Testing Target Zone Credibility with a Limited Dependent Variable Rational Expectations Model

Meral Karasulu

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Abstract

This essay applies a limited dependent variable rational expectations model to estimate the French Franc/Deutsche Mark (FF/DM) exchange rate in order to test the credibility of the European Exchange Rate Mechanism (ERM) for these currencies.

The existing literature treats the exchange rate within the band as an unbounded continuous variable. The exchange rate within a target zone is a bounded variable censored beyond the upper and lower band margins. If the censored nature of the exchange rate is ignored the parameter estimates will be biased. The confidence intervals for expected realignment will reflect this bias and distort the result of credibility tests.

The limited dependent variable rational expectations model integrates this feature of the exchange rate mechanism into the estimation process. Moreover, it explicitly models expectations of economic agents who will incorporate the bounded nature of the data into their information sets when forming expectations about exchange rate movements.

I find considerable support for modeling the exchange rate using a limited dependent variable framework. My results indicate that accounting for the band in the drift adjustment method significantly modifies the results of credibility tests. As opposed to earlier findings in the literature, confidence intervals for the expected realignment are wider than those resulting from ordinary least squares estimates and from a rational expectations model obtained without imposing the band. Furthermore, my results trace the history of the ERM realignments for the FF/DM and in each case correctly identify the period before and after a realignment as a period lacking credibility. The model predicts a gradual widening of confidence intervals after 1980 until the end of 1990. Although a zero expected realignment

is contained in the confidence intervals for most of this period, the widening of the interval also suggests a tension building up, possibly leading to a larger realignment.

Contents

1 Introduction

The theoretical implications of exchange rate target zones have been the focus of several studies recently (see Krugman [10], Bertola and Caballero [1], Svensson [19, 20, 21] among others). After Krugman's work that incorporated continuous time stochastic modeling for exchange rate determination within a target zone there have been several empirical studies that tested the implications of target zone models. The European Exchange Rate Mechanism (ERM) and the Bretton Woods system constitute the two examples which have been studied in this framework.

After the collapse of Bretton Woods which incorporated very narrow band margins similar doubts arose concerning the credibility of the ERM. The performance of the ERM since 1979 has been mixed. Until 1992 there were 11 realignments of the central parities. This practice amounts to devaluing the currencies and raises credibility problems concerning the sustainability of the ERM. The recent widening of the band margins has been seen by many as the demise of the ERM.

Recently a number of empirical papers have appeared aiming at estimating the expectations of devaluation and testing the credibility of the target zone for ERM currencies. This literature follows the drift adjustment method of Svensson [20] to model the expected realignments. However, these models treat the expected depreciation within the band as an unbounded continuous variable. The exchange rate within a target zone is a bounded variable censored beyond the upper and lower band margins. If the bounded nature of the exchange rate is ignored the parameter estimates obtained from such models will be biased. The confidence intervals for expected realignment will reflect this bias and distort the result of credibility tests.

I employ a two limit Tobit model to integrate this feature of the exchange rate mechanism into the estimation process for the French Franc/Deutsche Mark (FF/DM) exchange rate within the band. Moreover, economic agents will incorporate this fact into their information sets when forming expectations about exchange rate movements. By assuming rational expectations in a limited dependent variable framework I can account for the effect of expectations on expected depreciation as well. The consideration of limited dependent variable rational expectations differentiates my model from a standard two-limit Tobit model in the sense that even if no observations are censored, the model cannot be consistently estimated using a linear regression framework due to the effect of expectations of depreciation on exchange rates.

The rest of the paper is organized as follows. In the next section I review the operating principles of the ERM and its experience since 1979. The third section describes various tests used to assess the credibility of the ERM in the literature and reports some of their findings. Section 4 introduces the limited dependent variable rational expectations model and its econometric methodology. I report the empirical findings in Section 5. Section 6 summarizes and concludes.

2 Institutional Background of the ERM

The exchange rate mechanism of the European Monetary System started in 1979 as an agreement among eight European countries (Germany, France, Belgium, Netherlands, Luxembourg, Denmark, Ireland and Italy) to restrict their bilateral exchange rates within specified limits. Each currency has a central rate related to the European Currency Unit (ECU). The ECU-related central rates are expressed as a certain quantity of currency per ECU. These ECU-related central rates are used to calculate a series of *bilateral central rates* for each participating country. Until 1993, exchange rates were allowed to fluctuate around these bilateral central rates within a band of $\pm$ 2.25% (For Italy the band width was $\pm$ 6% before January, 1990). If a currency reaches either side of this fluctuation band for any bilateral central rate, intervention in participating currencies is compulsory.

Adjustments of central rates are subject to a common procedure and they must be approved by all countries participating in the ERM. A realignment of central rates is equivalent to a depreciation or revaluation but it doesn't affect the width of the band.

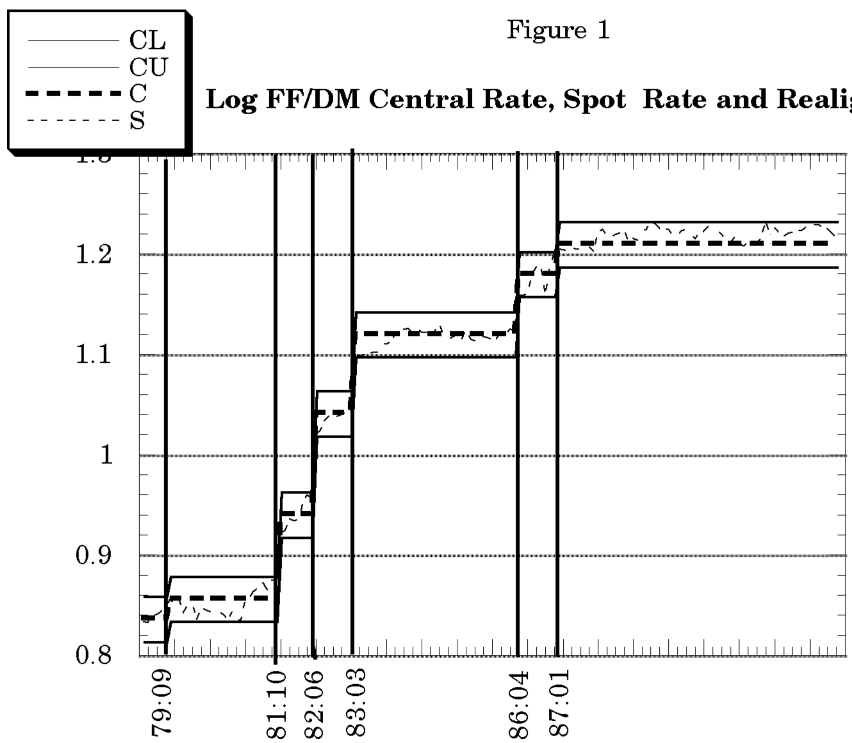
2.1 The Credibility of the ERM

Realignments of the central rates pose an important problem for the ERM. Since one of the principal motivations behind the exchange rate agreement was to foster exchange rate stability by ironing out excessive fluctuations, frequent realignments can endanger this objective by undermining the credibility of the target zone. The experience of the ERM since 1979 shows some differences over the years. By 1987, there were 11 realignments of various magnitudes. In only the first four years, central rates were adjusted seven times. There were no realignments between 1987 and 1992 except for the adjustment of the Italian Lira after this currency's band margin has been reduced to ± 2.25%. The study of the ERM before 1992 revealed a tendency toward a stable exchange rate system with no realignments. However, this tendency was interrupted by the 1992 crisis and the subsequent widening of band margins in 1993. This recent event brought the questions of credibility once more to the attention of policymakers and researchers.

For the FF/DM rate, there were six realignments during the sample period between 1979:03 and 1992:04. The realignment dates and the central FF/DM rate are presented in Figure 1. After the third devaluation in 1982, the realignment size decreases. A similar trend holds for the other ERM currencies. The lack of realignments after 1987 is mainly attributed to the Basle-Nyborg Agreement of 1987 which strengthened the intervention and policy coordination arrangements of the ERM by extending the credit facilities and by allowing countries to use these credit facilities before a currency reached the band limits.

Figure 1

Log FF/DM Central Rate, Spot Rate and Realignments



3 Testing Target Zone Credibility

There has been basically two methods proposed for testing target zone credibility. Each one will be briefly discussed below.

3.1 Rate of Return Bands

This method compares the observed interest rates with the interest rate bands implied by the target zone under a no-arbitrage condition. Svensson [19] applied this method for testing the credibility of the Swedish target zone.

Following Svensson [19] the annualized rate of return on a foreign currency investment in period t of duration τ months can be expressed as follows:

$$R_t^\tau = (1+i^*)(\frac{S_{t+\tau}}{S_t})^{\frac{12}{\tau}} - 1 \tag{1}$$

where S_t denotes the spot exchange rate in period t and i^* is the foreign interest rate. Within a target zone the spot exchange rate is restricted between the band limits:

$$\underline{S} \leq S \leq \overline{S} \tag{2}$$

where $\overline{S}$ and $\underline{S}$ are the upper and lower bands for the exchange rate, respectively. The exchange rate band implies that the rate of return will also be restricted to a band:

$$\begin{aligned} \underline{R_t^\tau} \leq R_t^\tau &\leq \overline{R_t^\tau} \\ \underline{R_t^\tau} &= (1+i^*)(\tfrac{\underline{S}}{S_t})^{\frac{12}{\tau}} - 1 \\ \overline{R_t^\tau} &= (1+i^*)(\tfrac{\overline{S}}{S_t})^{\frac{12}{\tau}} - 1 \end{aligned} \tag{3}$$

where $\overline{R}$ and $\underline{R}$ represent the corresponding bands for the rate of return. Under a credible target zone regime and the assumption of no arbitrage the observed domestic interest rate must lie inside the rate of return band given above. If for some periods the credibility of the target zone is jeopardized and domestic interest rates fall outside the bands then an agent can borrow (lend) abroad and lend (borrow) at home and earn arbitrage profits. Svensson [19] identifies these periods as reflecting lack of credibility of the target zone.

This approach is equivalent to testing whether expected future exchange rates calculated from the following uncovered interest parity relationship are inside or outside the target zone band:

$$S_{t,t+\tau} = S_t[(1+i_t)/(1+i_t^*)]^{\frac{\tau}{12}} \tag{4}$$

where $S_{t,t+\tau}$ is the expected value at time t of the exchange rate in period $t+\tau$. If the target zone is credible the expected future exchange rate should be within the target zone band.

This method however does not explicitly model devaluation expectations and the effect of the exchange rates within the band on expected realignments. Moreover, since it involves a simple comparison of the actual interest rates with the implied interest bands, no statistical judgment can be made concerning the degree of credibility. Chen and Giovannini [6] present empirical evidence that for ERM currencies, the interest differentials are a poor predictor of the central parity realignments.

The second approach that will be discussed below overcomes these drawbacks by explicitly modeling and estimating the expectations of devaluation.

3.2 Uncovered Interest Parity and Drift Adjustment Method

This method starts with decomposing the log of the spot exchange rate, s, into the log of the central parity, c and the log percentage deviation from the central parity x (exchange rate within the band hereafter):

$$s_t \equiv c_t + x_t \tag{5}$$

Then the expected realignment between t and $t+\tau$ can be expressed as :

$$E_t[\Delta c_{t+\tau}] = E_t[\Delta s_{t+\tau}] - E_t[\Delta x_{t+\tau}] \tag{6}$$

According to equation 6 expected realignment equals total expected depreciation minus the expected depreciation within the band. Under the assumption of uncovered interest rate parity the expected change in central parity, or the expected realignment, can be rewritten as:

$$E_t[\Delta c_{t+\tau}] = \delta^\tau - E_t[\Delta x_{t+\tau}] \tag{7}$$

where δ^τ is the interest rate differential between the home country and the foreign country for maturity τ. This formulation assumes that the expected devaluation of the spot rate is given by the interest rate differential implied by uncovered interest parity. Using a continuous time portfolio choice model Svensson [21] shows that for reasonable values of relative risk aversion and expected devaluation sizes the foreign exchange risk premium in a target zone is very small. Based on this finding the assumption of uncovered interest rate parity is a good approximation for the expected devaluation of the spot rate.

Equation 7 has empirical implications for testing the credibility of the target zone. Once the expected change of the exchange rate within the band is modeled one can obtain estimates of expected realignments. Rose and Svensson [18], Svensson [19, 20], Chen and Giovannini [5, 6] and Caramazza [3] use the same formulation to estimate realignment expectations.

Using this methodology the credibility of a target zone can be tested as follows. A confidence band for the expected realignment can be obtained by estimating the expected exchange rate within the band and subtracting its confidence interval from the interest differential. If the target zone is credible, zero must be contained in the confidence band for the expected realignment at all times. This is the approach taken by the empirical papers mentioned above.

The main challenge with this methodology is the estimation of the exchange rate expectations within the band. The presence of the band is part of the information set of rational agents and hence should be incorporated by the econometrician into the estimation procedure. Caramazza [3] uses a simple difference equation to estimate the expected devaluation within the band. A similar approach is taken by Svensson [19, 20] where he includes the domestic and foreign interest rates as additional explanatory variables. None of these studies explicitly account for the effect of the band on the movement of exchange rates within the band. In the target zone the log deviation from the central parity x_t (the exchange rate within the band) is restricted by the fluctuation band $-L \leq x_t \leq L$. By definition this variable is bounded and conventional methods such as OLS would result in biased estimates. Using the following OLS regression the nature of the bias can be demonstrated as follows:

$$x_t = \beta' y_t + \epsilon_t \tag{8}$$

OLS requires the error term to be uncorrelated with the regressors. However, the band restriction on the exchange rate within the band implies that the error term will also be censored:

$$-L - \beta' y_t \leq \epsilon_t \leq L - \beta' y_t \tag{9}$$

This censoring causes the error term to depend on the regressors and results in biased estimates. Chen and Giovannini [6] consider this problem explicitly and propose a logarithmic transformation for the exchange rate within the band. They employ the following transformation which results in an unconstrained variable:

$$v_t^* = ln(\frac{L + x_t}{L - x_t}), \qquad -L \leq x_t \leq L \tag{10}$$

Hence instead of estimating x_t they estimate the transformed and unbounded variable v_t^*. They find that accounting for the presence of the band significantly changes the results of the credibility test by narrowing the confidence bands. However the transformation they employed has been criticized since it lacks any theoretical rationale and can not be used to justify a similar transformation by rational agents when forming expectations.

This paper will use the limited dependent rational expectations method developed by Pesaran and Samiei [15] to model the movements of expected exchange rates within the band. The following section describes the methodology and the expected improvements that can be achieved utilizing it.

4 Econometric Methodology

4.1 Limited Dependent Variable Rational Expectations Model

The exchange rate within a target zone is a limited dependent variable censored outside the band margins. Economic agents will incorporate this fact into their information sets when forming expectations about exchange rate movements. For instance, if the French Franc is close to its upper band limit against the DM, economic agents would either expect this trend to be reversed if they believe in credible interventions by policymakers, or would expect this upward trend to continue if they expect a realignment. In order to integrate the limited-dependent nature of the exchange rate into the estimation process I will use a limited dependent variable rational expectations model (LTDRE Model hereafter). Pesaran and Samiei [15] use a similar model to estimate spot exchange rates (s) in a target zone. Here I apply their modeling strategy to estimate exchange rates within the band (x).

$$x_{t+\tau} = \begin{cases} L & \text{if} \quad x^*_{t+\tau} \geq L \\ x^*_{t+\tau} & \text{if} \quad -L < x^*_{t+\tau} < L \\ -L & \text{if} \quad x^*_{t+\tau} \leq -L \end{cases} \tag{11}$$

where $x^*_{t+\tau}$ is determined by:

$$x^*_{t+\tau} - x_t = \alpha + \gamma E_t[\Delta x_{t+\tau}] + \boldsymbol{\beta} \boldsymbol{y_{t+\tau}} + \boldsymbol{\delta} \boldsymbol{h_t} + \varepsilon_{t+\tau}, \qquad \varepsilon_t \sim N(0, \sigma^2_\varepsilon) \tag{12}$$

The model differs from a regular two-limit Tobit model in a significant way. For a variable generated by a two-limit Tobit model, the bias of ignoring the limited dependent nature of the data will be proportional to the number of censored data points in the sample. This will not generally be the case for this model. I assume that expectations of rational agents help to determine the exchange rate. Hence not only the estimation technique but also the rational expectations solution of the model must take into account the two-limit censoring of the variable.

4.1.1 Rational Expectations Solution

In order to solve the model I will assume rational expectations. The expectations of variables in $\boldsymbol{y_t}$ are assumed to be generated by the following model:

$$\boldsymbol{y_{t+\tau}} = \boldsymbol{R} \boldsymbol{z_t} + \boldsymbol{\nu}_t, \qquad \boldsymbol{\nu}_t \sim N(0, \Sigma) \tag{13}$$

The two error processes ε and ν are assumed to be uncorrelated at all lags. The formulation of the auxiliary model allows for several different specifications including lagged values of $\boldsymbol{y_t}$. If perfect foresight was assumed a prediction rule for $\boldsymbol{y_{t+\tau}}$ would not be necessary. Since the model incorporates rational expectations, the above process for the exogenous variables is assumed in order to model their rational expectations formed at t. Hence $\boldsymbol{z_t}$ includes variables that are known at time t. The band limits in this model are constant. Since the realignment affects the central rate and not the width of the fluctuation band, L, this is an innocuous assumption.

If the presence of bands is ignored, expectations of the exchange rate are given by:

$$E_t[x_{t+\tau}] = \frac{x_t + \boldsymbol{\beta} \boldsymbol{E_t}[\boldsymbol{y_{t+\tau}}] + \boldsymbol{\delta} \boldsymbol{E_t}[\boldsymbol{h_t}]}{(1 - \gamma)} \tag{14}$$

The appropriate solution, however, should account for the band if we assume that economic agents form their expectations rationally. In order to derive the rational expectations solution for the limited dependent variable I will follow the method described by Lee [11]. Rational expectations models for limited dependent variables were first introduced by Chanda and Maddala [4]. Several other studies considered different aspects of this issue including both calculation and existence of a solution under different assumptions. The solution method used in Pesaran and Samiei [15], although it corrects some of the previous errors in the literature, still fails to provide a completely accurate solution. Lee remedies these drawbacks by offering a general framework in which he proves the existence and uniqueness of the rational expectations solution for limited dependent variable models under fairly general distributional assumptions.

In the two-limit Tobit model, the observed dependent variable $x_{t+\tau}$ at time $t+\tau$ will be:

$$x_{t+\tau} = \min\{\mathrm{L}, \max\{x^*_{t+\tau}, -\mathrm{L}\}\} \tag{15}$$

The upper and lower limits are known at time t and are assumed to be constant. The margins of the band (L) in the ERM were determined by the 1979 agreement and are publicly announced. However, the recent widening of the band margin itself refutes the constancy assumption. Nevertheless, the period covered by this study extends until 1992, prior to this instance.

The agent at time t does not know whether $x_{t+\tau}$ is above or below the band margins. Let $I_{1,t+\tau}, I_{2,t+\tau}$ and $I_{3,t+\tau}$ be the dichotomous indicators representing the three different regimes:

$$\begin{aligned} I_{1,t+\tau} &= 1 \quad if \quad x^*_{t+\tau} \le -L \\ I_{2,t+\tau} &= 1 \quad if \quad x^*_{t+\tau} \ge L \\ I_{3,t+\tau} &= 1 \quad if \quad -L < x^*_{t+\tau} < L \end{aligned} \tag{16}$$

The probabilities for each regime are :

$$\begin{aligned} E_t[I_{1,t+\tau}] = \mathrm{Prob}(I_{1,t+\tau} = 1|t) = &\quad \Phi(\underline{\theta}) \\ E_t[I_{2,t+\tau}] = \mathrm{Prob}(I_{2,t+\tau} = 1|t) = &\quad 1 - \Phi(\overline{\theta}) \\ E_t[I_{3,t+\tau}] = \mathrm{Prob}(I_{3,t+\tau} = 1|t) = &\quad \Phi(\overline{\theta}) - \Phi(\underline{\theta}), \end{aligned} \tag{17}$$

where Φ is the cumulative distribution function of the standard normal distribution and $\overline{\theta}$ and $\underline{\theta}$ are given by:

$$\begin{aligned}
\overline{\theta} &= [L - \alpha - \gamma E_t[\Delta x_{t+\tau}] + x_t - \boldsymbol{\beta E_t[y_{t+\tau}]} - \boldsymbol{\delta h_t}]/\sigma \\
\underline{\theta} &= [-L - \alpha - \gamma E_t[\Delta x_{t+\tau}] + x_t - \boldsymbol{\beta E_t[y_{t+\tau}]} - \boldsymbol{\delta h_t}]/\sigma
\end{aligned}$$

with

$$\begin{aligned}
\sigma^2 &= \sigma_\varepsilon^2 + \boldsymbol{\beta'\Sigma\beta} \\
\boldsymbol{E_t[y_{t+\tau}]} &= \boldsymbol{Rz_t}
\end{aligned} \tag{18}$$

Equation 15 can be written as :

$$x_{t+\tau} = -LI_{1,t+\tau} + I_{2,t+\tau}L + I_{3,t+\tau}x^*_{t+\tau} \tag{19}$$

Using the regime probabilities the expectation of the exchange rate within the band is:

$$\begin{aligned}
E_t[x_{t+\tau}] &= [\Phi(\overline{\theta}) - \Phi(\underline{\theta})][\alpha + \gamma E_t[x_{t+\tau}] + (1-\gamma)x_t + \boldsymbol{\beta E_t[y_{t+\tau}]} + \boldsymbol{\delta h_t}] \\
&\quad -[\phi(\overline{\theta}) - \phi(\underline{\theta})]\sigma - L\Phi(\underline{\theta}) + L[1 - \Phi(\overline{\theta})].
\end{aligned} \tag{20}$$

Equation 20 presents the rational expectations solution for the expected exchange rate within the band when the band limits of the target zone are accounted for. Apparently, $E_t[x_{t+\tau}]$ is a nonlinear function of the underlying parameters and a closed form solution cannot be obtained. However, as shown by Lee [11] for any value of γ, a solution exists and it is unique for $\gamma \leq 1$. Following Pesaran and Samiei [15] I reproduce a simple numerical examination of this relationship in Figure 2. For this experiment the fundamentals were generated according to $w_t = w_t^e + \xi_t$, where $\xi_t \sim N(0, \sigma)$. The values of w_t^e are chosen from the range [-100,100]. The rational expectations solution is calculated iteratively using equation 20 for $\sigma = 20$ and $\gamma = 0.5$. Figure 2 displays the familiar S-shape for the expected exchange rate within the target zone. Unlike the continuous time target zone models, where fundamentals determine the exchange rate, the deterministic relationship here is between the fundamentals and the expected exchange rates. The exchange rate is related to fundamentals through the stochastic S-shape relationship. None of the estimation methods thus far employed for the expected exchange rates within the band have this property. Hence employing this model enables me to explicitly incorporate a stochastic version of one of the implications of the target zone literature into the estimation procedure.

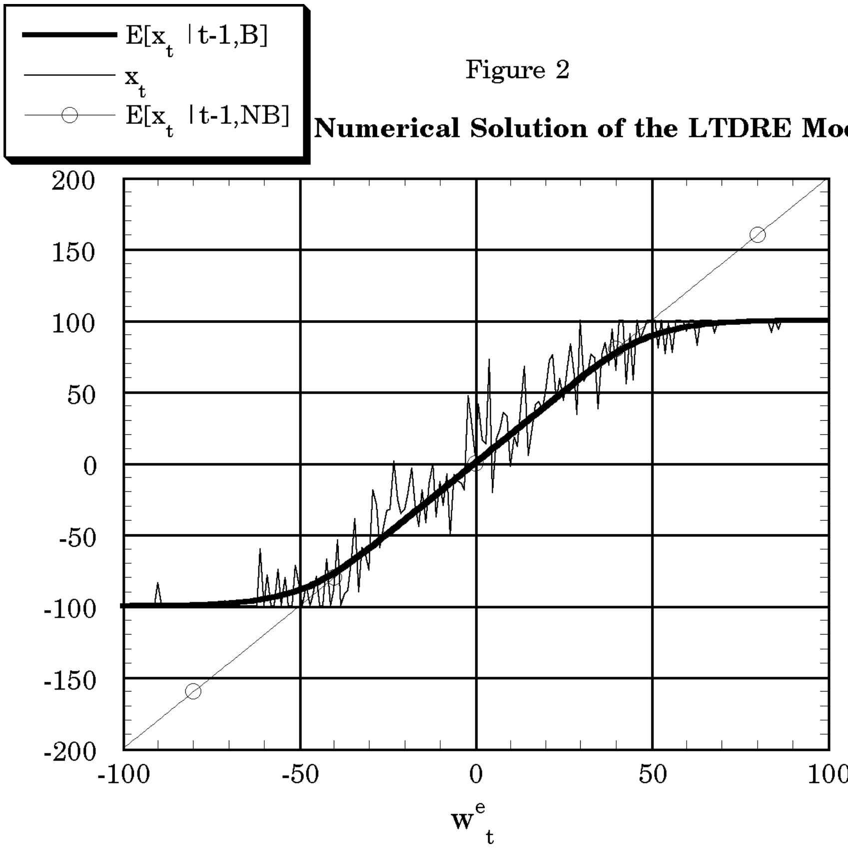


Figure 2

Numerical Solution of the LTDRE Model

4.2 Estimation Method

I employ the two-step maximum likelihood (2SML) technique to estimate expected depreciation within the band. The log-likelihood function for the model is:

$$
\begin{aligned}
log(\mathcal{L}) \quad = \quad & \sum_0 log[\Phi(\underline{\theta'}] + \sum_2 log[1-\Phi(\overline{\theta'})] \\
& -n\ log(2\pi\sigma_\varepsilon^2)/2 \\
& -\sum_1 [\Delta x_{t+\tau} - \alpha - \gamma(E_t[x_{t+\tau}] - x_t) - \boldsymbol{\beta' y_{t+\tau}} - \boldsymbol{\delta h_t}]^2/2\sigma_\varepsilon^2 \ ,
\end{aligned}
\tag{21}
$$

with

$$
\begin{aligned}
\overline{\theta'} \quad &= \quad [L - \alpha - \gamma E_t[\Delta x_{t+\tau}] + x_t - \boldsymbol{\beta' y_{t+\tau}} - \boldsymbol{\delta h_t}]/\sigma_\varepsilon \\
\underline{\theta'} \quad &= \quad [-L - \alpha - \gamma E_t[\Delta x_{t+\tau}] + x_t - \boldsymbol{\beta' y_{t+\tau}} - \boldsymbol{\delta h_t}]/\sigma_\varepsilon \ ,
\end{aligned}
\tag{22}
$$

where n is the total number of non-censored observations and $E_t[x_{t+\tau}]$ is given by equation 20. Indices $0, 1, 2$ refer to observations at the lower limit, within the band and at the upper limit of the target zone, respectively.

What differentiates this model from an ordinary two-limit Tobit model is the dependence of $E_t[x_{t+\tau}]$ on the underlying parameters of the log-likelihood function. This dependence requires a numerical solution for $E_t[x_{t+\tau}]$ each time derivatives of the log-likelihood function are calculated in the estimation stage. Note that when there are no observations at the boundaries the first two terms in the log-likelihood function disappear. In an ordinary two-limit Tobit model this would permit the use of ordinary least squares (OLS) without causing a bias in the parameter estimates. However, here the very presence of the band influences devaluation expectations and thus the outcome, even if no observations are censored. Accordingly, the estimates obtained from a model that ignores the effect of the band on expectations will still be biased even when there are no censored observations in the sample. The problem in this case arises from the misspecification of the expectations.

The 2SML estimator in this context is equivalent to the two-step procedure discussed in Pagan [14]. It involves estimating the parameters of the above log-likelihood function conditional on the parameters of the $\mathbf{y_t}$ process obtained from a first step OLS estimation. The two-step estimation is necessary in order to impose restrictions arising from the dependence of $E_t[x_{t+\tau}]$ on the parameters of the $\mathbf{y_t}$ process. 2SML will be asymptotically less efficient than the full information maximum likelihood (FIML) estimates since the first step parameter estimates, $\mathbf{R}$ and $\mathbf{\Sigma}$, will not take account of the dependence of the second step parameters on the parameters of the $\mathbf{y_t}$ process. Nevertheless, the 2SML estimator is computationally more efficient and is shown to perform reasonably well in small samples. Pesaran and Samiei [15] perform Monte Carlo studies and compare the properties of parameter estimates for both FIML and 2SML when the bands are taken into account, as well as OLS estimates which ignore the band. The efficiency of the estimates obtained using 2SML is superior to that of OLS. For our purposes this has a direct bearing on the confidence interval of the realignment expectations. Another feature of this model is that the determination of the exchange rate is linked to fundamentals. Previous studies as discussed above employ simple autoregressive specifications for the exchange rate within the band. The common finding that neither a monetary nor a portfolio balance model explains the behavior of exchange rates better than a simple autoregressive model is not necessarily true for exchange rates in a target zone. Pesaran and Samiei [16] offer empirical evidence for the Deutsche Mark/French Franc exchange rate using both the monetary and the portfolio balance model. Their results show that a model which takes appropriate consideration of the bands can explain 75 percent of the variation in spot exchange rates.

5 Empirical Results

5.1 The Data

The study covers the two largest countries in the ERM, Germany and France. Since the Deutsche Mark is the only currency that never underwent a bilateral devaluation, the model will be estimated for the bilateral bands relative to the Deutsche Mark.

I use a two-country monetary model for exchange rate determination. The fundamental variables, $\mathbf{y_t}$, are the relative money supplies and relative industrial outputs. In order to capture possible lagged adjustments I also include lagged values of these variables, exchange rates and the interest rate differential ($\mathbf{h_t}$). The highest common frequency for these data is monthly. Data are obtained from International Financial Statistics and OECD Main Economic Indicators data files. The value of τ that will be used in this study is three months. The sample covers the period from 1979:03 until 1992:04. The definitions of the variables are as follows:

$$
\begin{aligned}
m_t &= \text{log of the ratio of French to German money supplies (M1+Quasi-Money)} \\
q_t &= \text{log of the ratio of French to German industrial output (Index of Industrial Production)} \\
i_t &= \text{interest rate differential : PIBOR-FIBOR} \\
&= \text{3-month Paris Interbank Offer Rate - 3-month Frankfurt Interbank Offer Rate} \\
x_t &= \text{FF/DM (log of the ratio of the US dollar exchange rates)}
\end{aligned}
$$

5.2 Two-limit Censored Model

I employ the Quasi-Newton maximization routine of Davidon-Fletcher-Powell with numerical gradients to estimate the parameters of the log-likelihood function. The numerical solution for $E_t[x_{t+\tau}]$ at each iteration is calculated using Brent's root finding algorithm for nonlinear functions. Further discussion of these algorithms can be found in Press *et al.* [17].

The first-step estimates of $\mathbf{R}$ and $\mathbf{\Sigma}$ are obtained using OLS. The variance-covariance matrix of the first step parameters is calculated using a Newey-West correction for a moving average (MA) component of order two. This correction is necessitated by the overlapping data problem in estimating parameters of the $\mathbf{y_{t+\tau}}$ process in equation 13. The auxiliary regression in this first stage includes lagged values of $\mathbf{y_{t+\tau}}$, namely an autoregressive scheme with 12 lags. However, since the information set may include variables known only at time t, the projection horizon ($\tau = 3$) is longer than the sampling interval of the data. The use of overlapping observations implies a MA component of order $\tau - 1$ in the error process.

The results of this model are presented in Table 1. Calculation of the variance-covariance matrix of the estimates is based on the method described by Murphy and Topel [13]. Since we apply a two-stage estimation method the variance of the second stage estimates must be adjusted to account for the sampling error in the first stage estimates. The resulting variance covariance matrix takes the following form:

$$\Sigma_{\Gamma}^{-1}[\Omega' \Sigma_R \Omega]\Sigma_{\Gamma}^{-1} \tag{23}$$

where

$$\begin{aligned} \Gamma &= (\alpha, \gamma, \beta, \delta) \\ \Omega &= -E\frac{\partial^2 \mathcal{L}}{\partial R \partial \Gamma'} \\ \Sigma_R &= \text{variance covariance matrix of first step estimates} \end{aligned} \tag{24}$$

The estimation results indicate that depreciation expectations significantly affect the determination of the exchange rate within the band. The negative coefficient implies that agents' expectations affect the exchange rate negatively. Intuitively, this can happen if policymakers foresee agents' expectations and try to counteract this trend by changing policy variables. For instance, if agents expect the FF to depreciate against DM, policymakers in both countries could intervene in money markets by increasing the German money supply and by decreasing French money supply in order to counteract the effect of expectations. The positive coefficients on current and 3-month lagged relative money supply variable and the negative coefficients on the interest rate differential support this possibility in this Bilson [2] and Frenkel [7] type monetary model of exchange rate determination. The position of the exchange rate within the band has a significantly negative effect on the exchange rate after three months. This is in accordance with the mean-reversion property of the exchange rate within the band established in the previous literature.

The parameter estimates in Table 1 represent the partial derivatives of the expected latent variable with respect to the regressors and hence are not readily comparable to those obtained from the unbounded models which have the usual multiplier interpretation. The multipliers for the observed depreciation must be calculated using the partial derivatives of the prediction equation given below:

$$\begin{aligned} E[\Delta \hat{x}_{t+3}] &= -L\Phi(\underline{\theta}') + L[1 - \Phi(\overline{\theta'})] \\ & [\Phi(\overline{\theta'}) - \Phi(\underline{\theta}')]\{\alpha + \gamma E_t[\Delta x_{t+3}| - L < x^*_{t+3} < L] + \\ & \boldsymbol{\beta E_t[y_{t+3}] + \delta h_t}\} + \sigma_\varepsilon[\phi(\underline{\theta}') - \phi(\overline{\theta'})] \end{aligned} \tag{25}$$

where the rational expectations solution conditional on the exchange rate being within the band is given by the following nonlinear function:

$$\begin{aligned} E_t[\Delta x_{t+3}| - L < x^*_{t+3} < L] &= [\Phi(\bar{\theta}) - \Phi(\underline{\theta})]\{\alpha + \gamma E_t[\Delta x_{t+3}| - L < x^*_{t+3} < L] + \\ & x_t + \boldsymbol{\beta E_t[y_{t+3}] + \delta h_t}\} + \sigma[\phi(\underline{\theta}) - \phi(\bar{\theta})] \end{aligned} \tag{26}$$

Note that the calculation of the probabilities in equation 25, $\Phi(\underline{\theta}')$, and $\Phi(\overline{\theta'})$ requires a numerical solution for the rational expectation of the exchange rate based on the appropriate conditioning set in each case. The rational expectations solution for the exchange rate will be different depending on the regime and hence will affect the probability of that regime. This effect does not depend on the actual number of observations that are censored since the predicted probability for each regime in the rational expectation solution is generated by the total sample. This fact introduces another nonlinearity into the confidence bands of expected realignments. Even if the point estimates of the parameters are similar to those obtained from the unbounded models estimated using OLS and 2SML (RE model without the band) the confidence intervals will differ due to this nonlinearity.

The nonlinearity of the model necessitates a quadratic approximation to the prediction rule in order to calculate the confidence interval. The details of this derivation are presented in the appendix.

One of the common findings of the target zone literature has been the presence of conditional heteroscedasticity of the exchange rate within the band. Tobit models are not immune to this kind of misspecification and lose their consistency properties. Testing and correcting for conditional heteroscedasticity in our model is not trivial, since both the estimation and the solution to the rational expectations model would require major modifications. Moreover, a simple residual based test would be misleading since the residual of the model is truncated and the test statistic based on it will be biased as well. Nevertheless as a diagnostic tool I performed an ARCH test of order 12 using the residuals of the model obtained by taking the difference of the dependent variable and the prediction obtained using equation 25. The value of the regression F-statistic for this case is 2.8669 with a significance level of 0.0016. I then performed the same test dropping the 4 observations for which the band limits are reached and hence a residual contribution to the loglikelihood function can not be calculated. As expected the value of the test statistic drops to 2.0309 with a significance level of 0.0329 rejecting the alternative for conditional heteroscedasticity. As another diagnostic tool, which overcomes the problem of truncated errors in an ARCH test using OLS, I derived the Lagrange Multiplier test for the LTDRE model using the methodology provided by Lee and Maddala [12] for standard one limit Tobit models. However, although an extension of their methodology to standard two limit models with conditional heteroscedasticity is feasible, the same generalization for the LTDRE model requires the evaluation of a T-dimensional integral for the rational expectations solution and would not be feasible. Hence instead of testing for time variation in the conditional variance of the error term, I test a simpler form of heteroscedasticity of the following form:

$$\sigma^2_{t,\varepsilon} = \mathcal{G}(\alpha^{'} + s_t \delta^{'}) \tag{27}$$

where s_t is a vector of exogenous variables (without a constant term) in the model and the null hypothesis is $H_0 : \delta^{'} = 0$. Since conditional heteroscedasticity has been established for the exchange rate within the band, it seems reasonable to include the 12-month lagged exchange rate in s_t. The derivation of the LM test is based on the derivative of the unrestricted loglikelihood with respect to $\delta^{'}$evaluated at the null. It is distributed as a χ^2 with one degrees of freedom, since the restriction involves one parameter, $\delta^{'}$. The value of the test statistic is 0.15882 with a tail probability of 0.69025 implying that the null can not be rejected at the 5% level. Based on these results it can be argued that the LTDRE model captures a better approximation to the exchange rate within the band and hence the common finding of conditional heteroscedasticity might be reflecting the misspecification of the linear models used in the literature.

5.3 The Rational Expectations Model Without Bands

In order to assess the importance of nonlinearities introduced by rational expectations in this limited dependent variable framework I estimate the model without considering the exchange rate band. The rational expectations solution for the expected exchange rate when the band limits are ignored is given in equation 14. Substituting this solution into equation 12 I obtain the unbounded rational expectations model (The RE model without the band hereafter):

$$E_t[\Delta x_{t+\tau}] = \frac{\alpha}{1-\gamma} + \frac{\gamma \boldsymbol{\beta E_t[y_{t+\tau}]}}{1-\gamma} + \boldsymbol{\beta y_{t+\tau}} + \frac{\boldsymbol{\delta h_t}}{1-\gamma} + \varepsilon_{t+\tau} \tag{28}$$

This model ignores the band limits both at the stage of expectation formation and estimation. Since there are only 4 censored observations out of 146 any difference between this model and the model that properly accounts for the band will be due to the effect of the band on the expectation formation and not on the exchange rate itself.

This model is estimated using the 2SML method in order to impose the parameter restrictions implied by the rational expectations solution. As in the previous model, the variance-covariance matrix of the estimates is corrected using the same methodology. The estimation results are presented in Table 2. Although none of the fundamental variables are significantly different from zero, expected depreciation has a significantly positive coefficient. The confidence interval for the expected depreciation is calculated using a similar approximation as before.

5.4 The OLS Model

As discussed previously, the bias introduced into OLS parameter estimates when the bounded nature of the dependent variable is ignored is proportional to the number of observations that are censored. Greene [9] proves that the slope parameters of the OLS model will be biased downward in a one limit Tobit model and offers a method to correct for the bias. However, in our model the solution to the rational expectations model provides a second source of possible bias that can not be corrected using this method. The bias in that case is of the nature of an errors in variables problem, since ignoring the bands will cause an error in the rational expectations solution that is correlated with the models error term.

For comparison purposes I estimate the model using OLS. The results are presented in Table 3. Similar models have been used in the literature to estimate the exchange rate within the band. Caramazza's [3] model includes a constant term and the three-period-lagged exchange rate within the band. Svensson [19, 20] includes the domestic and foreign interest rates as well.

The results indicate that none of the fundamental variables' parameters except that of the three-month lagged interest rate differential are significantly different from zero. The three-month lagged exchange rate has a significant and negative coefficient confirming the mean reversion of the exchange rate within the band.

5.5 Confidence Intervals and Expected Realignments

Using Equation 7 I subtract the confidence interval of the expected 3-month depreciation from the interest rate differential in order to calculate the confidence intervals for expected realignment. Figures 3 and 4 compare the results of the LTDRE model with those from OLS and the RE model without the band. The OLS model gives rise to narrower confidence bands for the target zone as compared to the two RE models. The LTDRE model generates the widest band among the three models. This result contradicts the earlier findings of Chen and Giovannini [6] who obtained narrower band margins for their model. The nonlinearity of the LTDRE model gives rise to asymmetrical confidence bands and the width of the band varies considerably over the prediction horizon. For the beginning of the ERM the confidence band is very narrow indicating small expected realignment sizes. After the first three realignments the band width widens considerably. This suggests a reputation effect. If economic agents bestowed unwarranted trust on the new ERM mechanism at the outset, they were quick to learn from the misfortunes of the system. After 1990, this trend reverses itself towards a narrower confidence band which might be a consequence of the credibility-reinforcing Maastricht treaty.

Figure 3

95% Confidence Interval for Expected Realignment

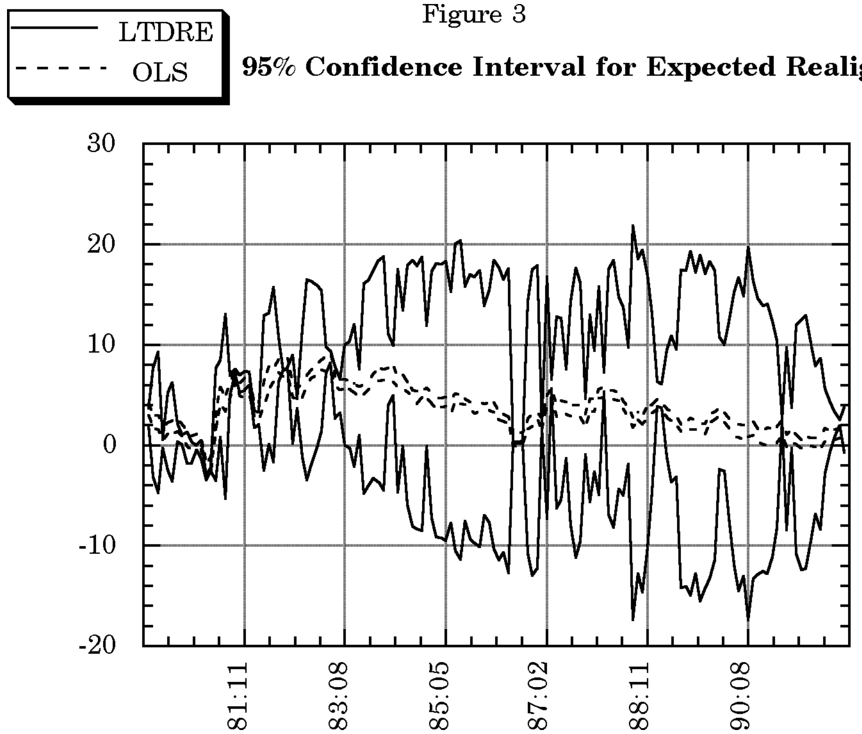
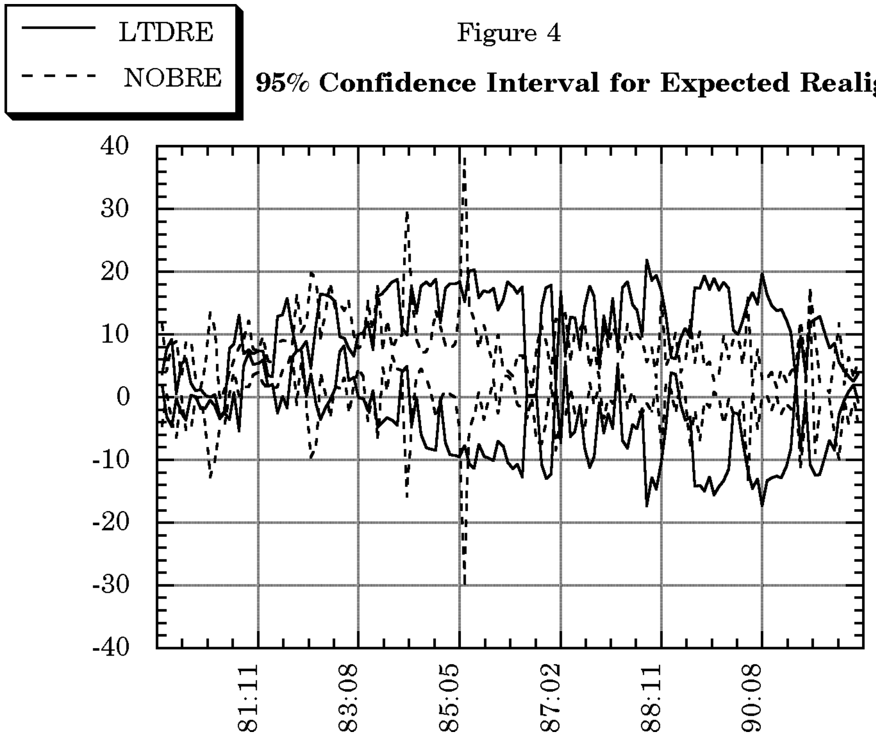


Figure 4

95% Confidence Interval for Expected Realignment



The confidence band of the OLS model is almost always above zero, rejecting the credibility of the ERM throughout the sample. The RE model without the band indicates a similar lack of credibility, however with more periods of credibility.

Figure 5, 6, and 7 show the zero crossings of the confidence bands of the three models. A spike upwards indicates that the lower confidence band is above zero, pointing to an expected depreciation of the FF central rate against the DM. Similarly a spike downwards implies an expected appreciation of the FF/DM central rate. All the three models predict an expected appreciation of the central rate for the period 81:03-81:04.

Figure 5

OLS Model

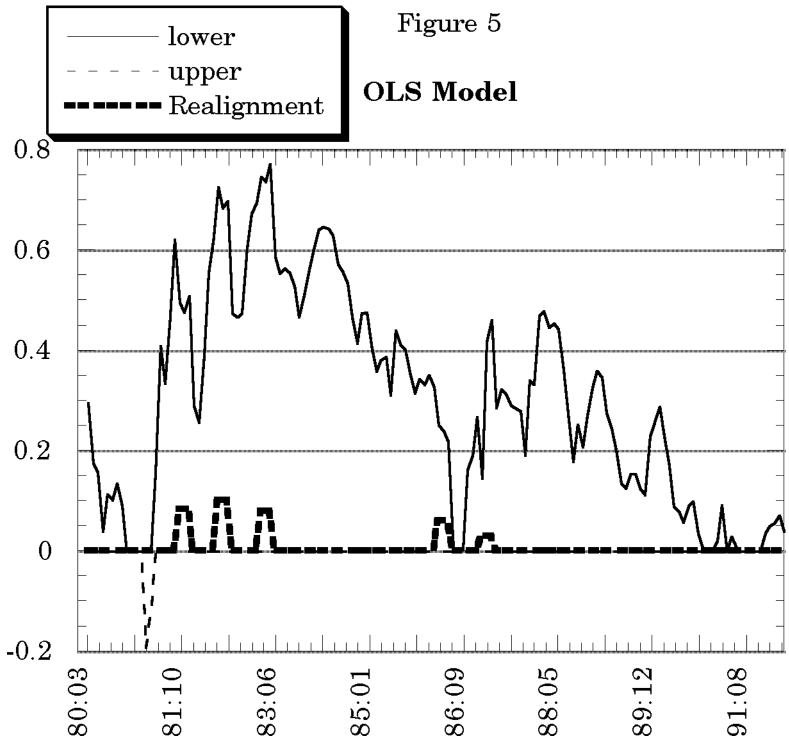


Figure 6

Unbounded RE Model

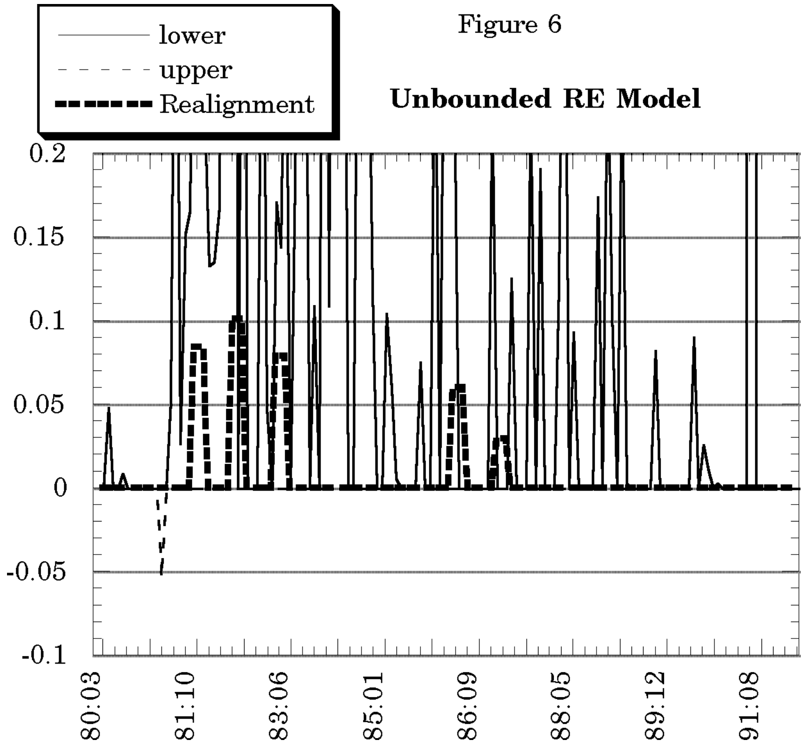
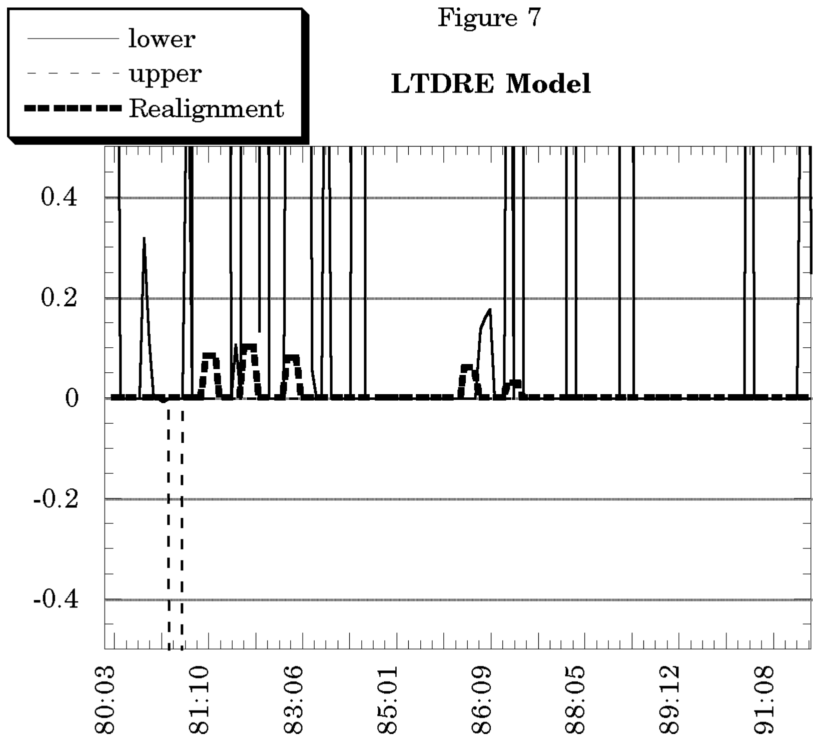


Figure 7

LTDRE Model



The OLS model always predicts an expected depreciation except for the periods 80:11-81:04, 86:07-86:08, 90:12-91:01, and 91:07-91:11. Throughout the prediction horizon the width of the confidence band does not vary considerably. Nevertheless, after 1988 the expected realignment size decreases.

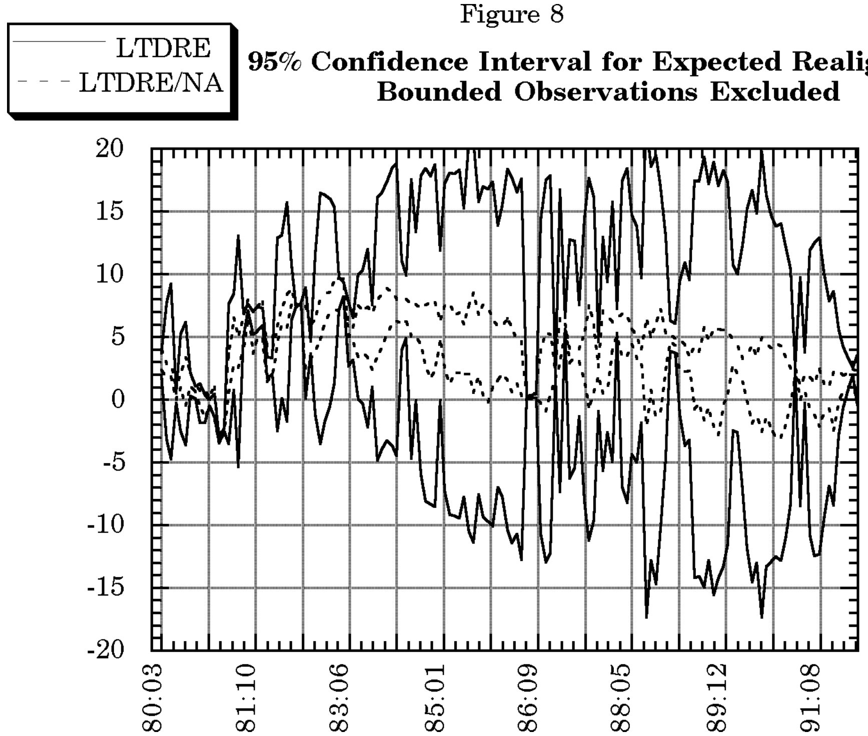
The RE model without the band has more zero crossings indicating several periods with credibility and several others lacking it. It predicts all the five realignments with correct direction, but also predicts several others that failed to materialize. It also suggests a decline in expected realignments after 1990.

The LTDRE model is able to predict all five realignments with the correct sign. Moreover the number of expected realignments are considerably fewer than those of the other models. The model is able to identify long periods of the sample when there were no expectations of realignment. Moreover, the frequency of zero crossing decreases after 1987, which corresponds to the period during which there are no realignments in the data for the FF/DM exchange rate. The model is superior to the other models in its prediction of identifying the right periods of the target zone as lacking credibility. However, the width of the confidence band is larger than those obtained from the OLS and the RE model without the band. This suggests that the expected size of realignment predicted by the LTDRE model is much higher than the other models.

It can be argued that the four observations which are on the band limits are driving the estimates for the LTDRE model. In order to test this hypothesis I reestimated the LTDRE model dropping these four observations. Figure 8 displays the comparison of the confidence intervals of this LTDRE model with the original one. The width of the confidence band decreases considerably although it still is wider than that obtained from the OLS model. Based on these results it can be argued that the bounded nature of the data is indeed the main cause in obtaining the differences in the width of the confidence bands of expected realignment obtained from the Tobit model. However, this finding only strengthens the rationale for modeling the exchange rate using a technique that takes account of the bounded nature of the data.

Figure 8

95% Confidence Interval for Expected Realignment
Bounded Observations Excluded



6 Conclusion

In conclusion I find that the limited dependent variable rational expectations model is superior to the simple OLS model and the RE model without the band in estimating the three-month depreciation of the FF/DM exchange rate within the ERM target zone. The confidence bands for expected realignments are wider than those of the two other models, implying that modeling the data using the two-limit Tobit model significantly modifies the credibility tests for expected realignments.

The LTDRE Model predicts all five realignments of the FF/DM rate during the sample period and is also able to identify the periods without a realignment with much higher accuracy than the comparable unbounded models. The confidence band at the beginning of the ERM agreement is relatively narrow as compared to the period after the first four realignments. This finding is in accordance with the reputation argument that after realignments occur, the expected realignment size increases without necessarily excluding possibility of no realignments. After 1990 the confidence band starts narrowing. This period can be identified as a reinforcement of credibility in the ERM due to the Maastricht treaty.

A Appendix: Confidence Interval of the LTDRE Model

The confidence interval of the predicted depreciation within the band is calculated using the following quadratic approximation:

$$\mathrm{Var}(E_t[\Delta \hat{x}_{t+3}]) = g_\Gamma \Sigma_\Gamma g_\Gamma'$$

where

$$g_\Gamma = \frac{\partial E_t[\Delta \hat{x}_{t+3}]}{\partial \Gamma}$$

and is given below :

$$\begin{aligned}
\frac{\partial E_t[\Delta \hat{x}_{t+3}]}{\partial \alpha} &= \frac{\partial \Phi(\underline{\theta}')}{\partial \alpha}\underline{\theta}\sigma - \frac{\partial \Phi(\overline{\theta}')}{\partial \alpha}\overline{\theta}\sigma + [\Phi(\overline{\theta}') - \Phi(\underline{\theta}')] \times \\
&\quad \{1 + \gamma \frac{\partial E_t[x_{t+3}| - L < x^*_{t+3} < L]}{\partial \alpha}\} + \sigma_\varepsilon[\frac{\partial \phi(\underline{\theta}')}{\partial \alpha} - \frac{\partial \phi(\overline{\theta}')}{\partial \alpha}] \\
\frac{\partial E_t[\Delta \hat{x}_{t+3}]}{\partial \gamma} &= \frac{\partial \Phi(\underline{\theta}')}{\partial \gamma}\underline{\theta}\sigma - \frac{\partial \Phi(\overline{\theta}')}{\partial \gamma}\overline{\theta}\sigma + [\Phi(\overline{\theta}') - \Phi(\underline{\theta}')] \times \\
&\quad \{\gamma \frac{\partial E_t[x_{t+3}| - L < x^*_{t+3} < L]}{\partial \gamma} + (E_t[x_{t+3}| - L < x^*_{t+3} < L] - x_t)\} + \\
&\quad \sigma_\varepsilon[\frac{\partial \phi(\underline{\theta}')}{\partial \gamma} - \frac{\partial \phi(\overline{\theta}')}{\partial \gamma}] \\
\frac{\partial E_t[\Delta \hat{x}_{t+3}]}{\partial \boldsymbol{\beta}} &= \frac{\partial \Phi(\underline{\theta}')}{\partial \boldsymbol{\beta}}\underline{\theta}\sigma - \frac{\partial \Phi(\overline{\theta}')}{\partial \boldsymbol{\beta}}\overline{\theta}\sigma + [\Phi(\overline{\theta}') - \Phi(\underline{\theta}')] \times \\
&\quad \{\gamma \frac{\partial E_t[x_{t+3}| - L < x^*_{t+3} < L]}{\partial \boldsymbol{\beta}} + E_t\boldsymbol{y_{t+3}}\} + \\
&\quad \sigma_\varepsilon[\frac{\partial \phi(\underline{\theta}')}{\partial \boldsymbol{\beta}} - \frac{\partial \phi(\overline{\theta}')}{\partial \boldsymbol{\beta}}] \\
\frac{\partial E_t[\Delta \hat{x}_{t+3}]}{\partial \boldsymbol{\delta}} &= \frac{\partial \Phi(\underline{\theta}')}{\partial \boldsymbol{\delta}}\underline{\theta}\sigma - \frac{\partial \Phi(\overline{\theta}')}{\partial \boldsymbol{\delta}}\overline{\theta}\sigma + [\Phi(\overline{\theta}') - \Phi(\underline{\theta}')] \times \\
&\quad \{\gamma \frac{\partial E_t[x_{t+3}| - L < x^*_{t+3} < L]}{\partial \boldsymbol{\delta}} + \boldsymbol{h_t}\} + \\
&\quad \sigma_\varepsilon[\frac{\partial \phi(\underline{\theta}')}{\partial \boldsymbol{\delta}} - \frac{\partial \phi(\overline{\theta}')}{\partial \boldsymbol{\delta}}]
\end{aligned}$$

where

$$\frac{\partial E_t[x_{t+3}|-L<x^*_{t+3}<L]}{\partial\alpha} = \frac{\frac{-L}{\sigma}[\phi(\bar{\theta})+\phi(\underline{\theta})]+[\Phi(\bar{\theta})-\Phi(\underline{\theta})]}{1-\gamma[\Phi(\bar{\theta})-\Phi(\underline{\theta})]+\gamma\frac{L}{\sigma}[\phi(\bar{\theta})+\phi(\underline{\theta})]}$$

$$\frac{\partial E_t[x_{t+3}|-L<x^*_{t+3}<L]}{\partial\gamma} = \frac{\partial E_t[x_{t+3}|-L<x^*_{t+3}<L]}{\partial\alpha}(E_t[x_{t+3}|-L<x^*_{t+3}<L]-x_t)$$

$$\begin{aligned}\frac{\partial E_t[x_{t+3}|-L<x^*_{t+3}<L]}{\partial\boldsymbol{\beta}} &= \{-\frac{L}{\sigma^2}\phi(\bar{\theta})[\sigma E_t\boldsymbol{y_{t+3}}+\Sigma\boldsymbol{\beta}\bar{\theta}]-\frac{L}{\sigma^2}\phi(\underline{\theta})[\sigma E_t\boldsymbol{y_{t+3}}+\Sigma\boldsymbol{\beta}\underline{\theta}]+\\ &\quad [\phi(\underline{\theta})-\phi(\bar{\theta})]\frac{\Sigma\,\boldsymbol{\beta}}{\sigma}\}\times\\ &\quad \frac{1}{1-\gamma[\Phi(\bar{\theta})-\Phi(\underline{\theta})]+\gamma\frac{L}{\sigma}[\phi(\bar{\theta})+\phi(\underline{\theta})]}\end{aligned}$$

$$\frac{\partial E_t[x_{t+3}|-L<x^*_{t+3}<L]}{\partial\boldsymbol{\delta}} = \frac{-\frac{L}{\sigma}[\phi(\bar{\theta})+\phi(\underline{\theta})]+[\Phi(\bar{\theta})-\Phi(\underline{\theta})]\boldsymbol{h_t}}{1-\gamma[\Phi(\bar{\theta})-\Phi(\underline{\theta})]+\gamma\frac{L}{\sigma}[\phi(\bar{\theta})+\phi(\underline{\theta})]}$$

Table 1: 2SML Estimates of the LTDRE model : Dependent variable Δx_{t+3}†

Independent Variables	Parameter Estimates
Intercept	-5.322
	(-0.271)
$E_{t-3}[x_t] - x_{t-3}$	-0.588
	(-2.990)
m_t	3.214
	(0.272)
q_t	-1.536
	(-0.078)
m_{t-3}	6.251
	(39.137)
m_{t-12}	-5.058
	(-30.697)
q_{t-3}	-0.912
	(-0.471)
q_{t-12}	1.799
	(0.099)
i_{t-3}	-0.392
	(-22.849)
i_{t-12}	-0.182
	(-5.090)
x_{t-3}	-1.762
	(-3.583)
x_{t-12}	-0.076
	(-0.297)
σ_ε	0.950
Maximized Loglikelihood	-199.474
$R^2 = 1 - [\sigma^2/var(\Delta x_{t+3})]$	0.399

†t-statistics are in parentheses.

Table 2: 2SML Estimates of the RE model without the band: Dependent variable Δx_{t+3}†

Independent Variables	Parameter Estimates
Intercept	-1.304
	(-0.338)
$E_{t-3}[x_t] - x_{t-3}$	0.662
	(2.446)
m_t	2.606
	(0.932)
q_t	-0.139
	(-0.001)
m_{t-3}	-0.541
	(-0.087)
m_{t-12}	-1.037
	(-0.089)
q_{t-3}	-0.215
	(-0.035)
q_{t-12}	0.329
	(0.002)
i_{t-3}	-0.083
	(-0.614)
i_{t-12}	-0.034
	(-0.153)
x_{t-3}	-0.237
	(-0.771)
x_{t-12}	-0.012
	(-0.296)
σ_ε	0.926
Maximized Loglikelihood	-196.033
$R^2 = 1 - [\sigma^2/var(\Delta x_{t+3})]$	0.428

†t-statistics are in parentheses.

Table 3: OLS Estimates without taking account of the band: Dependent variable Δx_{t+3}†

Independent Variables	Parameter Estimates
Intercept	-3.301
	(-1.747)
x_{t-3}	-0.701
	(-7.240)
m_t	3.559
	(0.799)
q_t	-1.310
	(-0.447)
m_{t-3}	2.421
	(0.826)
m_{t-12}	-3.258
	(-0.979)
q_{t-3}	-0.619
	(-0.606)
q_{t-12}	1.477
	(0.501)
i_{t-3}	-0.2431
	(-2.991)
i_{t-12}	-0.109
	(-0.902)
x_{t-12}	-0.038
	(-0.413)
σ_ε	0.926
R^2	0.424

†t-statistics are in parentheses.

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