phi_t \tag{1.2}$$

where dm_t represents the monetary authorities intervention in the exchange rate market and ϕ_t is a shock on the velocity of money. This money velocity is modeled according to a brownian movement with drift expressed as:

$$d\phi_t = \alpha\, dt + \sigma\, d\omega_t; \qquad \alpha > 0 \tag{1.3}$$

the drift α represents the trend movements in ϕ_t, and, as a result of h_t. ω_t is modeled as a Wiener process that, in general, is described by $\omega_t \sim N(0; \sigma_t^2)$.

To solve the equation (1:1) we must use the Ito lema. The expected exchange rate depreciation rate is:

$$E_t\,(de_t/dt) = \alpha\, e'\,(h_t) + \frac{\sigma^2}{2}\, e''\,(h_t) \tag{1.4}$$

where e' and e'' represent the first and second derivatives of the function "$e(h_t)$" respectively.

Substituting (1:4) into (1:1) we obtain:

$$e_t = e(h_t) = h_t + c\left\{\alpha e'(h_t) + \frac{\sigma^2}{2} e''(h_t)\right\} \tag{1.5}$$

The general solution of this equation is:

$$e_t = h_t + c\alpha + M_1 \exp(\lambda_1 h_t) + M_2 \exp(\lambda_2 h_t) \tag{1.6}$$

where M_1 and M_2 represent the integral constants, and λ_1 and λ_2 are the roots of the characteristic equation:

$$\frac{c\sigma^2}{2}\lambda^2 + c\alpha\lambda - 1 = 0 \tag{1.7}$$

Once solved, we obtain:

$$\lambda_1 = -\frac{\left\{\left[\alpha^2 + \frac{2\sigma^2}{c}\right]^{1/2} + \alpha\right\}}{\sigma^2} < 0 \tag{1.8.a}$$

$$\lambda_2 = \frac{\left\{\left[\alpha^2 + \frac{2\sigma^2}{c}\right]^{1/2} - \alpha\right\}}{\sigma^2} > 0 \tag{1.8.b}$$

To get a concrete value of integral constants M_1 and M_2 that determine the SS curve, and to get a unique solution, this curve must be tangent to the edges of the band, as the slope of the curve tends to zero in the edges of the band. This result represents the Dornbusch's condition of "smooth pasting". The smooth pasting is a concept taken from options theory, which, in this case, can be expressed as:[1]

$$e'(h_{max}) = 0 \qquad \text{when} \qquad e_{max} = e(h_{max}) \tag{1.9.a}$$

[1] [34, Vid. Sodal, 1998]

$$e'(h_{min}) = 0 \qquad \text{when} \qquad e_{min} = e(h_{min}) \tag{1.9.b}$$

and implies the following system of equations when can solve M_1 and M_2:

$$1 + M_1 \lambda_1 \exp(\lambda_1 h_{min}) + M_2 \lambda_2 \exp(\lambda_2 h_{min}) = 0 \tag{1.10.a}$$

$$1 + M_1 \lambda_1 \exp(\lambda_1 h_{max}) + M_2 \lambda_2 \exp(\lambda_2 h_{max}) = 0 \tag{1.10.b}$$

The solution is:

$$e_t = e(h_t) = h_t + c\alpha + N \tag{1.11}$$

where:

$$N = \frac{\{\lambda_2 \exp(\lambda_2 h_{max} + \lambda_1 h_t) - \lambda_2 \exp(\lambda_2 h_{min} + \lambda_1 h_t)\}}{\lambda_1 \lambda_2 \exp(\lambda_2 h_{min} + \lambda_1 h_{max}) - \lambda_1 \lambda_2 \exp(\lambda_2 h_{max} + \lambda_1 h_{min})} +$$

$$+ \frac{\{\lambda_1 \exp(\lambda_1 h_{min} + \lambda_2 h_t) - \lambda_1 \exp(\lambda_1 h_{max} + \lambda_2 h_t)\}}{\lambda_1 \lambda_2 \exp(\lambda_2 h_{min} + \lambda_1 h_{max}) - \lambda_1 \lambda_2 \exp(\lambda_2 h_{max} + \lambda_1 h_{min})}$$

The graphic representation [figure 1] is a curve with "S" shape that implies a reduction in exchange rate volatility as far as the exchange rate gets closer to the edges of the band.

One of the aspects deeply studied by target zones literature has been the evaluation of credibility degree of the target zone.[2]

There are different methodologies to estimate the expected depreciation of exchange rate in a target zone. They use a mix of assumptions like perfect and imperfect target zone credibility and/or infinitesimal or marginal, or intramarginal intervention.[3] The common characteristic of all of them is the

[2] Vid: the survey by Gámez and Torres (1996)

[3] From the so called "Basic Model" developed by Krugman (1991), taking into account the poor results of his empirical tests, several ways of development have arised out addressed to improve the flexibility of the assumptions about perfect credibility of the bands and infinitesimal intervention. Vid: Bertola and Caballero (1992.a, 1992.b), Svensson (1991), Bertola and Svensson (1993), Svensson (1992) or Tristani (1994), among others.

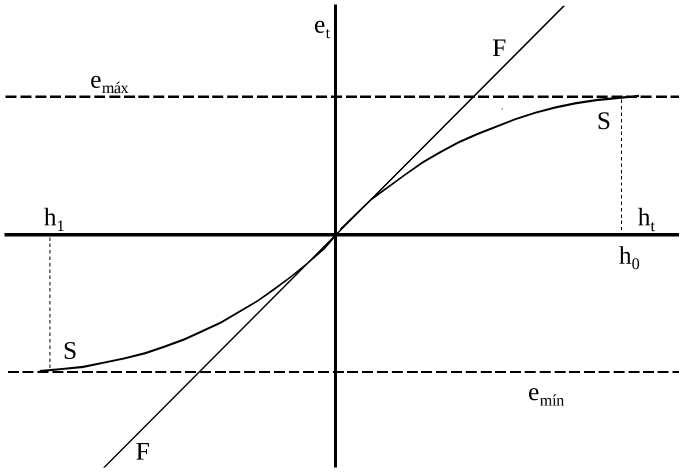


Figure 1: The exchange rate in a target zone with infinitesimal intervention and full credibility.

introduction of a stochastic continuous time modelling, taking the exchange rate like a no-censured dependent variable.[4]

However, the limited nature of exchange rate can't be ignored in a system when that variable is submitted to the edges of the band, neither can be ignored the fact that economic agents includes in their expectations such limited nature; as this aspect can, on some way, influence on the estimation an significance level of studies on the target zone subject. We propose a model of target zone in discrete time where we take into account the censored nature of the exchange rate an in which the parameters of the model will be estimated by maximum likelihood.

There are a lot of papers about the econometric estimation of models with censured dependent variables.[5] This work developed from initial paper by Tobin

[4] Since the edition of Bertola and Svensson (1993) paper, a lot of new methods have been developed to pull up information about market expectations. We can emphasize the papers by Mizrach (1995), Ayuso and Pérez Jurado (1997), Gómez Puig and Montalvo (1997), Söderlind and Svensson (1997) or Bekaert and Gray (1998), which detail target zones models with stochastic devaluation jumps, constants or variables along time.

[5] A model with truncate dependent variables is identified by the presence of unknown

(1958), who suggested an iterative process to solve this kind of equations and to estimate by maximum likelihood. This work was followed by the papers by Chanda and Maddala (1983), Shonkweiler and Maddala (1985), Pesaran (1989) or Holt and Johnson (1989). Recent developments can be encountered in the papers by Pesaran and Samiei (1992.a, 1992.b, 1995), Donald and Maddala (1992), Lee (1994) or Pesaran and Ruge-Murcia (1996, 1998).

The theoretical model of exchange rate determination that we use in this paper is a extension of Dornbusch (1976) model for two countries, and it is estimated for the Spanish peseta/German mark exchange rate from June 1989 to May 1998. We divide the time period in two subperiods due to the ampliation of band. This is the case of peseta/mark exchange rate: the exchange rate band with was initially §6% and evolved to a §15% on August 2nd 1993. The estimated technique we are going to use in the paper is the formulated by Pesaran and Ruge-Murcia (1999) to …nd a unique solution to limited dependent variable model, subject to stochastic jumps in the target zone.

2 The LD-RE[6] Exchange Rate Determination Model

2.1 The Theoretical Model

The model of exchange rate determination that we use in the paper is a dynamic exchange rate model with two countries and predetermined prices. This model is a extension of Dornbusch's (1976) model, adding variable output and without considering that the economy is always in the potential output. We include in the model a equation explaining prices adjustment. The money supplies are endogenously determined. Following Papell (1984.a, 1984.b), the

observations that are placed out of a speci…c rank. On the other hand, the observational character of the exogenous variables can describe a model with censured variables. [1, Vid: Amemiya, 1984]

[6] "Limited Dependent Rational Expectations Model"

equations are the following:

$$\left.\begin{array}{l} m_t - p_t = -\alpha_1 r_t + \alpha_2 y_t + \varepsilon_{0t} \\ m_t^* - p_t^* = -\alpha_1 r_t^* + \alpha_2 y_t^* + \varepsilon_{0t}^* \end{array}\right\} \text{ Substracting both equations, we get:}$$

$$(m_t - m_t^*) = (p_t - p_t^*) - \alpha_1 (r_t - r_t^*) + \alpha_2 (y_t - y_t^*) + \nu_{0t} \qquad (2.1.1)$$

that represents money market equilibrium.

The output in a time period could be different to full employment level and the adjustment equation, expressed for each country, is:

$$\left.\begin{array}{l} y_t = \alpha_0 + \alpha_3 (e_t - p_t + p_t^*) - \alpha_4 i_t + \varepsilon_{1t} \\ y_t^* = \alpha_0^* + \alpha_3^* (e_t - p_t + p_t^*) - \alpha_4 i_t^* + \varepsilon_{1t}^* \end{array}\right\} \text{ Substracting both equations, we get:}$$

$$(y_t - y_t^*) = (\alpha_0 - \alpha_0^*) - \alpha_4 (i_t - i_t^*) + \alpha_5 (e_t - p_t + p_t^*) + \nu_{1t} \qquad (2.1.2)$$

The prices are predetermined and respond to excess of demand by:

$$\left.\begin{array}{l} p_{t+1} - p_t = \alpha_6 (y_t - \bar{y}) + \varepsilon_{2t} \\ p_{t+1}^* - p_t^* = \alpha_6 (y_t^* - \bar{y}^*) + \varepsilon_{2t}^* \end{array}\right\} \text{ Substracting both equations, we get:}$$

$$\left[\left(p_{t+1} - p_{t+1}^*\right) - (p_t - p_t^*)\right] = \alpha_6 (y_t - y_t^*) - \alpha_6 (\bar{y} - \bar{y}^*) + \nu_{2t} \qquad (2.1.3)$$

The following equation express the conditions of UIP to exchange rate:

$$E_t (e_{t+1}/I_t) - e_t = (r_t - r_t^*) + PR_t \qquad (2.1.4)$$

The real interest rate follows the Fisher equation for each country:

$$\left.\begin{array}{l} i_t = r_t - (p_{t+1} - p_t) \\ i_t^* = r_t^* - \left(p_{t+1}^* - p_t^*\right) \end{array}\right\} \text{ Substracting both equations, we get:}$$

$$(i_t - i_t^*) = (r_t - r_t^*) - \left[\left(p_{t+1} - p_{t+1}^*\right) - (p_t - p_t^*)\right] \qquad (2.1.5)$$

where $\begin{cases} \nu_{0t} = \varepsilon_{0t} - \varepsilon^*_{0t} \\ \alpha_5 = \alpha_3 + \alpha^*_3 \\ \nu_{1t} = \varepsilon_{1t} - \varepsilon^*_{1t} \\ \nu_{2t} = \varepsilon_{2t} - \varepsilon^*_{2t} \end{cases}$

The equations of money and good markets equilibrium are standard. Equation (2:1:1) represents the money market equilibrium with predetermined prices in the short run, where y_t is the log of output, r_t is the nominal interest rate, p_t is the log of prices, ε_{jt} is a error term [shock] and the asterisk denotes foreign country.

Equation (2:1:2) represents aggregate demand function. In the case of predetermined prices we assume that in the short run the output is demand determined.[7] The aggregate demand depends on real exchange rate, $(e_t - p_t + p^*_t)$, and on the real interest rate i_t.[8]

Equation (2:1:4) is the UIP condition where e_t is the log of exchange rate, I_t is a information set used by economic agents in period t, and PR_t is the risk premium. With perfect capital mobility, the UIP condition implies that interest rates differential plus the risk premium equals the expected depreciation of exchange rate.

The last equation (2:1:5) express the Fisher condition under the assumption of predetermined prices.

To get the equation that describes the equilibrium level of exchange rate, first, we substitute (2:1:5) into (2:1:2) and we obtain:

$$\left\{\left(p_{t+1} - p^*_{t+1}\right) - (p_t - p^*_t)\right\} = \frac{1}{\alpha_4}(y_t - y^*_t) - \frac{1}{\alpha_4}(\alpha_0 - \alpha^*_0) -$$

$$- \frac{\alpha_5}{\alpha_4}(e_t - p_t + p^*_t) - (r_t - r^*_t) - \nu_{1t} \qquad (2.1.6)$$

[7] The seminal Dornbusch (1976) model would suppose that the production is placed always at the full employment level.

[8] This function can be modelled including the real interest rate instead of the nominal one. [23, Vid: Mathieson, 1977] and [3, Vid: Bhandari, 1982]

Substituting (2:1:6) into (2:1:3), we get:

$$(p_t - p_t^*) = \frac{1}{\alpha_5}(\alpha_0 - \alpha_0^*) - \left(\frac{1 - \alpha_6\alpha_4}{\alpha_5}\right)(y_t - y_t^*) + e_t + \frac{\alpha_4}{\alpha_5}(r_t - r_t^*) +$$

$$+\frac{\alpha_6\alpha_4}{\alpha_5}(\bar{y} - \bar{y}^*) + \frac{\alpha_4}{\alpha_5}(\upsilon_{1t} + \upsilon_{2t}) \qquad (2.1.7)$$

Mixing the expressions (2:1:7) and (2:1:4), and substituting into (2:1:1) we get the equation that describes the evolution of exchange rate as a function of its fundamentals like:

$$e_t = \left\{\frac{(\alpha_0 - \alpha_0^*)}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)} + \frac{\alpha_6\alpha_4}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)}(\bar{y} - \bar{y}^*)\right\} +$$

$$+ \left\{\frac{(\alpha_4 - \alpha_1\alpha_5)}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)}\right\} E_t(e_{t+1}/I_t) - \left\{\frac{\alpha_5}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)}\right\}(m_t - m_t^*) +$$

$$+ \left\{\frac{(\alpha_2\alpha_5 - 1 + \alpha_4\alpha_6)}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)}\right\}(y_t - y_t^*) + \left\{\frac{(\alpha_4 - \alpha_1\alpha_5)}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)}\right\} PR_t +$$

$$+ \left\{\frac{\alpha_5}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)}\right\}\upsilon_{0t} + \left\{\frac{\alpha_4}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)}\right\}(\upsilon_{1t} + \upsilon_{2t}) -$$

$$- \left\{\frac{(\alpha_1\alpha_5 - \alpha_4)}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)}\right\}\mu_{3t} \qquad (2.1.8)$$

To simplifying, the notation, we call:

$$\beta_0 = \frac{(\alpha_0 - \alpha_0^*) + \alpha_6\alpha_4(\bar{y} - \bar{y}^*)}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)}$$

$$\beta_1 = \frac{(\alpha_4 - \alpha_1\alpha_5)}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)}$$

$$\beta_2 = \frac{\alpha_5}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)}$$

$$\beta_3 = \frac{(\alpha_2\alpha_5 - 1 + \alpha_4\alpha_6)}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)}$$

$$\varepsilon_t = \frac{\alpha_5 \upsilon_{0t} + \alpha_4 (\upsilon_{1t} + \upsilon_{2t}) - (\alpha_1\alpha_5 - \alpha_4)\, \mu_{3t}}{(\alpha_4 - \alpha_1\alpha_5 - \alpha_5)}$$

and we get the following expression:

$$e_t = \beta_1 E_t (e_{t+1}/I_t) + \chi h_t + \varepsilon_t \qquad (2.1.9)$$

* $\chi = [\beta_0; -\beta_2; \beta_3; \beta_1]$ is a 1 x 4 vector of coefficients

where: $h_t' = [1; (m_t - m_t^*); (y_t - y_t^*); PR_t]$ such h_t is a 4 x 1 vector of fundamentals

In a target zone regime there are a maximum and a minimum limits that the exchange rate can get with respect to the central parity, o_t, that we call e_{max} and e_{min}.respectively. Without generality lost, we can assume that the band is symmetric. Let ρ be the band width.

In this case, we can assume that the exchange rate is described by the following non lineal process:

$$e_t = \begin{cases} e_{max;t} & \text{if} \quad \beta_1 E_t (e_{t+1}/I_t) + \chi h_t + \varepsilon_t \geq e_{max;t} \\ e_t^* & \text{if} \quad e_{min;t} < \beta_1 E_t (e_{t+1}/I_t) + \chi h_t + \varepsilon_t < e_{max;t} \\ e_{min;t} & \text{if} \quad \beta_1 E_t (e_{t+1}/I_t) + \chi h_t + \varepsilon_t \leq e_{min;t} \end{cases} \qquad (2.1.10)$$

where:

$$e_t^* = \beta_1 E_t (e_{t+1}/I_t) + \chi h_t + \varepsilon_t$$

$$e_{max;t} = o_t + \frac{\rho}{2}; \; y \; e_{min;t} = o_t - \frac{\rho}{2}$$

The solve this equation we must take expectations over a infinitive sequential of censored variables, analytically described by a infinite set of integrals and unsolved mathematically.[9] To obtain a unique and stable solution to our model we use the approach proposed by Pesaran and Ruge-Murcia (1999) and it is

[9] This aspect was studied by Pesaran and Samiei (1995) finding a exact solution in a LD-RE model with perfect credibility of the band and h_t composed by variables serially independents.

based on previous works done by Pesaran and Samiei (1992.a, 1992.b). In the appendix of their paper, Pesaran and Ruge-Murcia shown that the stable solution to a mathematical model with future expectation is equivalent to a model with current expectations.

The solution to the model with current expectations and target zones force us to reformulate equation (2.1.9) as follows:

$$e_t = \beta_1 E_{t-1}(e_t / I_{t-1}) + \delta f_t + \varepsilon_t \tag{2.1.11}$$

where δ is a 1 x n vector of parameters and $f_t = [h_t, \Delta h_{t-1}, \ldots]$ is a n x 1 vector of fundamentals.

Starting from equation (2.1.11) we can express the exchange rate in a target zone as:

$$e_t = \begin{cases} e_{max,t} & \text{if} \quad \hat{e}_t \geq e_{max,t} \\ \hat{e}_t & \text{if} \quad e_{min,t} < \hat{e}_t < e_{max,t} \\ e_{min,t} & \text{if} \quad \hat{e}_t \leq e_{min,t} \end{cases} \tag{2.1.12}$$

where:

$$\hat{e}_t = \beta_1 E_{t-1}(e_t / I_{t-1}) + \delta f_t + \varepsilon_t$$

2.2 Identification of the Stochastic Process of the Variables

To obtain a unique and stable solution to the exchange rate equation (2.1.12) we need to specify the stochastic process followed by the variables in the model.

We use a similar process that Pesaran and Ruge-Murcia (1999), because we are going to use their econometric approach to estimate the model.

- The expression to the fundamentals are the following:

$$f_t = \Theta_1 \omega_{1,t-1} + u_t \tag{2.2.1}$$

where f_t is a n x 1 vector of fundamentals, Θ_1 is a n x j matrix of coefficients, $\omega_{1,t-1}$ is a j x 1 vector of predetermined variables including lagged values of f_t and e_t; and u_t is a n x 1 vector of shocks.

- The rational expectations solution of equation (2.1.11), when we do not take into account the band, is expressed by the following linear function:

$$E_{t-1}(e_t/I_{t-1}) = \frac{\delta f_t^e}{1-\beta_1} \quad \text{where} \quad f_t^e = E_{t-1}(f_t/I_{t-1}) = \Theta_1 \omega_{1,t-1} \tag{2.2.2}$$

- We assume that the central parity, o_t, is normally fixed, but can make discrete jumps occasionally. Then:

$$e_{i,t} = e_{i,t-1} + a_t(b_t + z_t) \quad \text{for} \quad e_{i,t} = e_{max}, o, e_{min} \tag{2.2.3}$$

where a_t is 1 or 0 depending on whether is a realignment in central parity or not. The size of realignment, when it happens ($a_t = 1$), is measured by $(b_t + z_t)$. z_t represents the non-predictable component [shock] and b_t is the predictable, follow the law:

$$b_t = \Theta_2 \omega_{2,t-1} \tag{2.2.4}$$

being Θ_2 a 1 x k vector of fixed coefficients and $\omega_{2,t-1}$ a k x 1 vector of fundamentals included in I_{t-1}.

- We assume that economic agents, when take their expectations, consider as stochastic the nature of the band as well as the monetary authorities intervention inside of the band. As the band is known in $(t-1)$, the agents take in I_{t-1} the value of a_{t-1}. Besides, they need to incorporate in their exchange rate expectations a prediction about a_t. We assume that a_t depends only on a_{t-1} following a Markov Chain[10] with transition probability matrix:

$$P(t) = \begin{pmatrix} P_{00}(t) & P_{01}(t) \\ P_{10}(t) & P_{11}(t) \end{pmatrix} \tag{2.2.5}$$

[10] In a Markov chain, the value of a variable in period "t" dependes on only on the value of this variable in "$(t-1)$", and does not depends on any other value in the historical serie. [36, Vid: Stokey and Lucas, con Prescott, 1989]

where $\begin{cases} P_{i,j}(t) = prob(a_t = j / a_{t-1} = i); \; i,j = 0,1 \\ P_{i,0}(t) + P_{i,1}(t) = 1; \; i = 0,1 \end{cases}$

This formulation allow us to impose additional restrictions on the elements of $P(t)$. In this case, $P_{i,j}(t)$ could be expressed like:

$$P_{i,j}(t) = \Phi(\omega_{3,t-1}) \tag{2.2.6}$$

where $\Phi(\cdot) : \mathbb{R} \rightarrow [0,1]$, and $\omega_{3,t-1}$ represents predetermined variables included in I_{t-1}.[11]

- The shocks ε_t, u_t and z_t are normally distributed with zero mean and a constant variance-covariance matrix:

$$Cov\begin{pmatrix} \varepsilon_t \\ z_t \\ u_t \end{pmatrix} = \begin{pmatrix} \sigma_\varepsilon^2 & 0_{1\times 1} & 0_{1\times j} \\ 0_{1\times 1} & \sigma_z^2 & 0_{1\times j} \\ 0_{j\times 1} & 0_{j\times 1} & \Omega_{j x j} \end{pmatrix} \tag{2.2.7}$$

where $0_{1\times j}$ is a 1 x j vector of zeros and Ω is a positive-definite variance-covariance matrix of u_t.

As we have incorporated a dummy variable a_t which takes 1 or 0 depending on whether there is a band realignment, we can reformulate the exchange rate equation (2.1.12) to take this fact into account. Besides, we make a set of transformations to get an expression of the LD-RE model as a function of the shocks. To do this, we substitute f_t^e from equation (2.2.2) into (2.2.1):

$$f_t = f_t^e + u_t \tag{2.2.8}$$

Substituting (2.2.8) into (2.1.11):

$$e_t = \beta_1 E_{t-1}(e_t / I_{t-1}) + \delta f_t^e + \delta u_t + \varepsilon_t \tag{2.2.9}$$

Calling $\eta_t = \delta u_t + \varepsilon_t$, such $Var(\eta_t) = \sigma_\eta^2 = \sigma_\varepsilon^2 + \delta \Omega \delta'$, and substituting in the last equation, we obtain:

$$e_t = \beta_1 E_{t-1}(e_t / I_{t-1}) + \delta f_t^e + \eta_t \tag{2.2.10}$$

[11] We will include lagged values of e_t and f_t, but not of $E_{t-1}(e_t / I_{t-1})$.

Operating:

$$\eta_t = e_t - \beta_1 E_{t-1}(e_t/I_{t-1}) - \delta f_t^e \qquad (2.2.11)$$

If we call now $\vartheta_t = \frac{\eta_t}{\sigma_\eta}$, to typify η_t and substituting in (2.2.11):

$$\vartheta_t = \frac{e_t - \beta_1 E_{t-1}(e_t/I_{t-1}) - \delta f_t^e}{\sigma_\eta} \qquad (2.2.12)$$

If there is not band realignment $a_t = 0$, the equation (2.2.3) is transformed in:

$$e_{i,t} = e_{i,t-1}, \quad \text{for} \quad e_i = e_{max}, e_{min} \qquad (2.2.13)$$

Taking this equation into account, we express ϑ_t as:

$$\vartheta_{i,t} = \frac{e_{i,t-1} - \beta_1 E_{t-1}(e_t/I_{t-1}) - \delta f_t^e}{\sigma_\eta}, \quad \text{for} \quad i = max, min \qquad (2.2.14)$$

Following the same procedure, when $a_t = 1$ and defining $\varphi_t = \delta u_t + \varepsilon_t - z_t$, with $Var(\varphi_t) = \sigma_\varphi^2 = \sigma_\varepsilon^2 + \delta - \delta' + \sigma_z^2$, and calling $\theta_t = \frac{\varphi_t}{\sigma_\varphi}$, we can express θ_t as:

$$\theta_{i,t} = \frac{e_{i,t-1} + b_t - \beta_1 E_{t-1}(e_t/I_{t-1}) - \delta f_t^e}{\sigma_\varphi}, \quad \text{where} \quad i = max, min \qquad (2.2.15)$$

Then, we can formulate equation (2.1.12) distinguishing whether there is a realignment [$a_t = 1$], or not, [$a_t = 0$]. The LD-RE proposed model could be applied with perfect credibility case as well as with imperfect credibility. The model specification is:

$$e_t = \begin{cases} e_{max,t-1} & \text{if} \quad \vartheta_t \geq \vartheta_{max,t} \\ \beta_1 E_{t-1}(e_t/I_{t-1}) + \delta f_t^e + \eta_t & \text{if} \quad \vartheta_{min,t} < \vartheta_t < \vartheta_{max,t} \\ e_{min,t-1} & \text{if} \quad \vartheta_t \leq \vartheta_{min,t} \end{cases} \quad \text{when } a_t = 0$$

(2.2.16.a)

$$e_t = \begin{cases} e_{max,t-1} + b_t + z_t & \text{si} \quad \theta_t \geq \theta_{max,t} \\ \beta_1 E_{t-1}(e_t/I_{t-1}) + \delta f_t^e + \eta_t & \text{si} \quad \theta_{min,t} < \theta_t < \theta_{max,t} \\ e_{min,t-1} + b_t + z_t & \text{si} \quad \theta_t \leq \theta_{min,t} \end{cases} \quad \text{when } a_t = 1$$

(2.2.16.b)

2.3 Resolution of Rational Expectations in the Model

To solve the model specified in equations (2.2.16.a) and (2.2.16.b) we need to determine before the solution for the exchange rate expectations $E_{t-1}(e_t/I_{t-1})$.

Assuming that in the period $(t-1)$ economic agents know the value of $a_{t-1} = i; \ \forall i = 0, 1$, the conditional exchange rate expectation could be expressed like:

$$E_{t-1}(e_t/I_{t-1}) = E_{t-1}(e_t/I_{t-1}; a_t = 0) \times P_{i0}(t) + E_{t-1}(e_t/I_{t-1}; a_t = 1) \times P_{i1}(t) \qquad (2.3.1)$$

$\forall i = 0, 1$, where the values of $P_{i0}(t)$ and $P_{i1}(t)$ are given for the i-esima row of $P(t)$ matrix, and verify the restriction $P_{i,0}(t) + P_{i,1}(t) = 1$.

Taken into account equations (2.2.16.a) and (2.2.16.b) we can express the conditional exchange rate expectations as:

- $$E_{t-1}(e_t/I_{t-1}; a_t = 0) = E_{t-1}(e_t/I_{t-1}; \vartheta_t \geq \vartheta_{max,t}) \times prob(\vartheta_t \geq \vartheta_{max,t}) +$$
$$+ E_{t-1}(e_t/I_{t-1}; \vartheta_{min,t} < \vartheta_t < \vartheta_{max,t}) \times prob(\vartheta_{min,t} < \vartheta_t < \vartheta_{max,t}) +$$
$$+ E_{t-1}(e_t/I_{t-1}; \vartheta_t \leq \vartheta_{min,t}) \times prob(\vartheta_t \leq \vartheta_{min,t}) \qquad (2.3.2.a)$$

- $$E_{t-1}(e_t/I_{t-1}; a_t = 1) = E_{t-1}(e_t/I_{t-1}; \theta_t \geq \theta_{max,t}) \times prob(\theta_t \geq \theta_{max,t}) +$$
$$+ E_{t-1}(e_t/I_{t-1}; \theta_{min,t} < \theta_t < \theta_{max,t}) \times prob(\theta_{min,t} < \theta_t < \theta_{max,t}) +$$
$$+ E_{t-1}(e_t/I_{t-1}; \theta_t \leq \theta_{min,t}) \times prob(\theta_t \leq \theta_{min,t}) \qquad (2.3.2.b)$$

- And:

$$\bullet \left\{ \begin{array}{l} prob(\vartheta_t \geq \vartheta_{max,t}) = 1 - F(\vartheta_{max,t}) \\ prob(\vartheta_{min,t} < \vartheta_t < \vartheta_{max,t}) = F(\vartheta_{max,t}) - F(\vartheta_{min,t}) \\ prob(\vartheta_t \leq \vartheta_{min,t}) = F(\vartheta_{min,t}) \end{array} \right. \qquad (2.3.3.a)$$

$$
\begin{cases}
prob(\theta_t \geq \theta_{max,t}) = 1 - G(\theta_{max,t}) \\
prob(\theta_{min,t} < \theta_t < \theta_{max,t}) = G(\theta_{max,t}) - G(\theta_{min,t}) \\
prob(\theta_t \leq \theta_{min,t}) = G(\theta_{min,t})
\end{cases}
\qquad (2.3.3.b)
$$

where $F(\cdot)$ and $G(\cdot)$ denote cumulative distribution functions of ϑ_t and θ_t respectively.

From a econometric point of view and following Pesaran and Ruge-Murcia (1999), sometimes is convenient to suppose that shocks are normally distributed.[12] The standardized variables ϑ_t and θ_t will be $N(0;1)$, and $H(\cdot)$ and $L(\cdot)$ will denote, respectively, the density functions. The value of $E_{t-1}(e_t/I_{t-1})$ that will solve equation (2.3.1) will be the following rational expectations solution:

$$
\begin{aligned}
E_{t-1}(e_t/I_{t-1}) = \{ & e_{max,t-1}[1 - H(\vartheta_{max,t})] + \sigma_\eta [L(\vartheta_{min,t}) - L(\vartheta_{max,t})] + \\
& + [\beta_1 E_{t-1}(e_t/I_{t-1}) + \delta f^e_t][H(\vartheta_{max,t}) - H(\vartheta_{min,t})] \quad + e_{min,t-1} H(\vartheta_{min,t}) \} \times \\
& \times P_{i0}(t) + \{(e_{max,t-1} + b_t)[1 - H(\theta_{max,t})] + \sigma_\gamma [L(\theta_{min,t}) - L(\theta_{max,t})] + \\
& + [\beta_1 E_{t-1}(e_t/I_{t-1}) + \delta f^e_t][H(\theta_{max,t}) - H(\theta_{min,t})] + \\
& + (e_{min,t-1} + b_t) H(\theta_{min,t}) \} \times P_{i1}(t) \qquad (2.3.5)
\end{aligned}
$$

$\forall\ i = 0;1.$

We look for a unique solution to (2.3.5). We propose as a sufficient condition the following proposition, which can be proved showing the equivalence between this proposition and the formulated by Lee (1994) and Pesaran and Ruge-Murcia (1996, 1998).

[12] The results are valid also when we suppose a more general specification, for example assuming heteroskedastic shocks. In the empirical application that we include in the paper we assume that the conditional variance of the shock in the exchange rate equation is a function of squared deviation of exchange rate from central parity. In the case of fundamentals we assume homoskedastic shocks.

Proposition 1 For any $\beta_1 \in \Re$, and assuming that $F(\epsilon)$ and $G(\epsilon)$ are continuous and first-order differentiable probability distribution functions, then the rational expectations solution for the two-sided band with occasional jumps exits. If β_1 1, then the solution is also unique.

If this sufficient condition is verified we can find a unique solution to expression (2:3:5). The problem is that both equations are implicit solutions and, therefore, we need employ iterative procedures to calculate $E_{t-1}(e_t/I_{t-1})$. In our case, we employ the Newton-Raphson algorithm.[13]

3 Empirical Application of LD-RE Model

We choose the peseta/deutsche mark bilateral exchange rate as the dependent variable to estimate. The number of observations are 102, starting when Spain came into the Agrement of Exchange and Intervention of European Monetary System [june 1989] until last available data [may 1998]. During this period, the width of the band was modified from ±6% to ±15% on August, 2nd 1993. This fact force us to subdivide the total period in two subperiods.

In the total period four realignments occurred for the peseta: september, 17th 1992, november, 23th 1992, may, 14th 1993 and, march, 6th 1995; three realignments happened in the first subperiod and one in the second.

With respect to the fundamentals, the output in each country is measured by the Index of Industrial Production seasonally unadjusted.[14] The money supply is the M_1 series seasonally unadjusted and the interest rate is the three-month interbank money market rates. All the data were extracted from the Main Economic Indicators series of OECD. The central parity exchange rate

[13] Vid: Wallis (1980), Hansen and Sargent (1981) or Fair and Taylor (1983).

[14] Always we can argue, but we follow Espasa and Cancelo (1993): "In a econometrics model, when we try to study the dynamic relation among two or more variables, the analysis must to be do using the observed variables, never the extracted signals over the basic of eliminate stochastic seasonality" [11, Ch.. 4, pp. 318]. [41, Vid: Wallis, 1974]

is extracted from the Cuentas Financieras de la Economía Española (Spain Financial Accounts) published by Banco de España (Spain Central Bank).

3.1 Description of the Likelihood Function

To solve the proposed model, we have to estimate the parameters of the model: We use the Full Information Maximum Likelihood [FIML] method to do it.

To estimate the parameters, we assume that we have a stationary series with T elements $f\,¡_t g$ just as $t = 1; :::; T$, where $¡_t = f f_t; a_t; o_t; e_t g$. Besides, in period "t" economic agents incorporate the elements $¡_1; ¡_2; :::; ¡_t$ to the information set I_t, then:

$$\mathrm{prob}(¡_1; ¡_2; :::; ¡_t; :::; ¡_T) = \mathrm{prob}(¡_1) :\mathrm{prob}(¡_2 = I_1) :\mathrm{prob}(¡_3 = I_2) :::$$

$$:::\mathrm{prob}(¡_t = I_{t ¡ 1}) :::\mathrm{prob}(¡_T = I_{T ¡ 1}) \quad (3.1.1)$$

where:

$$\mathrm{prob}(¡_t = I_{t ¡ 1}) = \mathrm{prob}(f_t = I_{t ¡ 1}) :\mathrm{prob}(a_t = f_t; I_{t ¡ 1}) :\mathrm{prob}(o_t = a_t; f_t; I_{t ¡ 1}) :$$

$$:\mathrm{prob}(e_t = o_t; a_t; f_t; I_{t ¡ 1}) \quad (3.1.2)$$

Considering the characterization of the model variables given in two previous parts, we can write the likelihood function like:

$$L(\$) = L_f(\$_1) + L_a(\$_2) + L_o(\$_3) + L_e(\$_4) \quad (3.1.3)$$

where:

² $L_f(\$_1)$:

$$\Rightarrow L_f = -\left(\frac{|T|}{2}\right)\log(2\pi) - \frac{1}{2}\sum_{t=1}\log|\Omega_t| -$$

$$-\frac{1}{2}\sum_{t=1}(f_t - \Gamma_1\omega_{1;t-1})'\,\Omega_t^{-1}(f_t - \Gamma_1\omega_{1;t-1}) \qquad (3.1.4)$$

- $L_a(\varpi_2)$:

$$\Rightarrow L_a = \log prob(a_1) + \log prob(a_2/I_1) + \ldots + \log prob(a_T/I_{T-1}) \qquad (3.1.5)$$

- $L_o(\varpi_3)$:

$$\Rightarrow L_o = -\frac{1}{2}\sum_{t\in\zeta_1}\log\left(2\pi\sigma_z^2\right) - \frac{1}{2\sigma_z^2}\sum_{t\in\zeta_1}\left[(o_t - o_{t-1}) - \Gamma_2\omega_{2;t-1}\right]^2 \qquad (3.1.6)$$

where $\log[prob(o_t/a_t = 0; f_t; I_{t-1})] = \log(1) = 0$.

- $L_e(\varpi_4)$:

$$\Rightarrow L_e = \sum_{t\in\imath_1}\log[1 - H(\vartheta_{max;:t})] + \sum_{t\in\imath_3}\log[H(\vartheta_{min;:t})] -$$

$$-\frac{1}{2}\sum_{t\in\imath_2}\log\left(2\pi\sigma_\varepsilon^2\right) - \frac{1}{2\sigma_\varepsilon^2}\sum_{t\in\imath_2}\left[e_t - \beta E_{t-1}(e_t/I_{t-1}) - \delta f_t\right]^2 \qquad (3.1.7)$$

The estimation of the exact likelihood in equation $(3.1.3)$ raises a non linear optimization system that we have to solve. The estimates obtained when maximizing the likelihood function are the FIML.

To solve this non linear optimization problems, the most effective method of is to use iterative algorithms.[15] Generally there apply the called "Gradient Methods", and specifically the "Newton Method", which is a linear approach to the maximum using Taylor series.[16]

[15] [17, Vid: Greene (1998), pp. 175-187]

[16] In our case, we started the iterations using Newton algorithm, but to get the final results we changed to a "Cuasi-Newton Algorithm". Specifically, we finalize the iterative process using "Davidon-Fletcher-Powell [DFP] Algorithm".

3.2 Econometric Identification

First, we will make an approach to the method we are going to use to solve equation (2:1:9). Before, we describe the analytic expressions of estimating equations we have shown if there exist autocorrelation in the residuals. We have tested and there are due to exchange rate behavior as a random walk,[17] and thus, we are going to estimate exchange rate equation including, like an additional variable, the lagged exchange rate. The procedure was used before by Bajo (1986, 1987) who tested the existence of autocorrelation in the residuals in the peseta/mark exchange rate from 1977 to 1984, and there are corrected with the incorporation of lagged exchange rate.

The expression of fundamentals h_t that we are going to use assumes that h_t follows an autorregresive process that in our case will be an AR(1) with parameter P. Taking e_{t-1} as an additional variable, and assuming that a stable future rational expectation solution is equivalent to a stable current rational expectation solution, we can write the exchange rate process as:

$$e_t = \beta_1 E_{t-1}(e_t/I_{t-1}) + z_1(1-\beta_1)e_{t-1} + \chi h_t + \left(\frac{\chi P \beta_1}{1-P\beta_1}\right)\Delta h_t + \varepsilon_t =$$

$$= \beta_1 E_{t-1}(e_t/I_{t-1}) + \delta f_t + \varepsilon_t \qquad (3.2.1)$$

where $f_t' = [e_{t-1}; h_t; \Delta h_t]$ and z_1 is the root of the equation $\phi z + \beta_1 z^{-1} = 1$, such $|z_1| < 1$.

Then, the econometric specification that we will do is the following:

- $h_t' = [(m_t - m_t^*); (y_t - y_t^*); PR_t]$ will be approach by the following vector f_t:

$$f_t' = [(m_t - m_t^*); (y_t - y_t^*); x_t] \qquad (3.2.2)$$

[17] We have tested using ADF [Augmented Dickey-Fuller] and Phillips-Perron tests, and we can not reject the existence of an unit root.

with:

$$x'_t = \left\{ \begin{array}{c} 1; e_{t-1}; \left(r_{t-1} - r^*_{t-1}\right); (e_{t-1} - o_{t-1}); \\ \cdot\left(m_{t-1} - m^*_{t-1}\right); \cdot\left(y_{t-1} - y^*_{t-1}\right); \cdot\left(m_{t-2} - m^*_{t-2}\right); \\ \cdot\left(y_{t-2} - y^*_{t-2}\right); \cdot\left(r_{t-2} - r^*_{t-2}\right); \cdot(e_{t-2} - o_{t-2}) \end{array} \right\}$$

where we have included $\left(r_{t-1} - r^*_{t-1}\right)$ and $(e_{t-1} - o_{t-1})$ as a proxy variable to the risk premium. Besides, we have incorporated lags in the variable in order to correct the possibility of error in the estimation for approaching the solution of future rational expectations to the current ones.

- To estimate the exchange rate expectations, $E_{t-1}(e_t/I_{t-1})$,[18] the specification of $(m_t - m^*_t)$ and $(y_t - y^*_t)$ is, respectively, the following:[19]

$$\Delta \cdot (m_t - m^*_t) = \pi_0 + \pi_1 \cdot \left(m_{t-1} - m^*_{t-1}\right) + \pi_2 \cdot \left(m_{t-2} - m^*_{t-2}\right) +$$

$$+\pi_{12} \cdot \left(m_{t-12} - m^*_{t-12}\right) + \varepsilon_{1t} \qquad (3.2.3)$$

where ε_{1t} is white noise.

$$\Delta\,(y_t - y^*_t) = {}_0 + {}_1\left(y_{t-1} - y^*_{t-1}\right) + {}_2\left(y_{t-12} - y^*_{t-12}\right) + \varepsilon_{2t} \qquad (3.2.4)$$

where the shock ε_{2t} is white noise.

- The realignment process of central parity can be write as:

$$o_t = o_{t-1} + a_t\,(b_t + z_t) \qquad (3.2.5)$$

where we assume that b_t is constant, because only three realigments took place in the first period and only one in the second.

---

[18] If we don't take into account the target zone, the expression to estimate $E_{t-1}(e_t/I_{t-1})$ will be:

$$E_{t-1}(e_t/I_{t-1}) = \frac{[\gamma_1 (m_t - m^*_t) + \gamma_2 (y_t - y^*_t) + x_t]}{(1 - \beta_1)}$$

where $(m_t - m^*_t)$ and $(y_t - y^*_t)$ follow the expressions (3.2.3) and (3.2.4), respectively.

[19] We test the stationary nature of $(m_t - m^*_t)$ and $(y_t - y^*_t)$ using ADF test [Augmented Dickey-Fuller]. We can not reject the unit root in $(m_t - m^*_t)$, and we can reject in $(y_t - y^*_t)$ after correct the seasonal nature.

- The matrix of transition probabilities will be:

$$P(t) = \begin{pmatrix} P_{00}(t) & P_{01}(t) \\ 1 & 0 \end{pmatrix} \tag{3.2.6}$$

where $P_{11}(t)$ is zero, because we can't find two successive periods when a realignment of central parity took place. Depending of the model used for estimation, P_{01} will be zero, constant or a variable function that depends on $\left(r_{t-1} - r^*_{t-1}\right)$, $(e_{t-1} - o_{t-1})$, $\left[\Delta\left(m_{t-1} - m^*_{t-1}\right) - \Delta\left(m_{t-2} - m^*_{t-2}\right)\right]$ and $\left(y_{t-1} - y^*_{t-1}\right)$.

- We represent the shock ε_t in the exchange rate equation such that its variance express the possible effect of a reduction in exchange rate volatility, as target zones models predict.

$$\sigma^2_{\varepsilon_t} = \tau_0 + \tau_1 (e_{t-1} - o_{t-1})^2 \tag{3.2.7}$$

With respect to the variances of the shocks Ξ_{1t} and Ξ_{2t} we assume that there are homoskedastic.

- We got the variance-covariance matrix of the maximum likelihood estimator by calculating the estimator called "BHHH".[20]

3.3 Estimation Results

We have done the estimation using four different models in the two subperiods respectively. The Mod_1 model makes reference to a lineal rational expectations model, where the existence of the band doesn't matter in the economic agents expectations. Models Mod_2 , Mod_3 and Mod_4 are non linear rational expectations models in which the band influences agent expectations and their differences arise from the probability value: $P_{01} = 0$ in Z_2, P_{01} is a constant different from zero in Mod_3, and P_{01} is a variable function

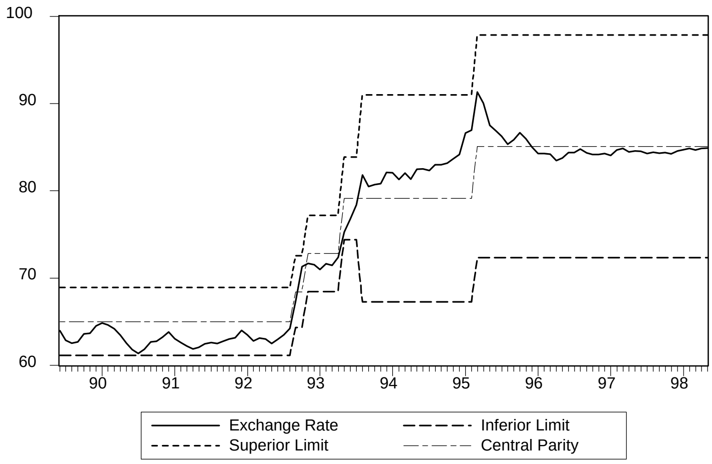
[20] Like Greene (1998) [17, pp. 123-125] explains the variance-covariance matrix of maximum likelihood estimator depends on the parameters. We have apply two alternative methods to estimate: First, the estimator used by Pesaran and Ruge-Murcia (1998), evaluating the second derivatives matrix of maximum likelihood estimator; second, using the BHHH matrix. Like Greene (1998) [17, pp. 124] says, to make use of this matrix is very convenient in some cases because we don't need any additional calculations to get it.

in Mod_4 that depends on $\left(r_{t-1} - r^*_{t-1}\right)$, $(e_{t-1} - o_{t-1})$, $\left(y_{t-1} - y^*_{t-1}\right)$ and $\left[\left(m_{t-1} - m^*_{t-1}\right) - \left(m_{t-2} - m^*_{t-2}\right)\right]$.

Figure 2 shows the evolution of exchange rate in the sample period, where there aren't values out of the band. The figure shows besides, the edges of the band and the central parity. Then, could be seen, clearly, the four realignments that taken place in the period and the enlargement of the band en august 1993.

A look of the figure, infers us to think, a priori, on a different behavior of the exchange rate between the two subperiods [september 1989 to july 1993, and november 1993 to may 1998].

Figure 2: Evolution of peseta/deutsche mark exchange rate



Then, we are going to study which of those models is the best in order to explain the behavior of the peseta/mark exchange rate. We will show this behavior from different viewpoints. First, we will study the values of the estimated coefficients in the alternative models. Second, we will illustrate it through the conditional variance of the exchange rate shock. Third, we will estimate the realignment probability of the bands in Mod_3 and Mod_4 models.

Finally, we will apply di¤erent selecting's criteria.

The estimated coe¢cient value in the alternative models, with their signi…cance levels for the two subperiods are in tables 1 and 2, respectively.[21] In the …rst period [september 1989 to july 1993] only the Mod_4 model shows parameters with signi…cance levels di¤erent from zero, using the t-statistic. Such parameters will explain better the exchange rate behavior in the period and they are the lagged exchange rate, expectation, lagged money supply and lagged interest rate di¤erential as a variable approaching to the risk premium.

In the second subperiods [november 1993 to may 1998] the results, in signi…cance terms, are not as conclusive as in the …rst one. In the lineal rational expectations model Mod_1 the parameter of exchange rate expectations is signi…cant, as in Mod_4 model, but it's not less than one.[22] Lagged exchange rate is signi…cant in the Mod_3 model.

With respect to the estimated conditional variance of the exchange rate shock, $\sigma^2_{\varepsilon_t}$, showed in tables 3 and 4, which equation was $\sigma^2_{\varepsilon_t} = \gamma_0 + \gamma_1 (e_{t-1} - o_{t-1})^2$, the di¤erences between subperiods are clear. In the …rst period, the variance, $\sigma^2_{\varepsilon_t}$, is constant and then homoskedastic. This result implies that, in the …rst subperiods, exchange rate variability doesn't depend on exchange rate position with respect to the central parity, and then doesn't verify the honeymoon e¤ect as predicted by the target zones literature, and represented by a shape curve between exchange rate and fundamentals.

In the second subperiods, all estimated coe¢cients values are close to zero and are not signi…cative. We can deduce a reduced exchange rate variability, at least since 1996 like can be shown in …gure 2.

In the econometric speci…cation of the rational expectations solution, we assume that this has a saddle path when the parameter z_1 takes the values

[21] Analyzed the correlation among the variables used in the estimation, and, taking into account to …nd two economic variable not correlated, we have observed same multicollinearity problems but not too much to be very signi…cant.

[22] If β_1 is not less than one, rational expectations solution could not be unique.

of 1:000, 1:008, 1:005 and 1:021 in Mod_1, Mod_2, Mod_3 and Mod_4 models respectively.[23] Then, the estimated value is not less than one in any model, suggesting that exchange rate follows a explosive path. In the …rst subperiods, we can say that there are not mean reversion as target zone models predict. Once the …nancial markets assign devaluation expectations to the peseta, the continuous intramarginal or in…nitesimal interventions of monetary authorities won't get intercept capital movements in the markets, usually in much more amount than interventions, and will drive to inevitable devaluation, and then a new central parity of exchange rate.

In the second subperiods, the estimated values of z_1 are, respectively, 0:967, 1:002, 0:995 and 0:997. In this case, the coe¢cient is less than one except in Mod_2 model. However, this value is close to 1 and then, with a cuasi-explosive path.

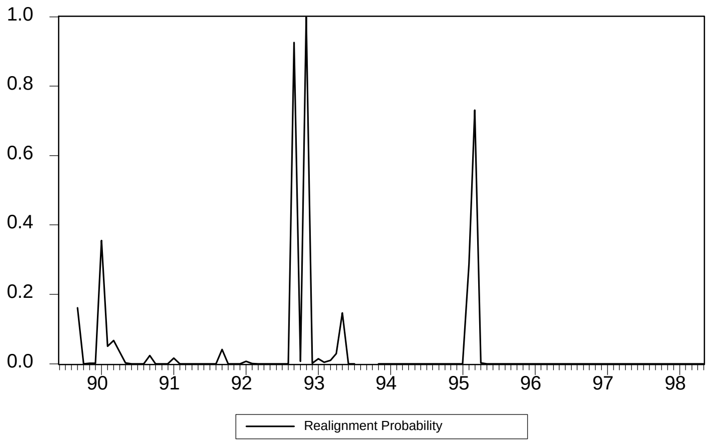
We have estimated the realignment probability of the band in Mod_3 and Mod_4. The tables 5 and 6 take the estimated values up in the two considered subperiods. In the nonlinear rational expectations Mod_3 model we assume a constant probability. A …rst approach to this value can be calculated taken into account the number of observations in the sample and the number of realignments happened and dividing both.[24] If we consider the …rst subperiods, the number of realignments were three and 47 the number of e¤ective observations $\left[\frac{3}{47} = 0:0638\right]$. The constant estimated value in the model was 0:0422. One possible explanation for this di¤erence could be the highest proximity between the two …rst realignments and we can approach the number of realignment to two. In this case, $\frac{2}{47} = 0:0425$, that is a value near to the estimated one. In the second subperiods, the number of observations are 55 and there is only one realignment; then, $\frac{1}{55} = 0:0182$. The estimated value was 0:0186.

[23] The values are calculated but not show in tables.

[24] That is, applying Laplace Rule:

$$P(\epsilon) = \frac{favorables}{possibles}$$

Figure 3: Estimated realigment probability



The Mod_4 model assumes that realignment probability depends on a constant, on $\left(r_{t-1} - r^*_{t-1}\right)$, $(e_{t-1} - o_{t-1})$, $\left(y_{t-1} - y^*_{t-1}\right)$ and $\Delta\left(m_{t-1} - m^*_{t-1}\right) - \Delta\left(m_{t-2} - m^*_{t-2}\right)$. In the first subperiods, the constant and output differentials are significantly different from zero. In the second subperiods either coefficients are significative. We can see The justification of this results in figure 3 which shows the realignments probabilities in the two subperiods. As a general rule, the observed peaks in probability corresponds to realignments;[25] first, in the beginning of 90's, which corresponds with tensions produced by the dollar fall and rumors about a revaluation of the deutsche mark that didn't happen, and the entrance of Italian lira to the narrow bands of EMS. Then, as was pointed out by Bekaert and Gray (1998), the exchange rate jumps must be modelized depending on the realignments,or on the movements inside the band, because most of the jumps inside the band are of the same amount than realignments.

In our case,the estimated probability in january 1990 [0:3556] is bigger than in may 1993 [0:1467], date when a realignment took place. The other tree peaks

[25] It may be taken into account that, due to lags in estimation, the real sample start in september 1989 and not in june; The second sample start in november 1993 and not in august. Figure 3 reflect the probability in the real sample.

correspond to realignments: september 1992 [0.9258], november 1992 [0.9989] and march 1995 [0.7309]. Then, the estimated probability adjust to the evidence shown in figure 2; when besides, we can see a smooth raise in the probability when the sterling pound incorporates to EMS and the opposite position with respect to the peseta desestabilizing the last one.

The only thing we miss in the estimation of the probability is the measure the possible effect on the probability of band enlargement due to information loss for dividing the sample in two.

To verify which model better explain the behavior of realignment probability [the Mod_3 model with constant probability or Mod_4 model with variable] we contrast both models using the likelihood ratio test, which is shown is table 7 for first period and 8 for the second. The likelihood ratio test is given by $LR = -2\left[L^3(\$) - L^4(\$)\right]$ and is distributed like a χ^2 with four degrees of freedom. For the first subperiods, the value of LR-Test is 41.724, and allows us not to reject Mod_4 model to a significative level of 99%. In the second subperiods the value is 7.228 and the significative level is 87%.

However, our intention is not only to study which model interprets better the probability, but also to find which one better explains exchange rate behavior. For this reason, we compare the four estimated models with two others that model the exchange rate behavior in a simple way. We modelized the exchange rate like a Random walk, RW, and like a GARCH(1,1) [Generalized Autorregressive Conditional Heteroscedasticity] process, RW_{GARCH}. The results and the different criteria used are compiled for both subperiods in tables 7 and 8 respectively.

The criteria used are the following:

- AIC [Akaike Information Criterion]: calculated like Pesaran and Ruge-Murcia (1999), that is the difference between the maximized value of the likelihood function associated to the exchange rate and the number of estimated parameters in each equation. [15 parameters in Mod_1 and Mod_2 models, 16 in Mod_3, 20 in Mod_4 2 in RW and 4 in RW_{GARCH} model][26]

- RMSFE [Root Mean Squared Forecast Errors] defined like:

$$RMSFE = \sqrt{\frac{\sum_{t=1}^{T} [e_t - E_{t-1}(e_t/I_{t-1})]^2}{T}} \qquad (3.3.1)$$

where T represents the observations number in the sample.

- AMFE [Absolute Mean Forecast Errors] defined like:

$$AMFE = \frac{\sum_{t=1}^{T} |e_t - E_{t-1}(e_t/I_{t-1})|}{T} \qquad (3.3.2)$$

where T represents the same than RMSFE.

In the first subperiods, the three criteria show that the better model is nonlinear rational expectations with variable probability of band realignment [Mod_4]. Then, the model which better explains the peseta/deutsche mark bilateral exchange rate is a model which incorporates the band in economic agents expectations and that are influenced by lagged exchange rate, the differential in the money supply and the risk premium approached by interest rate differential and in which the realignment probability exists with values different from zero and is function of output differentials between Germany and Spain.

With respect to the second subperiods the results are not as conclusives as in the first subperiods. We pointed out that, with the exception of march 1995 devaluation. This period can be represented by a stability in the exchange rate, at least since mid 1996. From the chosen criteria point of view, the RMSFE choose Mod_2 model follow by Mod_1 model. If we use AIC or AMFE criteria,

[26] About selection criteria of models see Lütkepohl (1991) [22, pp. 118-166]

the best model is Mod_1. In this model, economic agents don't take into account the band when form their expectations and the realignment probability of the band is zero. This result points out that with a band of 30% the economic agents act like a cuasi-‡exible exchange rate system and where a contractive …scal stance with a control on public de…cit since march 1996 and the ful…llment of convergence criteria have a positive in‡uence over exchange rate stability. The perspectives of incorporation of Spain in the …rst phase of EMU have made that realignment probability has been zero for the most of period.[27]

4 Conclusions

The argue about exchange rate behavior has been the object of special interest, academic and politic, with respect to the excessive volatility and realignments. A theoretical proposal driven to try to reduce the exchange rate volatility, and over all, its sudden movements has been the called " Target Zones Models" in continuous time. In this paper we develope a theoretical modelization their rational expectations, in discrete time, in the line with the LD-RE and we estimate it for the peseta/deutsche mark exchange rate. We employ such a model because, in di¤erence with ampli…ed target zone model, we have, not only the possibility of intramarginal intervention, stochastic realignment expectations and predetermined prices, but also that the existence of the band is taken into account when economic agents take expectations.

The estimation results show a clear di¤erence between the period before and after the modi…cation of the band width. The results, on the other band, can be surprising, at least for the …rst path of the sample, because don't verify the regularities found for other exchange rates in the EMS. However, they explain coherently the peseta/deutsche mark exchange rate evolution in the sample.

We …nd the following regularities:

[27] Like can …nd in …gure 3, of 55 observations that enter in the second subperiod, only nine takes a value di¤erent from zero.

- The sample from june 1989 to july 1993 is characterized by a strong volatility in the peseta/deutsche mark exchange rate, sometimes near to the maximum appreciation, and sometimes in the maximum limit of depreciation and besides the three central parity realigments. We …nd new regularities for the Spanish case di¤erents from Pesaran and Ruge-Murcia (1999) for french franc/deutsche mark exchange rate. These are the following:

  – There are not a shape curve between the exchange rate and fundamentals, and then, there is not honeymoon e¤ect like target zones literature predicts. On the contrary, like suggest Bertola and Caballero (1992.a, 1992.b), the realignment expectations in the band can invert the Krugman (1991) SS curve.

  – Once the agents expect that the peseta/deutsche mark exchange rate is going to devaluate, press with speculative attacks in such amount that either intramarginal or in…nitesimal interventions can imped devaluation.

  – The realignment probability of the band have existed and there has been not constant. Such realignment probability took positive values as inside take band as when the band is realigned.

  – The model that better explains the exchange rate evolution is this part of the sample is a LD-RE model with variable probability. This realignment probability depends on exchange rate expectations, the di¤erential in money supply and the risk premium approached by lagged interest rate di¤erential.

- The sample from august 1993 to may 1998 is characterized by a low volatility in the peseta/deutsche mark exchange rate, with the exception of devaluation on march 1995. This period wasn't analyzed by Pesaran and Ruge-Murcia (1999) and the results are totally news. This results has been the following:

  – The results are not conclusive with respect to maintenance of the " S" relation between exchange rate and fundamentals.

- Neither about the existence of mean reversion because z_1 takes values near to 1.
- The realignment probability of the band has been constant and near to zero with the exception of the period just before the devaluation in march 1995.
- We can not characterize exchange rate evolution with a model because the results are not conclusive. However, there are nearer to a linear rational expectations model than a nonlinear model with variable realignment probability. When we use the probability, on the other hand, the second one is better than the …rst one to predict the probability.

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Table 1: Estimated Parameters in the first sample (September 1989-July 1993)

Explanatory Variables	Mod_1	Mod_2	Mod_3	Mod_4
Constant	0.068 (0.022)	−0.825 (−0.245)	−0.326 (−0.149)	−0.535 (−0.124)
e_{t-1}	−0.819 (−0.590)	0.518 (0.344)	0.622 (0.650)	0.168** (1.883)
$E_{t-1}(e_t/I_{t-1})$	1.818 (1.295)	0.487 (0.341)	0.381 (0.451)	0.810*** (11.572)
$(m_t - m_t^*)$	−0.099 (−0.040)	−1.193 (−1.590)	0.024 (0.040)	−2.220*** (−1.943)
$(y_t - y_t^*)$	0.925 (0.541)	−1.026 (−0.584)	−0.504 (−0.051)	−0.015 (−0.002)
$\left(r_{t-1} - r_{t-1}^*\right)$	−0.344 (−0.259)	−0.567 (−0.450)	−0.323 (−0.317)	−1.218*** (−3.210)
$(e_{t-1} - o_{t-1})$	−0.012 (−0.065)	0.027 (0.214)	0.070 (0.008)	−0.018 (−0.021)
$\Delta\left(m_{t-1} - m_{t-1}^*\right)$	−1.305 (−0.395)	0.978 (0.466)	0.997 (0.721)	−0.394 (−0134)
$\Delta\left(y_{t-1} - y_{t-1}^*\right)$	−0.091 (−0.051)	−1.158* (−1.714)	−0.086 (−0.080)	0.371 (0.484)
$\Delta\left(m_{t-2} - m_{t-2}^*\right)$	−1.344 (−0.341)	0.165 (0.033)	0.593 (0.314)	0.365 (0.028)
$\Delta\left(y_{t-2} - y_{t-2}^*\right)$	0.169 (0.212)	−1.110 (−1.344)	−0.268 (−0.772)	−0.219 (−0.693)
$\Delta\left(r_{t-2} - r_{t-2}^*\right)$	0.056 (0.019)	0.653 (0.221)	0.385 (0.239)	0.056 (0.031)
$\Delta(e_{t-2} - o_{t-2})$	−0.073 (−0.073)	0.100 (1.610)	0.055 (0.630)	0.003 (0.0004)

Note: Mod_1 refers a linear RE model that does not take into account the effect of the band on expectations. Mod_2 , Mod_3 and Mod_4 are non lineal RE models where the band affects agents' expectations and diferents realignment probabilities. $P_{01} = 0$ in Mod_2, P_{01} is a constant different from zero in Mod_3 and P_{01} is a function of $\left(r_{t-1} - r_{t-1}^*\right)$, $(e_{t-1} - o_{t-1})$, $\Delta\left(m_{t-1} - m_{t-1}^*\right) - \Delta\left(m_{t-2} - m_{t-2}^*\right)$ and $\left(y_{t-1} - y_{t-1}^*\right)$ in Mod_4. The value into a parenthesis is the t-statistic and *, ** and *** denotes the significance of 10, 5 or 1 % respectively.

Table 2: Estimated Parameters in the second sample (November 1993-May 1998)

Explanatory Variables	Mod_1	Mod_2	Mod_3	Mod_4
Constant	-0.951 (-1.209)	0.007 (0.0006)	0.142 (0.363)	0.105 (0.328)
e_{t-1}	-0.068 (-0.317)	0.256 (0.449)	0.899^{***} (3.177)	0.129 (0.443)
$E_{t-1}(e_t/I_{t-1})$	1.070^{***} (4.623)	0.745 (1.324)	0.096 (0.338)	0.870^{***} (2.967)
$(m_t - m_t^*)$	-0.222 (-0.010)	-0.784 (-0.629)	0.246 (0.146)	0.273 (0.281)
$(y_t - y_t^*)$	0.038 (0.035)	-0.157 (-0.247)	-0.046 (-0.001)	-0.054 (-0.004)
$\left(r_{t-1} - r_{t-1}^*\right)$	-0.008 (-0.008)	-0.495 (-1.358)	-0.002 (-0.0008)	-0.012 (-0.007)
$(e_{t-1} - o_{t-1})$	-0.004 (-0.003)	0.016 (0.014)	0.006 (0.0008)	0.009 (0.010)
$\Delta\left(m_{t-1} - m_{t-1}^*\right)$	0.214 (0.014)	-0.075 (-0.067)	-0.275 (-0.016)	-0.347 (-0.046)
$\Delta\left(y_{t-1} - y_{t-1}^*\right)$	0.007 (0.010)	-0.080 (-0.020)	-0.011 (-0.0008)	-0.022 (-0.0007)
$\Delta\left(m_{t-2} - m_{t-2}^*\right)$	-0.131 (-0.031)	0.823 (0.321)	0.200 (0.058)	0.348 (0.274)
$\Delta\left(y_{t-2} - y_{t-2}^*\right)$	0.084 (0.069)	-0.320 (-0.321)	-0.115 (-0.007)	-0.161 (-0.018)
$\Delta\left(r_{t-2} - r_{t-2}^*\right)$	1.540 (0.077)	-1.641^{***} (-3.277)	-2.109 (-0.079)	-2.788 (-0.108)
$\Delta(e_{t-2} - o_{t-2})$	0.003 (0.003)	-0.044 (-0.012)	-0.004 (-0.003)	-0.007 (-0.0005)

Note: Mod_1 refers a linear RE model that does not take into account the effect of the band on expectations. Mod_2, Mod_3 and Mod_4 are non lineal RE models where the band affects agents' expectations and differents realignment probabilities. $P_{01} = 0$ in Mod_2, P_{01} is a constant different from zero in Mod_3 and P_{01} is a function of $\left(r_{t-1} - r_{t-1}^*\right)$, $(e_{t-1} - o_{t-1})$, $\Delta\left(m_{t-1} - m_{t-1}^*\right)$ $\Delta\left(m_{t-2} - m_{t-2}^*\right)$ and $\left(y_{t-1} - y_{t-1}^*\right)$ in Mod_4. The value into a parenthesis is the t-statistic and *, ** and *** denotes the significance of 10, 5 or 1 % respectively.

Table 3: Estimation of conditional variance of exchange rate shocks in the first sample (September 1989-July 1993)

Models	Constant	$(e_{t-1} - o_{t-1})^2$
Mod_1	1.900 (1.503)	0.000 (0.000)
Mod_2	1.445*** (5.162)	0.000 (0.000)
Mod_3	1.576*** (6.065)	0.000 (0.000)
Mod_4	1.219 (0.286)	0.000 (0.000)

Table 4: Estimation of conditional variance of exchange rate shocks in the second sample (November 1993-May 1998)

Models	Constant	$(e_{t-1} - o_{t-1})^2$
Mod_1	0.065 (0.007)	0.069 (0.004)
Mod_2	0.104 (0.008)	0.076 (0.008)
Mod_3	0.066 (0.0002)	0.067 (0.0002)
Mod_4	0.066 (0.007)	0.068 (0.005)

Note: Mod_1 refers a linear RE model that does not take into account the effect of the band on expectations. Mod_2 , Mod_3 and Mod_4 are non lineal RE models where the band affects agents' expectations and differents realignment probabilities. $P_{01} = 0$ in Mod_2, P_{01} is a constant different from zero in Mod_3 and P_{01} is a function of $\left(r_{t-1} - r^*_{t-1}\right)$, $(e_{t-1} - o_{t-1})$, $\Delta\left(m_{t-1} - m^*_{t-1}\right) - \Delta\left(m_{t-2} - m^*_{t-2}\right)$ and $\left(y_{t-1} - y^*_{t-1}\right)$ in Mod_4. The value into a parenthesis is the t-statistic and *, ** and *** denotes the significance of 10, 5 or 1 % respectively.

Table 5: Estimation of Realignment Probability of the Band in the first sample (September 1989-July 1993)

Explanatory Variables	Mod_3	Mod_4
Constant	0.042 (0.478)	-5.170^{***} (-2.042)
$\left(r_{t-1} - r^*_{t-1}\right)$		8.290 (0.849)
$(e_{t-1} - o_{t-1})$		2.098 (0.869)
$\left(y_{t-1} - y^*_{t-1}\right)$		-18.407^{***} (-2.715)
$\left[\left(m_{t-1} - m^*_{t-1}\right) - \left(m_{t-2} - m^*_{t-2}\right)\right]$		10.675 (0.788)
L_o	-11.264	-2.926

Table 6: Estimación de la probabilidad de reajuste de las bandas de fluctuación en la segunda submuestra (Noviembre 1993-Mayo 1998)

Explanatory Variables	Mod_3	Mod_4
Constant	0.018 (0.005)	-27.00 (-0.320)
$\left(r_{t-1} - r^*_{t-1}\right)$		-1.423 (-0.013)
$(e_{t-1} - o_{t-1})$		3.071 (0.005)
$\left(y_{t-1} - y^*_{t-1}\right)$		-14.382 (-0.241)
$\left[\left(m_{t-1} - m^*_{t-1}\right) - \left(m_{t-2} - m^*_{t-2}\right)\right]$		12.563 (0.036)
L_o	-4.980	-0.654

Note: The value into a parenthesis is the t-statistic and *, ** and *** denotes the significance of 10, 5 or 1 % respectively. L_o is the maximized value of log-likelihood function associated with changes in central parity.

Table 7: Selection Models Criteria in the first sample (September 1989-July 1993)

Models	L_e	AIC	RMSFE	AMFE	L($)	½
Mod_1	-40.084	-55.084	1.429	0.991	-	1
Mod_2	-37.233	-52.233	1.328	0.986	-	12.00
Mod_3	-39.671	-55.671	1.406	1.016	216.348	12.00
Mod_4	-27.139	-47.139	1.078	0.790	237.210	12.00
RW	-79.936	-81.936	1.375	0.988	-	1
RW_{GARCH}	-75.929	-79.929	1.389	0.978	-	1

Table 8: Selection Models Criteria in the second sample (November 1993-May 1998)

Models	L_e	AIC	RMSFE	AMFE	L($)	½
Mod_1	7.795	-7.205	0.1491	0.5542	-	1
Mod_2	0.232	-14.768	0.1465	0.5923	-	30.00
Mod_3	6.731	-9.269	0.150	0.5697	352.956	30.00
Mod_4	6.645	-13.355	0.1498	0.5709	356.570	30.00
RW	-87.006	-89.006	1.0845	0.6392	-	1
RW_{GARCH}	-68.768	-72.768	1.0929	0.6292	-	1

Note: Mod_1 refers a linear RE model that does not take into account the effect of the band on expectations. Mod_2 , Mod_3 and Mod_4 are non lineal RE models where the band affects agents' expectations and differents realignment probabilities. $P_{01} = 0$ in Mod_2, P_{01} is a constant different from zero in Mod_3 and P_{01} is a function of $(r_{t-1} - r^*_{t-1})$, $(e_{t-1} - o_{t-1})$, $\Delta(m_{t-1} - m^*_{t-1}) - \Delta(m_{t-2} - m^*_{t-2})$ and $(y_{t-1} - y^*_{t-1})$ in Mod_4. The RW and RW_{GARCH} models expresses exchange rate behavior like a random walk with drift, RW, with homoskedastic variance, and a conditional variance like a GARCH(1,1), RW_{GARCH}, respectively. L_e represents the value of maximized log-likelihood function associated with exchange rate and $L(\$) = L_f(\$_1) + L_a(\$_2) + L_o(\$_3) + L_e(\$_4)$ is the maximized value of log-likelihood.