**Assessing the credibility of a target zone:
Evidence from the EMS***

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ABSTRACT

In this paper we provide some new evidence on the credibility of the ERM. Our paper differs from the previous literature in three main respects. First, its main contribution is the use of several credibility indicators, some of them never been applied before to all the currencies under study. This allows to strengthen the results obtained in this paper. Second, we analyse a longer period than that considered in previous studies, covering the complete EMS history. Third, we have carried out a simple comparison of the prediction qualities of the different indicators, in order to explore their ability to capture the main ERM events.

Our results suggest credibility gains for most of the currencies before the monetary turmoil in 1992, followed by generalised credibility losses. After the widening of the fluctuation bands, there is evidence of a gradual improvement in credibility. Finally, the marginal credibility measure seems to be the best credibility indicator to capture the main events in the EMS history.

JEL classification numbers: C22, F31, F33

KEY WORDS: Credibility, Target zones, European Monetary System

1. Introduction

The European Monetary System (EMS) was initially planned as an agreement to reduce exchange rate volatility for a Europe in transition to a closer economic integration. Following its inception in March 1979, a group of European countries linked their exchange rates through formal participation in the Exchange Rate Mechanism (ERM). The essence of the ERM was that each participating country had an allowed range (target zone) within it its currency could fluctuate with respect to the others. In order to keep the exchange rates within the margins, the participating countries were obliged to intervene in the foreign exchange market if a currency approached the limits of its band. The realignment of the parities by the monetary authorities was possible, provided that all the members of the EMS agreed.

The fluctuation bands were originally set at $\pm 2.25\%$, but a $\pm 6\%$ band was set for Italy and the newcomers (Spain, the UK, and Portugal). After almost a year of unprecedented turmoil in the history of the EMS, the fluctuation bands of the ERM were broadened to $\pm 15\%$ in August 1993 (except for the Dutch guilder and the Deutschmark, which remained within the narrow bands of $\pm 2.25\%$). There have been fifty-eight realignments during the 1979-1998 period, implemented in nineteen discrete adjustments. It should be noted that thirty eight of such realignments were made prior to the currency turmoil of 1992/93.

Researchers and practitioners alike were caught up with these institutional arrangements, and a number of exchange rate target zone models have been introduced. The ERM is the most prominent example of a target zone exchange-rate system. Starting with the seminal study by Krugman (1991), a large number of papers have examined the behaviour of exchange rates in target zones (see Kempa and Nelles, 1999, for a review). The main result of the target zone model is that, with perfect credibility, the zone exerts a stabilising effect (the so-called "honeymoon" effect), reducing the exchange rate sensitivity to a given change in fundamentals. Nevertheless, in a target zone with credibility problems, expectations of future interventions tend to destabilise the exchange rate, making it less stable than the underlying fundamentals (Bertola and Caballero, 1992).

Credibility can be defined as the degree of confidence that economic agents assign to the announcements made by policymakers. In a context of an exchange rate target zone, like the EMS, credibility refers to the perception of economic agents with respect to the commitment to maintain the exchange rate around a central parity. Therefore, the possibility for the official authorities to change the central parity could be anticipated by the economic agents, triggering expectations of future changes in the exchange rate that could act as a destabilising element of the system.

The aim of this paper is to assess the degree of credibility of the ERM. Although the EMS has been analysed extensively, we depart from previous studies by using different credibility indicators, which have been proposed in the literature, to measure the agents perception towards the ERM commitments. At the same time, we extend the analysis to eight currencies participating in the ERM, and examine the complete EMS history, including, in our sample, events such as the monetary turmoil at the end of 1992 and the broadening of fluctuation bands in 1993.

The structure of the paper is as follows. Section 2 presents the credibility indicators. Section 3 contains the empirical results. In Section 4 we carry out a comparison of the credibility indicators used in this study. Finally, Section 5 offers some concluding remarks.

2. Credibility indicators

In this Section, we present the four credibility measures that we have used in this paper. Some of them have been widely employed in empirical literature, while others, like the marginal credibility indicator, have received much less attention.

2.1) Svensson's simple test

Svensson (1991) presented a simple test to study the credibility of a target zone exchange rate regime with fluctuation bands. There are two traditional versions of this test. In the first one, it is assumed that there is no arbitrage, while in the second version uncovered interest parity (UIP) is assumed to hold.

In order to compare this indicator with the one based on the drift-adjustment method (see subsection 2.2), a more recent variant of the former is usually estimated. Given that the log of the exchange rate s_t can be expressed as $s_t = x_t + c_t$, where x_t is the deviation of the log exchange rate from the log central parity c_t , the expected rate of currency depreciation within the band from time t to time $t+\tau$ is bounded by:

$$(\underline{x}_t - x_t) / \tau \leq E_t[\Delta x_{t+\tau}] / \tau \leq (\bar{x}_t - x_t) / \tau \quad (1)$$

where $\underline{x}_t$ and $\bar{x}_t$ are the lower and upper edges of the exchange rate bands, respectively, and τ is the maturity (being 3/12 for a 3-month maturity).

Taking into account the UIP hypothesis¹:

$$i_t - i_t^* = E_t[\Delta s_{t+\tau}] / \tau \quad (2)$$

and by separating the two elements of the exchange rate (i.e., the central parity and the exchange rate within the band), equation (2) can be rewritten as:

$$i_t - i_t^* = E_t[\Delta x_{t+\tau}] / \tau + E_t[\Delta c_{t+\tau}] / \tau \quad (3)$$

where i_t and i_t^* are the domestic and the foreign interest rate, respectively.

The expected variation rate in the exchange rate can be separated into two components: the expected rate of depreciation within the band and the expected rate of realignment of the central parity.

Combining equations (1) and (3), the expected rate of realignment is bounded according to:

$$i_t - i_t^* - (\bar{x}_t - x_t) / \tau \leq E_t[\Delta c_{t+\tau}] / \tau \leq i_t - i_t^* - (\underline{x}_t - x_t) / \tau \quad (4)$$

¹ Svensson (1992) and Ayuso and Restoy (1992) have estimated insignificant risk premia for the currencies in the ERM and, hence, the expected rate of depreciation is closely related to the interest rate differential.

In order to facilitate the comparison with the drift-adjustment method, we calculate a 100% confidence interval for the expected rate of realignment of the exchange rate under study *vis-à-vis* the German mark.

This recent version of Svensson's simple test has been criticised because it only takes into account the possibility of realignments in the limits of the band, thus placing an excessive weight on credibility. This is one of the reasons why the results obtained with this test might not be completely accurate.

2.2) The drift-adjustment method

This method, originally proposed by Bertola and Svensson (1993), computes an econometric estimate of the expectations of economic agents regarding the realignment in the ERM. These realignment expectations constitute an inverse measure of credibility. The drift-adjustment method assumes UIP to hold using the modified expression (3).

Moreover, if p_t^τ denotes the probability at time t of a realignment during the period from time t to $t+\tau$, it follows that:

$$E_t[\Delta x_{t+\tau}] = (1 - p_t^\tau) E_t[\Delta x_{t+\tau} / nr] + p_t^\tau E_t[\Delta x_{t+\tau} / r] \quad (5)$$

where the expectation terms on the right-hand side are sensitive to the absence of realignment (nr) or to the presence of realignment (r).

If g_t^τ denotes the expected rate of devaluation, then:

$$g_t^\tau = E_t[\Delta c_{t+\tau}] / \tau + \frac{p_t^\tau}{\tau} \{E_t[x_{t+\tau} / r] - E_t[x_{t+\tau} / nr]\} \quad (6)$$

where the first term on the right-hand side is the expected rate of realignment, and the second term is the expected rate of depreciation within the band when a realignment takes place.

Combining (3) and (5), and using (6), we obtain:

$$g_t^\tau = i_t - i_t^* - E_t[\Delta x_{t+\tau} / nr] / \tau \quad (7)$$

This procedure implies estimating the expected rate of depreciation within the band [the last term on the right-hand side of equation (7)], and then computing the expected rate of devaluation g_t^τ . Once g_t^τ is estimated, the corresponding 90 or 95 percent confidence intervals can be calculated. These intervals can be directly compared with those of the more recent version of Svensson's simple test.

When considering the practical implementation of the drift-adjustment method, the empirical studies that have computed this measure have used different econometric specifications for the expected rate of depreciation within the band. Lindberg *et al.* (1993), Svensson (1993), and Rose and Svensson (1994) have estimated a linear regression model where the exchange rate in $t+\tau$ depends on its value in moment t (and, in some cases, lagged exchange rates) and on the interest rate differential. On the other hand, Bertola and Svensson (1993) consider x_t as the only explanatory variable, assuming a mean-reverting model for the exchange rate within the band, as in Ayuso *et al.* (1994) and in Gómez and Montalvo (1997).

In this paper, the drift-adjustment method has been used to calculate the 90 percent confidence intervals for the expected rate of devaluation. To that end, we have estimated the expected rate of depreciation within the band using a linear regression model where the exchange rate and the domestic and foreign interest rates are taken as explanatory variables.

The drift-adjustment method has been criticised. In particular, it has been pointed out that the selection of the explanatory variables is *ad hoc*, without an appropriate theoretical framework. Furthermore, the non-stationarity of the exchange rate may generate some problems in the estimation of its expected rate of variation. These problems depend on its position within the band. Thus, it is important to be careful when we are interpreting the results obtained from this method.

2.3) Models of discrete choice

These kind of models aim to estimate the probability of realignment by means of econometric techniques. To that end, it is usually considered some explanatory variables to compute that probability, assuming normal or logistic distributions. Among the explanatory variables, the interest rate differential, the inflation differential, the current account balance, and the unemployment rate are usually considered, leading to estimates using monthly or quarterly data.

Edin and Vredin (1993) employ a two-step procedure suggested by Heckman (1976) to calculate both the probability and the expected size of the devaluation. In the first step of the estimation procedure, the probability of devaluation occurring at time $t+1$, based on information available at time t , is estimated. In the second step, the unconditional expectation of the rate of devaluation in period t is obtained.

We have introduced the exchange rate, the interest rate differential, and two target zone variables, i.e., the distance to the upper fluctuation band and to the central parity. The selection of these stem from our interest in the estimation of credibility with high frequency data

2.4) Marginal credibility

This credibility measure proposed by Weber (1991a) focuses on the ability of policy announcements to influence the public's expectations. It measures the impact of official announcements on exchange rates and may be thought of as the weight placed on the announcement when the public forms their expectations. This credibility measure is equal to one if the policy-maker always makes fully credible announcements, and tends to zero as the announcements become non-credible. Marginal credibility (α_t) is defined as:

$$s_t - E_{t-1}[s_t] = \gamma + \alpha_t [c_t - E_{t-1}[s_t]] + u_t \quad (8)$$

where the expectation operator is conditional to the information available in $t-1$, and where u_t is a random disturbance.

A model of the public's expectation forming process is required in order to estimate α_t . By applying the Kalman filter, α_t can be estimated, obtaining a different

value of α_t for each moment in the sample period, allowing the study of credibility through its evolution over time.

3. Empirical results

The credibility indicators introduced in the previous Section have been applied to weekly exchange and interest rates from eight ERM countries (Belgium, Denmark, France, Ireland, Italy, the Netherlands, Portugal and Spain). Data restrictions led us to use weekly data (the highest frequency available). Nevertheless, the use of weekly rates facilitates comparisons with previous studies and avoid problems with the day-of-the-week effects in the data. Wednesday spot rates and three-month interbank rates were obtained from the Bank of Spain and the Banco Bilbao Vizcaya Argentaria (BBVA). Given the central role of Germany in the European Union (see, e. g., Bajo-Rubio *et al.*, 2001), our exchange rates are expressed *vis-à-vis* the Deutschmark. The sample period runs from 13 March 1979 to 30 December 1998 (1034 observations), covering the complete EMS history. Figures 1a to 1h show the evolution of the exchange rates under study².

² The fluctuation bands were built by following Honohan (1979). We take into account the lack of symmetry between the two intervention limits due to the requirement that the upper intervention limit for currency X with respect to currency Y equals the lower intervention limit for currency Y with respect to currency X.

Fig 1a: BFR/DM exchange rate
(including ERM intervention limits) Fig 1b: DRK/DM exchange rate
(including ERM intervention limits) Fig 1c: ESC/DM exchange rate
(including ERM intervention limits) Fig 1d: FF/DM exchange rate
(including ERM intervention limits) Fig 1e: HFL/DM exchange rate
(including ERM intervention limits) Fig 1f: IRL/DM exchange rate
(including ERM intervention limits) Fig 1g: ITL/DM exchange rate
(including ERM intervention limits) Fig 1h: PTA/DM exchange rate
(including ERM intervention limits)

We will present the results following the same sequence we have used in the last Section when introducing the credibility indicators.

3.1) Svensson's simple test

Using the three-month interbank rate, as mentioned in Subsection 2.1, we calculated the more recent version of Svensson's simple test, obtaining the 100% confidence bands for the expected rates of devaluation using expression (4). In this way, the maximum and the minimum expected realignment are constructed by subtracting the minimum and the maximum possible rates of depreciation within the band, respectively, from the interest rate differential. The resulting expected rates of realignment are displayed in Figures 2a to 2h.

Except for the Dutch guilder, the difference between the maximum and minimum realignment increases after the broadening of the fluctuation bands to $\pm 15\%$ in August 1993. The results suggest credibility losses in the Spanish peseta, the Portuguese escudo and the Irish pound before the summer of 1992 in line with those reported by Ledesma *et al.* (1999a, 1999b and 2000), as well as some evidence of credibility gains for the Italian lira just before leaving the ERM as in Fernández-Rodríguez *et al.* (2001).

Figure 2: Maximum and Minimum Expected Rates of Realignment

Notes: MIN = minimum expected rate of realignment in the exchange rate vis-à-vis the Deutschmark, based on Svensson's simple test.

MAX = maximum expected rate of in the exchange rate vis-à-vis the Deutschmark, based on Svensson's simple test.

Vertical lines = actual ERM realignments and broadening of fluctuation bands.

It seems that this simple test is not very informative because of its sensitivity to the thickness of the fluctuation bands, as can be seen from its behaviour from August 1993 on.

3.2) The drift-adjustment method

In order to compute the expected devaluation rate using equation (7), we have to estimate the expected rate of depreciation within the band. Following Svensson (1993), we consider the linear regression

$$\frac{x_{t+\tau} - x_t}{\tau} = \sum_j \alpha_j d_j + \beta_1 x_t + \beta_2 i_t^* + \beta_3 i_t + \varepsilon_{t+\tau} \quad (9)$$

where $x_{t+\tau}$ and x_t are the exchange rate (log) deviation from the central parity in period $t+\tau$ and t , respectively, and where i_t and i_t^* are the national and German three-month interest rates, respectively. The variables d_j denote the dummies for the subperiods between the realignments and the widening of the bands³.

Svensson (1993) eliminates from the sample the 65 observations corresponding to the three months before a realignment took place, given that he, like us, uses $\tau = 3$ months. Given the important reduction in the number of observations implied by this strategy, we use equation (9) estimating the whole sample⁴. In this way, we are estimating the expected depreciation rate within the band that includes possible jumps in each realignment. Therefore, we obtain the expected rate of realignment, but not the expected devaluation rate g_t^τ (which, in addition, includes the expected jump in the exchange rate within the band in the realignments).

Following a “general-to-specific” modelling methodology [see, e. g., Hendry (1995)], equation (9) was continuously simplified and re-parameterised until a parsimonious representation of the data generation process was arrived at. The results, obtained by ordinary least squares (OLS), are shown in Tables 1a to 1h, where the standard errors have been corrected for serial correlation and heteroscedasticity (which results from the “overlapping observations” problem) using a Newey-West covariance estimator. As can be seen, the estimated coefficients for x , i and i^* are clearly significant. The coefficients for x_t are negative, indicating mean-reversion of the exchange rate within the band. The associated t -ratio for these coefficients safely rejects the null hypothesis of a unit root, as in Svensson (1993). With the sole exception of the Dutch guilder, the estimated signs of i and i^* are in accordance with those reported by Svensson (1993) and by Rose and Svensson (1994). Finally, the dummy variables are significant, except those related to the Portuguese escudo, the French franc and the Belgium franc, indicating the relevance of the different regimes in the history of the ERM.

³ We have also taken into account the widening of the bands, since this event produced a major change in the ERM, as can be observed in a greater fluctuation of the exchange rates before August 1993.

⁴ Gómez and Montalvo (1997) follow a similar approach.

Table 1a. Expected exchange rate depreciation within the band: BFR/DM

x	-3.9256 (0.1285)
i*	0.0598 (0.0178)
i	-0.0441 (0.0167)

Note: AR(1) estimation of equation (9). Newey-West standard errors within parentheses.

Table 1b. Expected exchange rate depreciation within the band: DKR/DM

D1	-0.0311 (0.0167)
D2	-0.0216 (0.0108)
D3	-0.0554 (0.0138)
D4	-0.0584 (0.0185)
D5	-0.0521 (0.0161)
D6	-0.0364 (0.0093)
X	-2.5318 (0.2471)
i*	0.0538 (0.0246)
i	-0.0312 (0.0205)

Note: OLS estimation of equation (9). Newey-West standard errors within parentheses. Di denote dummy variables for subperiods delimited by the realignments of the Danish crown and the widening of the bands.

Table 1c. Expected exchange rate depreciation within the band: ESC/DM

x	-1.9326 (0.4240)
i*	0.0964 (0.0513)
i	-0.0586 (0.0340)

Note: OLS estimation of equation (9). Newey-West standard errors within parentheses.

Table 1d. Expected exchange rate depreciation within the band: FF/DM

x	-3.8954 (0.1411)
i*	0.0600 (0.0276)
i	-0.0444 (0.0239)

Note: AR(1) estimation of equation (9). Newey-West standard errors within parentheses

Table 1e. Expected exchange rate depreciation within the band: HFL/DM	
D1	0.0541 (0.0173)
D2	0.0102 (0.0164)
D3	0.0173 (0.0099)
X	-2.8137 (0.4281)
i*	-0.0310 (0.0106)
i	0.0185 (0.0110)

Note: OLS estimation of equation (9). Newey-West standard errors within parentheses. Di denote dummy variables for the subperiods delimited by the realignments of the Dutch guilder and the widening of the bands.

Table 1f. Expected exchange rate depreciation within the band: IRL/DM	
D5	0.0490 (0.0171)
D6	0.1004 (0.0177)
D7	0.0924 (0.0237)
D8	0.0347 (0.0147)
D9	0.0614 (0.0321)
D11	0.0435 (0.0151)
X	-1.4964 (0.3085)
i*	0.0903 (0.0254)
i	-0.0870 (0.0217)

Note: OLS estimation of equation (9). Newey-West standard errors within parentheses. Di denote dummy variables for subperiods delimited by the realignments of the Irish pound and the widening of the bands.

Table 1g. Expected exchange rate depreciation within the band: LIT/DM	
D1	-0.0298 (0.2301)
D2	0.0218 (0.2460)
D3	-0.0287 (0.2540)
D4	-0.0282 (0.2527)
D5	-0.0682 (0.2306)
D6	-0.0358 (0.2144)
D7	-0.0153 (0.2136)
D8	-0.0208 (0.2166)
D9	0.0509 (0.2180)
D10	0.0056 (0.2336)
X	-2.7982 (0.4210)
i*	0.0540 (0.0719)
i	-0.0431 (0.1360)

Note: OLS estimation of equation (9). Newey-West standard errors within parentheses. Di denote dummy variables for subperiods delimited by the realignments of the Italian lira and the widening of the bands.

Table 1h. Expected exchange rate depreciation within the band: PTA/DM	
D1	-0.0641 (0.0216)
D2	-0.1254 (0.0231)
D4	0.1270 (0.0219)
D5	0.1448 (0.0223)
X	-2.7348 (0.2894)
i*	0.0561 (0.0286)
i	-0.0489 (0.0237)

Note: OLS estimation of equation (9). Newey-West standard errors within parentheses. Di denote dummy variables for subperiods delimited by the realignments of the Spanish peseta and the widening of the bands.

The estimated expected rate of realignment from equation (7) and the 90% confidence interval are plotted for each currency in Figures 3a to 3h . For most of the sample, the hypothesis that the expected rates of realignment are zero cannot be rejected in all the cases under study. Nevertheless, we detect some episodes where the expected rate of devaluation is positive: (i) before the realignments of the Italian lira in March and October 1981, (ii) before the realignment of the Irish pound in 1983, (iii) before the realignments of the Belgian franc in April 1986 and January 1987, (iv) around the time of the realignment of the Irish pound in February 1987, (v) the period covering the realignments of the Spanish peseta in September and November 1992, (vi) during the continued market pressures against the Danish krone registered in December 1992, (vii) before the realignment of the Irish pound in February 1993, (viii) after the widening of the ERM fluctuation bands in August 1993 for the Belgium franc, the Danish krone and the French franc, reflecting the speculative pressures against these currencies, (ix) during the first quarter of 1995 for the Danish krone, French franc, Irish pound, Portuguese escudo and Spanish peseta, reflecting the intensive speculative attacks against these currencies leading to the realignments of the Portuguese escudo and Spanish peseta in March 1995, and (x) during the September-December 1995 period for the French franc. In addition, there seems to be an increase in the expected rate of appreciation after the realignments of February 1982 (in the cases of the Belgium franc and the Dutch guilder), of March 1983 (for the Belgium franc and the French franc), of July 1985 (for the Danish krone) and of May 1993 (for the Spanish peseta).

Figure 3: Expected Rate of Realignment

Notes: RR = expected realignment rate in the exchange rate vis-à-vis the Deutschmark, based on estimation results in Table 2.

UL = 90 per cent confidence interval's upper limit.

LL = 90 per cent confidence interval's lower limit

Vertical lines = actual ERM realignments and broadening of fluctuation bands.

3.3) Models of discrete choice

Instead of estimating the probability of realignment proposed by Edin and Vredin (1993), we have estimated the value of that probability using the same weekly data employed in all the other credibility indicators analysed in this paper.

We have estimated a logit model based on the following equation:

$$P_t = P(y_t = 1) = \Phi(z_t' \delta) = \frac{e^{z_t' \delta}}{1 + e^{z_t' \delta}}; \quad z_t' \delta = \delta_1 + \delta_2 z_{1t} \quad (10)$$

where $\Phi(\cdot)$ is the logistic distribution function ($\Phi(\lambda)$ is the probability that a normally distributed random variable with zero mean and unit variance does not exceed λ), z_{1t} denotes an explanatory variable, and $P(y_t=0)=1-P_t$. The parameters in equation (10) are estimated by maximising the logarithm of the likelihood function with respect to individual observations:

$$\text{Log}L = \sum_{t=1}^T y_t \log \Phi(z_t' \delta) + \sum_{t=1}^T (1 - y_t) \log[1 - \Phi(z_t' \delta)] \quad (11)$$

The drift-adjustment method estimates the 90% confidence interval (calculated in section 2.2). If both limits of the interval were simultaneously greater or lesser than zero, the agents would have expected realignments with 90% confidence. Assuming that when $y_t=0$ there is no credibility and that when $y_t=1$ there is credibility, we use the drift-adjustment method to design the logit model. In other words, when $y_t=0$ the limits of the confidence interval for the expected rate of realignment are simultaneously greater or lower than zero. When $y_t=1$ this does not occur⁵. This strategy allows us to obtain the probability that agents assign to the credibility of the exchange rate regime in each moment of time.

We have used different approaches to estimate the probability that national commitments towards the ERM were credible, defining z_t as the explanatory variable: either the exchange rate, or the distance to the upper fluctuation band, or the distance to the central parity, or the interest rate differential. Tables 2a to 2h show the estimation for each one of these four options, while in Tables 3a to 3h we present the associated summary statistics of their estimated probability.

⁵ Note that this measure, when formulated in this manner, assigns credibility to any period when neither the lower bound of the confidence interval is positive nor the upper bound is negative.

Table 2a. Logit estimation results: BFR/DM				
Parameters	Belgian franc/ Deutschmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
δ_1	37.4581 (8.7702)	13.8981 (1.6425)	2.5048 (0.1585)	5.1489 (0.3524)
δ_2	-1.6932 (0.4238)	-34.1012 (4.3425)	0.2219 (0.1131)	-2.1861 (0.2257)

Note: Estimation of equation (10). Standard errors within parentheses.

Table 2b. Logit estimation results: DKR/DM				
Parameters	Danish crown/ Deutschmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
δ_1	65.7825 (8.6742)	5.6266 (0.3974)	3.2595 (0.6119)	4.7266 (0.3227)
δ_2	-16.3074 (2.2268)	-35.4790 (3.9583)	-1.0412 (0.6119)	-0.6735 (0.0967)

Note: Estimation of equation (10). Standard errors within parentheses.

Table 2c. Logit estimation results: ESC/DM				
Parameters	Portuguese escudo/ Deutschmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
δ_1	39.3021 (16.3266)	53.3191 (13.3732)	1.3961 (0.7254)	5.2382 (0.7250)
δ_2	-0.3544 (0.1582)	-2.1896 (0.5595)	0.1268 (0.0576)	-0.3623 (0.0898)

Note: Estimation of equation (10). Standard errors within parentheses.

Table 2d. Logit estimation results: FF/DM				
Parameters	French franc / Deutschmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
δ_1	224.4180 (22.8338)	6.4758 (0.4652)	3.2413 (0.1978)	3.7313 (0.2390)
δ_2	-65.1507 (6.6687)	-68.2629 (6.2563)	-3.6656 (0.5312)	-0.7452 (0.0964)

Note: Estimation of equation (10). Standard errors within parentheses.

Table 2e. Logit estimation results: HFL/DM				
Parameters	Dutch guilder/ Deutschmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
δ_1	-36.0372 (18.8494)	4.4871 (0.3157)	-2.3430 (0.8387)	4.2384 (0.2726)
δ_2	36.0384 (16.9258)	-46.9208 (23.3740)	279.3700 (40.7369)	-0.1570 (0.5780)

Note: Estimation of equation (10). Standard errors within parentheses.

Table 2f. Logit estimation results: IRL/DM				
Parameters	Irish pound/ Deutschmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
δ_1	8.7313 (1.7414)	3.8118 (0.2432)	3.0123 (0.2307)	7.18558 (0.6423)
δ_2	-14.1500 (4.5002)	-38.8093 (14.6986)	26.4156 (11.4170)	-0.6716 (0.0829)

Note: Estimation of equation (10). Standard errors within parentheses.

Table 2g. Logit estimation results: LIT/DM				
Parameters	Italian lira/ Deutschmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
δ_1	0.2057 (1.0346)	3.6997 (0.3243)	0.6788 (0.4564)	1.4431 (1.7229)
δ_2	0.0046 (0.0017)	-0.0564 (0.0205)	0.0846 (0.0182)	0.3554 (0.3781)

Note: Estimation of equation (10). Standard errors within parentheses.

Table 2h. Logit estimation results: PTA/DM				
Parameters	Spanish peseta/ Deutschmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
δ_1	9.4752 (1.7665)	3.4820 (0.2881)	0.6043 (0.3623)	6.2345 (0.7633)
δ_2	-0.0927 (0.0215)	-0.5875 (0.0904)	0.1785 (0.0435)	-0.9615 (0.1581)

Note: Estimation of equation (10). Standard errors within parentheses.

Table 3^a. Summary statistics of the estimated probability: BFR/DM				
	Belgian franc/ Deutschmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
Mean	0.9381	0.9381	0.9380	0.93881
Median	0.9318	1.0000	0.9309	0.9752
Maximum	1.0000	1.0000	0.9631	0.9988
Minimum	0.5884	9.80E-14	0.9245	7.73E-05
Std.Dev.	0.0446	0.1861	0.0150	0.1122
Skewness	-1.6486	-3.7514	0.9529	-3.9836
Kurtosis	12.6160	16.7110	2.0286	23.2086

Note: Estimation of equation (10). Standard errors within parentheses.

Table 3b. Summary statistics of the estimated probability: DKR/DM				
	Dutch guilder/ Deustchmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
Mean	0.9536	0.9536	0.9536	0.9536
Median	0.9750	0.9878	0.9595	0.9696
Maximum	1.0000	0.9964	0.9630	0.9928
Minimum	0.1724	0.0016	0.9312	0.0339
Std.Dev.	0.0866	0.1336	0.0113	0.0787
Skewness	-5.2411	-5.6536	-1.0734	-7.8390
Kurtosis	37.7665	36.6494	2.3452	76.3020

Note: Estimation of equation (10). Standard errors within parentheses.

Table 3c. Summary statistics of the estimated probability: ESC/DM				
	Portuguese escudo/ Deustchmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
Mean	0.9534	0.9534	0.9534	0.9534
Median	0.9545	1.0000	0.9605	0.9705
Maximum	1.0000	1.0000	0.9799	0.9947
Minimum	0.8492	0.1406	0.8516	0.7288
Std.Dev.	0.0337	0.1328	0.0267	0.0566
Skewness	-0.9148	-3.6566	-1.8591	-2.2292
Kurtosis	3.9123	17.0534	6.2079	7.3145

Note: Estimation of equation (10). Standard errors within parentheses.

Table 3d. Summary statistics of the estimated probability: FF/DM				
	French franc/ Deustchmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
Mean	0.9478	0.9478	0.9478	0.9478
Median	0.9567	0.9778	0.9460	0.9610
Maximum	0.9634	0.9900	0.9543	0.9900
Minimum	0.9071	0.1222	0.9445	0.6371
Std.Dev.	0.0167	0.1054	0.0034	0.0508
Skewness	-1.4770	-4.8736	1.0004	3.3217
Kurtosis	3.6892	29.0056	2.1805	16.0281

Note: Estimation of equation (10). Standard errors within parentheses.

Table 3e. Summary statistics of the estimated probability: HFL/DM				
	Dutch guilder/ Deustchmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
Mean	0.9855	0.9855	0.9855	0.9855
Median	0.9890	0.9877	0.9934	0.9855
Maximum	0.9928	0.9889	1.0000	0.9878
Minimum	0.9398	0.8885	0.3226	0.9819
Std.Dev.	0.0084	0.0085	0.0523	0.0010
Skewness	-2.5042	-7.2734	-8.3636	1.4972
Kurtosis	9.2513	67.6254	80.0823	5.7247

Note: Estimation of equation (10). Standard errors within parentheses.

Table 3f. Summary statistics of the estimated probability: IRL/DM				
	Irish pound/ Deustchmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
Mean	0.9700	0.9700	0.9700	0.9700
Median	0.9686	0.9744	0.9625	0.9949
Maximum	0.9944	0.9768	0.9983	0.9998
Minimum	0.9189	0.9086	0.9511	4.45E-05
Std.Dev.	0.0168	0.0115	0.0149	0.0903
Skewness	-0.5518	-2.7485	0.7981	5.8730
Kurtosis	2.7323	10.6210	2.0093	46.3832

Note: Estimation of equation (10). Standard errors within parentheses.

Table 3g. Summary statistics of the estimated probability: LIT/DM				
	Italian lira/ Deustchmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
Mean	0.9555	0.9555	0.9555	0.9555
Median	0.9660	0.9624	0.9703	0.9560
Maximum	0.9766	0.9758	0.9990	0.9757
Minimum	0.9061	0.8528	0.7762	0.9321
Std.Dev.	0.0220	0.0227	0.0451	0.0074
Skewness	-0.9012	-2.3304	-1.4853	0.0517
Kurtosis	2.4253	9.2270	4.8676	2.3770

Note: Estimation of equation (10). Standard errors within parentheses.

Table 3h. Summary statistics of the estimated probability: PTA/DM				
	Spanish peseta/ Deustchmark exchange rate	Distance to upper band	Distance to central parity	Interest rate differential with Germany
Mean	0.8956	0.8956	0.8956	0.8956
Median	0.8683	0.9288	0.9053	0.9240
Maximum	0.9778	0.9720	0.9717	0.9983
Minimum	0.7203	0.1180	0.6804	0.3291
Std.Dev.	0.0653	0.1196	0.0628	0.1065
Skewness	0.0452	-3.7853	-0.6040	1.9295
Kurtosis	1.36222	19.9376	2.8880	8.5444

Note: Estimation of equation (10). Standard errors within parentheses.

As can be seen in these tables, the estimated coefficients are all statistically significant, and the estimated (credibility) probabilities have a mean greater than 0.9, suggesting a subjective probability of realignment of 0.1.

Time series of the probability of credibility have been calculated using the estimation results of Tables 2a to 2h.

In Figures 4a to 4h we only plot the results obtained using the interest rate differential with respect to Germany as the explanatory variable⁶. The results for this indicator suggest that credibility effects varied among ERM countries and among subperiods:

- Belgium: according to Figure 4a, the Belgian franc was perceived as credible in all subperiods considered, except for three episodes where a temporary fall of credibility is detected: around its realignment in April 1986, in February 1990 (around the crisis in asset markets and before the entry of Italian lira in the narrow bands), and after the widening of the ERM fluctuation bands in August 1993,
- Denmark: in the case of the Danish krone, only before the widening of the ERM fluctuation bands in August 1993 we find evidence of absence of credibility (see Figure 4b).
- France: as shown in Figure 4c, the results for the French franc suggest a lack of credibility in January 1988 (during the turmoils in the financial markets), from September to November 1992 (possibly reflecting the heavy market pressure on this currency after the closeness of the vote affirming the Maastricht Treaty), in January-February 1993, and during the first quarter of 1995, reflecting in both cases the intensive speculative attacks on the French franc.
- Ireland: in the case of the Irish pound, we find evidence of lack of credibility before its realignment in August 1986, in February 1987 (after the realignment in January), in November 1992 (reflecting the heavy market pressure against this currency), and before its realignment in February 1992.

⁶ Plots of the results obtained using the exchange rate, the distance to the upper fluctuation band, and the distance to the central parity as the explanatory variable are available from the corresponding author upon request.

- Italy: the results for the Italian lira indicate evidence of credibility during the whole period, excepting the first two months after it re-joined the ERM with the new wide band in November 1996.
- The Netherlands: as can be seen in Figure 4f, our results suggest that the Dutch guilder was perceived as credible during the entire sample period.
- Portugal: the results for the Portuguese escudo indicate a temporary fall of credibility during the turbulence in the currency markets in September 1992, after the realignment of the Irish pound in February 1993 and in June 1994 (around the crack in the financial markets in May and in June 1994) (see Figure 4g).
- Spain: as seen in Figure 4h, for the Spanish peseta we detect a lack of credibility during the period covering its realignments in September and November 1992, in January and February 1993 (reflecting the heavy market pressure against this currency), and before its realignment in March 1995.

Figure 4: Estimated Devaluation Probabilities

Notes: Inverse of devaluation probabilities for the exchange rate vis-à-vis the Deutschmark, based on estimation results in Table 3, column 5.

Vertical lines = actual ERM realignments and broadening of fluctuation bands.

3.4) Marginal credibility

Marginal credibility focuses on the influence that policy announcements have on the expectations of private agents, and may be thought of as the weight these agents place on such announcements.

In this paper, changes in the ERM central parity are the announcements. The estimation of marginal credibility (α_t) is based on equation (8), where the random disturbance u_t is normal with a zero mean and a constant variance.

Before estimating α_t , we have to obtain the expectations on the exchange rate. We generate the expected exchange rate using the best ARIMA model for each exchange rate.

To estimate marginal credibility, we have used the Kalman filter in order to analyse the dynamic behaviour of the estimated α_t during the sample period. As is well known, the Kalman filter is an updating estimation method which bases the regression estimates for each time period on the last period's estimates plus the data for the current time period (i. e., it bases estimates on data up to and including the current period).

The model estimated is the following:

$$y_t = w_t' \beta_t + \varepsilon_t; \quad \varepsilon_t \sim N(0, \sigma^2 h_t) \quad (12)$$

$$\beta_t = T\beta_{t-1} + \eta_t; \quad \eta_t \sim N(0, \sigma^2 Q_t) \quad (13)$$

where y_t is a vector of differences $s_t - E_{t-1}(s_t)$, w_t' is a row vector made of one and differences $c_t - E_{t-1}(s_t)$. Equation (13) is called the transition equation (which describes the evolution of a set of state variables), whereas equation (12) is the measurement equation (which describes how the data actually observed is generated from the state variables). β_t is the state vector that follows a random walk and T is an identity 2×2 matrix. The initial conditions are established by $\beta_0 \sim N(\beta_0, P_0)$, where P_0 is a variance-covariance matrix for the initial conditions. Finally, h_t is the variance of the errors in the measurement equation and Q_t is the variance-covariance matrix for the errors in the transition equation.

The Kalman filter is a recursive method that computes the optimal estimate of the state variables in period t , based precisely on information available in t . For each period, we use a conditional maximum likelihood to the information set up for that period. The logarithm of the likelihood function is defined as follows:

$$\log L = -\frac{T}{2} \log 2\pi - \frac{1}{2} \log \sigma^2 - \frac{1}{2} \sum_{t=1}^T \log f_t - \frac{1}{2} \sum_{t=1}^T \xi_t' f_t \xi_t \quad (14)$$

where σ^2 is computed from the recursive residuals, $f_t = w_t' P_{t/t-1} w_t + h_t$ is a scalar and $\xi_t = y_t - E_{t-1}[y_t]$

The use of an econometric technique that allows for changes in the values of the parameters over time may be appropriate for the study of credibility in a target zone stabilising interventions by the central banks, speculative movements by private agents and realignments modify the parameters of the process along the period studied. In fact, this possibility was pointed out by Weber (1991a, 1991b) before the monetary turmoil of September 1992, and more recently by Darvas (1998).

Tables 4a to 4h report the estimation results. The upper panel in that table reports OLS estimates of α_t as a benchmark for comparisons.

Table 4a. Kalman filter estimates of marginal credibility: BFR/DM

α (ML)	0.7179 (0.1267)
Mean	0.6061
Median	0.5897
Maximum	0.7179
Minimum	0.4596
Std. Dev.	0.0884
Skewness	-0.0436
Kurtosis	1.5777

Note: Estimation by maximum likelihood (ML).
Standard errors within parentheses.

Table 4b. Kalman filter estimates of marginal credibility: DKR/DM

α (ML)	0.6574 (0.2021)
Mean	0.5591
Median	0.5429
Maximum	1.4908
Minimum	-0.1030
Std. Dev.	0.2406
Skewness	0.4947
Kurtosis	4.7415

Note: Estimation by maximum likelihood (ML).
Standard errors within parentheses.

Table 4c. Kalman filter estimates of marginal credibility: ESC/DM

α (ML)	0.7220 (0.2046)
Mean	0.6533
Median	0.6803
Maximum	0.7220
Minimum	0.4998
Std. Dev.	0.0686
Skewness	-0.6717
Kurtosis	2.0659

Note: Estimation by maximum likelihood (ML).
Standard errors within parentheses.

Table 4d. Kalman filter estimates of marginal credibility: FF/DM

α (ML)	1.1947 (0.2084)
Mean	0.9318
Median	0.9469
Maximum	1.6412
Minimum	0.0168
Std. Dev.	0.2900
Skewness	-0.2770
Kurtosis	2.8684

Note: Estimation by maximum likelihood (ML).
Standard errors within parentheses.

Table 4e. Kalman filter estimates of marginal credibility: HFL/DM

α (ML)	1.2127 (0.5108)
Mean	1.0097
Median	1.0734
Maximum	1.7357
Minimum	0.0072
Std. Dev.	0.3079
Skewness	-1.1592
Kurtosis	4.2665

Note: Estimation by maximum likelihood (ML).
Standard errors within parentheses.

Table 4f. Kalman filter estimates of marginal credibility: IRL/DM

α (ML)	0.8859 (0.3479)
Mean	0.8723
Median	0.9479
Maximum	1.8274
Minimum	-0.0554
Std. Dev.	0.3512
Skewness	-0.5014
Kurtosis	2.5205

Note: Estimation by maximum likelihood (ML).
Standard errors within parentheses.

Table 4g. Kalman filter estimates of marginal credibility: LIT/DM

	March 1979 to September 1992	November 1996 to December 1998
α (ML)	0.6394 (0.0887)	0.6478 (0.1625)
Mean	0.2620	0.6319
Median	0.2050	0.6377
Maximum	0.6394	0.6394
Minimum	0.0166	0.5956
Std. Dev.	0.2202	0.0114
Skewness	0.4987	-1.7388
Kurtosis	1.7852	4.9695

Note: Estimation by maximum likelihood (ML).
Standard errors within parentheses.

Table 4h. Kalman filter estimates of marginal credibility: PTA/DM

α (ML)	0.4107 (0.1362)
Mean	0.4555
Median	0.4487
Maximum	0.5954
Minimum	0.3726
Std. Dev.	0.0547
Skewness	0.9431
Kurtosis	2.8589

Note: Estimation by maximum likelihood (ML).
Standard errors within parentheses.

Figures 5a to 5h display, for each currency under study, the evolution of the estimated marginal credibility when the expected exchange rates are based on the best ARIMA model. The dynamic behaviour of this indicator is, in general, not as irregular as previous indicators. What follows is a country-by-country analysis of the results.

- Belgium: the Belgian franc experienced a fall in credibility from 1979 to 1986, with the only exception of some credibility gains after its realignment in February 1982. A different picture emerges after its realignment in April 1986, where there is a steadily rise in credibility (See Fig 5a).
- Denmark: as can be seen in Figure 5b, the Danish krone registered a clear improvement in credibility from the beginning of the ERM, although from October-November 1985 (with the entrance of Portugal and Spain in the European

Communities) there was a fall in credibility that was smoothed with the broadening of the ERM fluctuation bands in August 1993.

- France: the results for the French franc suggest some evidence of credibility losses between its realignment in June 1982 and March 1983, as well as in February 1995 (due to speculative attacks to this currency) (see Figure 5c).
- Ireland: as shown in Figure 5d, we find evidence of lack of credibility for the Irish pound from December 1980 to its realignment in March 1983 (with the worsening in the interest rate differential with respect to the US) with an important decline in December 1982 (coinciding with the significant fall of the Pound sterling). After strong gains in credibility, there are temporary losses in June 1993 (previous to the broadening of the bands), and after the Italian lira rejoined the ERM in November 1996.
- Italy: the results for the Italian lira show evidence of credibility losses until its realignment in March 1983, followed by a gradual improvement in credibility until September 1992, when its participation in the ERM was suspended (see Figure 5e). The results also suggest that when the Italian lira re-joined the ERM it experienced credibility levels higher than before it left.
- The Netherlands: as can be seen in Figure 5f, our results indicate temporary credibility losses for the Dutch guilder from September 1979 (coinciding with a general realignment of parities) to its realignment in June 1982.
- Portugal: the results for the Portuguese escudo suggest a fall of credibility until its realignment in November 1992, followed by a steady improvement, the only exception being a temporary lack of credibility around its realignment in May 1993 (see Figure 5g).
- Spain: as seen in Figure 5h, the Spanish peseta shows evidence of a lack of credibility until its realignment in November 1992, followed by a steady improvement until May 1994 (coinciding with the turmoil in the financial markets), with further credibility gains after its realignments in March 1995.

Figure 5: Marginal credibility

Notes: Credibility indicator based on estimation results in Table 5.
Vertical lines = actual ERM realignments and broadening of fluctuation bands.

4. Comparison among indicators

The primary purpose of this Section is to explore the differences among the indicators studied in the previous sections. In particular, we compare the indicators according to their ability to capture the main episodes in EMS history. We consider two simple methods: the first one tries to offer a visual device for the comparison, the second one gives us an efficiency ranking based on the construction of a non-parametric piecewise frontier over the credibility measures.

4.1. A simple graphic method

Here we present here a simple graphic method in order to obtain a first image of the degree of efficiency associated with each credibility indicator. We have investigated the changes of the first and second order moments prior to the main events of the sample period. In particular, for each indicator and for each exchange rate, we examined the month prior to the main events: the realignments and the broadening of the bands (August 1993)⁷.

Once we calculated the mean and the standard deviation for the whole period, as well as for the different subperiods, we measured the percentage differences between the values for each one of these subperiods and the corresponding values for the complete period. Then, we placed the six⁸ indicators from the greatest to the smallest degree of detection of the selected events (i.e., from the greatest to the smallest percentage difference between the subperiods and the whole period). In this way, we assigned scores from 1 to 6 according to the place occupied by each measure in each event detected. For each exchange rate, we have six scores, one for each indicator, corresponding to the mean and the standard deviation for the subperiods.

In Figure 6 we have considered for each one of the six indicators under study, the mean and the standard deviation separately. We have added the mean scores and the standard deviation scores corresponding to the events selected for each exchange rate. Therefore, the closer a position to the origin of an indicator, the better its ability is to predict the events during the month before. The closer position with respect to the origin (96, 147) corresponds to marginal credibility. This indicator seems to be the most accurate in predicting the events selected (i.e., the realignments of each exchange rate and the broadening of the bands). Marginal credibility presents a better balance in both the mean and the standard deviation.

The crisis probability indicator, based on the exchange rate, for both mean and standard deviation gets a worse position (96, 160) than marginal credibility due to a lower degree of detection in terms of the mean. The relative goodness of the exchange rate could be explained if the level and the changes of this variable are closely followed by agents in the foreign exchange markets. The drift-adjustment method (238, 44) seems to be the best indicator with respect to the changes in the mean, but is the worst one according to the volatility. It is surprising that the indicators based on the existence of a target zone do not provide the best predictions. The credibility indicators based on the distances to the upper band and to the central parity might have lost their relevance due to the great length of the period following the widening of the bands until December 1998. The great width of the fluctuation bands may have diminished the ability of these variables in capturing the main events.

⁷ The choice of a subperiod prior to each one of the selected events tries to capture the predictive quality of the different measures. Nevertheless, it must be pointed out that we are not taking into account the number of events registered by each indicator; this last element could have been an alternative criterium in order to carry out the comparison.

⁸ Svensson's simple test was eliminated given its mentioned sensitivity to the size of the fluctuation bands.

Figure 6.- Comparison among indicators
in μ (order in mean) and in σ (order in standard deviation)

Note: DAM=drift-adjustment method, L1=crisis probability from the exchange rate, L2=crisis probability from central parity distance, L3= crisis probability from upper band distance, L4=crisis probability from the interest rate differential, and MC=marginal credibility.

4.2. Relative efficiency

The second approach uses a non-parametric method to calculate the relative efficiency of indicators. In particular, Data Envelopment Analysis (DEA) allows the use of linear programming methods to construct a non-parametric piecewise surface over the indicators.

We have modified the comparison perspective with respect to the simple method reported in the previous section. First, we obtain a ranking by distinguishing both among exchange rates and each event. Second, we consider simultaneously the variation in mean and the variation in standard deviation in all the realignments in the history of the ERM and in the broadening of the bands (August 1993).

In this way, for each critical subperiod and each event we applied an input-oriented DEA method in which the inputs are the inverse of the variation in the mean of the indicator and the inverse of the variation in the standard deviation of the indicator,

with respect to their values for the complete period. Following a simplification similar to Cooper *et al.* (2000, p. 173), we can define an output with the value 1, since in our problem we have only two inputs: the inverse of the variation in the mean and the inverse of the variation in the standard deviation.

The DEA method allows the achievement of an efficient frontier. We are interested in obtaining the maximum outputs by minimising the quantity of inputs. We have to solve this input-orientated linear programming problem for each credibility indicator⁹:

$$\begin{aligned}
 & \min_{\theta, \lambda} \theta_i \\
 \text{st} \quad & -y_i + Y\lambda \geq 0 \\
 & \theta_i x_i - X\lambda \geq 0 \\
 & N1'\lambda = 1 \\
 & \lambda \geq 0
 \end{aligned}$$

where θ_i is the scalar that measures the degree of efficiency of each indicator, as proposed by Farrell (1957). A value of 1 tells us that this indicator is on the frontier, i.e., it is efficient, while a value less than 1 shows that is inefficient, $1-\theta$ being the input percentage that could be reduced in order to reach efficiency. λ is a $N \times 1$ vector of parameters which allows us to obtain a fictitious and efficient credibility indicator from the observations. X is a $K \times N$ input matrix, and Y is a $M \times N$ output matrix, K being the number of inputs, M the number of outputs, and N the number of indicators. x_i and y_i represent the vector of inputs and the vector of outputs associated to the i -th indicator, respectively. The first restriction is to fix the output while the second one is an indication of the need to minimise the inputs used. The third restriction permits a variable returns to scale approach.

⁹ A comprehensive description of these methods can be found in Seiford and Thrall (1990). In this paper we have used the DEAP 2.1.

Table 5a. Relative efficiency. DEA analysis for all realignments

Date	DAM	L1	L2	L3	L4	MC
BFR/DM						
24/09/79	1 (1;5)	1 (2;1)	0.841 (6;6)	0.984 (5;4)	0.989 (4;3)	1 (3;2)
05/10/81	1 (1;5)	1 (2;1)	0.665 (4;6)	0.963 (5;3)	0.947 (6;4)	1 (3;2)
22/02/82	1 (1;6)	1 (3;1)	1 (2;2)	0.981 (5;5)	1 (4;3)	1 (6;4)
14/06/82	1 (1;5)	1 (4;1)	0.243 (2;6)	0.989 (6;3)	1 (5;2)	0.979 (3;4)
21/03/83	1 (1;6)	0.898 (4;4)	1 (2;1)	0.818 (6;5)	0.972 (5;2)	0.961 (3;3)
07/04/86	1 (1;3)	1 (6;4)	0.742 (2;6)	1 (5;2)	0.781 (4;5)	1 (3;1)
12/01/87	1 (1;4)	0.913 (5;3)	0.026 (2;6)	0.981 (6;2)	0.607 (3;5)	1 (4;1)
02/08/93	1 (1;5)	0.796 (4;4)	1 (3;1)	0.929 (6;3)	0.151 (5;6)	1 (2;2)
DKR/DM						
24/09/79	1 (1;6)	1 (3;1)	0.979 (4;5)	1 (5;3)	0.980 (6;4)	1 (2;2)
26/11/79	1 (1;5)	1 (3;1)	0.993 (4;2)	0.981 (6;4)	0.975 (5;6)	1 (2;3)
05/10/81	1 (1;6)	1 (3;1)	0.986 (4;3)	0.979 (6;4)	0.907 (5;5)	1 (2;2)
14/6/82	1 (1;6)	1 (3;1)	0.987 (4;3)	0.973 (5;5)	1 (6;2)	1 (2;4)
21/03/83	1 (1;6)	1 (2;1)	0.774 (5;5)	0.897 (6;4)	1 (4;2)	0.986 (3;3)
07/04/86	1 (1;6)	1 (3;1)	1 (4;3)	1 (5;2)	0.960 (6;5)	1 (2;4)
12/01/87	1 (1;6)	1 (3;2)	0.945 (5;4)	1 (6;3)	0.938 (4;5)	1 (2;1)
02/08/93	1 (1;6)	0.406 (3;5)	0.439 (4;4)	0.454 (5;3)	1 (2;1)	0.473 (6;2)

Note: DAM=drift-adjustment method, L1=crisis probability from the exchange rate, L2=crisis probability from central parity distance, L3= crisis probability from upper band distance, L4=crisis probability from the interest rate differential, and MC=marginal credibility. In parentheses, on the left side appears the order of that indicator according to the change of mean while on the right side the order in change of standard deviation.

Table 5b. Relative efficiency. DEA analysis for all realignments.

Date	DAM	L1	L2	L3	L4	MC
ESC/DM						
23/11/92	1	1	1	0.909	0.791	0.979
	(1;3)	(6;1)	(5;2)	(4;5)	(3;6)	(2;4)
17/05/93	1	1	1	0.898	0.605	1
	(1;5)	(6;2)	(5;1)	(4;4)	(3;6)	(2;3)
02/08/93	1	0.759	1	0.242	0.777	1
	(1;6)	(4;4)	(3;1)	(5;5)	(6;3)	(2;2)
06/03/95	1	0.863	0.390	0.930	1	1
	(1;4)	(3;5)	(2;6)	(5;3)	(4;2)	(6;1)
FF/DM						
24/09/79	1	1	1	1	0.988	1
	(1;6)	(2;1)	(3;4)	(5;3)	(6;5)	(4;2)
05/10/81	1	1	0.961	0.984	0.956	1
	(1;6)	(2;1)	(3;4)	(4;3)	(6;5)	(5;2)
14/06/82	1	1	0.985	1	1	1
	(1;6)	(2;1)	(3;5)	(4;3)	(6;4)	(5;2)
21/03/83	1	1	0.875	0.934	1	0.972
	(1;6)	(2;1)	(4;5)	(5;4)	(6;2)	(3;3)
07/04/86	1	1	1	1	0.906	1
	(1;5)	(2;1)	(3;2)	(4;3)	(6;6)	(5;4)
12/01/87	1	1	0.911	0.966	0.863	1
	(1;6)	(2;1)	(3;4)	(5;3)	(4;5)	(6;2)
02/08/93	1	0.796	0.848	1	0.261	1
	(1;5)	(6;4)	(4;3)	(2;2)	(5;6)	(3;1)
HFL/DM						
24/09/79	1	0.878	0.880	0.322	1	1
	(1;5)	(4;4)	(5;3)	(2;6)	(6;2)	(3;1)
21/03/83	1	0.871	0.922	0.893	1	1
	(1;6)	(3;5)	(4;3)	(5;4)	(6;1)	(2;2)

Note: DAM=drift-adjustment method, L1=crisis probability from the exchange rate, L2=crisis probability from central parity distance, L3= crisis probability from upper band distance, L4=crisis probability from the interest rate differential, and MC=marginal credibility. In parentheses, on the left side appears the order of that indicator according to the change of mean while on the right side the order in change of standard deviation.

Table 5c. Relative efficiency. DEA analysis for all realignments.

Date	DAM	L1	L2	L3	L4	MC
IRL/DM						
24/09/79	1	0.973	0.362	0.607	1	1
	(1;6)	(3;3)	(5;5)	(6;4)	(4;1)	(2;2)
05/10/81	1	1	0.976	0.970	1	1
	(1;6)	(3;1)	(6;4)	(5;5)	(4;2)	(2;3)
14/06/82	1	1	0.976	0.971	1	1
	(1;6)	(4;2)	(6;4)	(5;5)	(3;1)	(2;3)
21/03/83	1	1	0.946	0.943	1	1
	(1;6)	(4;3)	(6;4)	(5;5)	(3;1)	(2;2)
07/04/86	1	1	0.976	0.978	0.123	1
	(1;5)	(5;1)	(6;4)	(4;3)	(2;6)	(3;2)
04/08/86	1	0.978	0.948	0.837	0.885	1
	(1;6)	(3;2)	(5;3)	(4;5)	(6;4)	(2;1)
12/01/87	1	0.988	0.945	0.935	0.880	1
	(1;5)	(6;2)	(5;3)	(4;4)	(2;6)	(3;1)
01/02/93	1	0.286	0.261	0.254	1	0.298
	(1;6)	(6;3)	(5;4)	(4;5)	(2;1)	(3;2)
02/08/93	1	0.935	0.896	0.890	1	1
	(1;6)	(4;3)	(5;4)	(6;5)	(3;1)	(2;2)
16/03/98	1	0.968	0.915	1	1	1
	(1;6)	(5;4)	(6;5)	(4;3)	(3;2)	(2;1)
PTA/DM						
14/09/92	1	1	0.937	0.900	0.906	0.969
	(1;6)	(3;1)	(4;3)	(2;5)	(5;4)	(6;2)
23/11/92	1	1	0.873	0.961	0.907	0.890
	(1;3)	(4;1)	(5;6)	(2;5)	(3;4)	(6;2)
17/05/93	1	1	1	0.858	1	1
	(1;6)	(5;2)	(4;3)	(3;5)	(2;4)	(6;1)
02/08/93	1	0.886	1	1	0.485	1
	(1;6)	(5;2)	(3;3)	(2;5)	(6;4)	(4;1)
06/03/95	1	1	0.475	0.779	1	0.946
	(1;4)	(3;3)	(2;6)	(4;5)	(5;1)	(6;2)

Note: DAM=drift-adjustment method, L1=crisis probability from the exchange rate, L2=crisis probability from central parity distance, L3= crisis probability from upper band distance, L4=crisis probability from the interest rate differential, and MC=marginal credibility. In parentheses, on the left side appears the order of that indicator according to the change of mean while on the right side the order in change of standard deviation.

The results are presented in Tables 5a, 5b, and 5c. We report the efficiency scores for each method and each exchange rate, by a number that varies between zero and 1. The drift-adjustment method, marginal credibility, and the crisis probability based on the exchange rate are the closest to the efficiency frontier. This supports the results obtained from the previous comparison.

The drift-adjustment method is in all cases an efficient indicator. The reason is that this indicator is the best one according to one of the inputs (the inverse of variation in the mean) but the worst according to the other input, as can be checked in the numbers in parentheses that indicate the position in the previous method of comparison. In spite of this, the measure is on the frontier due to its extreme position with respect to changes in the mean. The drift-adjustment method always appears on the frontier in spite of its limitations in capturing crises in terms of volatility.

Marginal credibility appears with a value of 1 in 34 out of the 44 possible cases. It is especially clear in the case of the currencies with a longer history in the ERM. As can be observed in the previous section, this indicator is very accurate in detecting crises in the mean, as well as in the standard deviation. This indicator is situated in a more centred position on the frontier. If an observer looks at both the changes in level and in volatility, marginal credibility is the most appropriate indicator.

The credibility measure based on the exchange rate seems to be a good indicator, obtaining a value of 1 in 28 cases.

We have used weekly data due to data availability restrictions. As shown in Ledesma-Rodríguez *et al.* (1999a, 2000), daily data confirm the relevance of marginal credibility and presents a greater advantage with respect to the rest of the credibility measures when the objective is to detect the main realignments that occurred during the sample period. This fact could be related to the capability of the marginal credibility indicator in capturing the volatility of the series. When using daily data, the information is processed more efficiently, avoiding the smoothing of the volatility curve when the frequency is reduced to the weekly level.

5. Concluding remarks

In this paper we have provided some new evidence on the credibility of the ERM. Our paper differs from the previous literature in three main respects. First, its main contribution is the use of several credibility indicators, some of which have never been applied before to all the currencies under study. This allows to strengthen the results obtained in this paper. Second, we analyse a longer period than that considered in previous studies, covering the complete EMS history. Third, we have carried out a simple comparison of the prediction qualities of the different indicators, in order to explore their ability to capture the main ERM events: both realignments and the broadening of the bands in August 1993.

The country-to-country analysis made in this paper shows: (i) before the currency crisis in late 1992, for most of the countries, the exchange rate policy was credible, except for the Italian case (a similar conclusion is derived in Weber, 1991a); (ii) the 1992 currency turbulence was accompanied, in the first instance, by credibility losses in all countries, except Belgium and the Netherlands. This is consistent with the

fact that the Dutch guilder and the Belgian franc along, with the Deutschmark, were the only currencies that were not affected by speculative attacks during the fall of 1992; (iii) after the widening of the fluctuation bands there was a gain in credibility for the currencies participating in the ERM, with the exception of the Belgian franc and the Irish pound. This is consistent with the claims by both Ayuso *et al.* (1994) and Sosvilla-Rivero *et al.* (1999) that the broadening of the bands led to a decrease in volatility to levels comparable to those prevailing before the crisis.

These results are consistent with the evolution of the nature of the EMS (see, e. g. De Grauwe, 2000). First, the relatively large fluctuations bands in the EMS (compared to those in the Bretton Woods system), together with relatively small and frequent realignments, helped to reduce the size of speculative capital movements and stabilised the system during the 1980s. At the start of the 1990s, however, the evolution of the EMS into a truly fixed exchange rate system with almost perfect capital mobility led to credibility losses in a context of policy conflict among EMS countries about how to face the severe recession experienced in 1992-93. Finally, after the crisis of 1993, the EMS changed its nature in drastic ways. The EMS gained credibility with the enlargement of the fluctuation bands to $\pm 15\%$ (reducing the scope for large speculative gains) and with the fixed exchange rate commitment among potential EMU-member countries. As a result, speculation became a stabilising factor and the market rates converged closer and closer to the fixed conversion rates, although the world was hit by a major crisis during the second half of 1998 (De Grauwe *et al.*, 1999).

We have also compared indicators according to their ability to detect the main events in the history of the ERM. Marginal credibility (i.e., an indicator that recognises the changing nature of the central parities, the width of the bands, and the realignment expectations in the history of the ERM) is an accurate indicator in detecting a crisis in the mean, as well as in the standard deviation. If an observer looks at both the changes in level and in volatility, the marginal credibility is the most accurate indicator. The drift-adjustment method seems to be a very good way to predict the events by the changes in mean, but the worst if we consider the changes in the standard deviation.

We consider that our results are of interest, not only for the European experience in the 1979-1998 period, but also for the analysis of other possible target zones as the new ERM (ERM II), linking the currencies of non-Euro area Member States to Euro -both current European Union Member States and future candidates- (see ECOFIN, 2000). The EMS experience suggests that such a exchange rate system can only work within the framework of a temporary regime towards a full monetary union, since it is too fragile as a permanent monetary regime. The 1979-1998 period has shown us that the ERM-II could face similar problems to those experienced by the EMS during 1992-1993, i.e., that if the prospect for a quick entry of the “out” members are weak, there could be speculative crises and a possible collapse of the arrangement.

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