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TARGET ZONES AND EXCHANGE RATES: AN EMPIRICAL INVESTIGATION

ABSTRACT

In this paper we develop an empirical model of exchange rates in a target zone. The model is general enough to nest most theoretical and empirical models in the existing literature. We find evidence of two types of jumps in exchange rates. *Realignment jumps* are those that are associated with the periodic realignments of the target zone and *within-the-band jumps* are those that can be accommodated within the current target zone. The exchange rate may jump outside the current target zone band, in the case of a realignment, but when no jump occurs the target zone is credible (there is zero probability of a realignment) and the exchange rate must stay within the band. We incorporate jumps, in general, by conditioning the distribution of exchange rate changes on a jump variable where the probability and size of a jump vary over time as a function of financial and macroeconomic variables. With this more general model, we revisit the empirical evidence from the European Monetary System regarding the conditional distribution of exchange rate changes, the credibility of the system, and the size of the foreign exchange risk premia. In contrast to some previous findings, we conclude that the FF/DM rate exhibits considerable non-linearities, realignments are predictable and the credibility of the system did not increase after 1987. Moreover, our model implies that the foreign exchange risk premium becomes large during speculative crises. A comparison with the Deutschemark/Dollar rate suggests that an explicit target zone does have a noticeable effect on the time-series behavior of exchange rates.

Geert Bekaert
Graduate School of Business
Stanford University
Stanford, CA 94305-5015
and NBER

Stephen F. Gray
Fuqua School of Business
Duke University
Durham, NC 27706

1 Introduction

More than 20 years after the break-down of the Bretton Woods system, the day-to-day behavior of exchange rates continues to puzzle both the academic community and policy makers. The recent currency crisis in the European Monetary System (EMS) and the continued strength of the yen relative to the dollar, supposedly defying fundamentals, has heightened concerns among policy-makers about "aberrant" exchange rate movements. In fact, a recent IMF-study calls for the re-imposition of managed target zones among the major currencies.

These developments are likely to renew interest in the operation of exchange rate target zones. What are the dynamics of exchange rates, interest rates and central bank interventions within target zones? To what extent have central bank interventions contributed to sustainable target zones, what triggers them to break down? Are speculative crises of the sort recently encountered by the EMS predictable? Beginning with Krugman (1991), there is a large theoretical literature on target zones. Smith and Spencer (1991) and de Jong (1994), however, illustrate that these models have had limited empirical success when confronted with data from the European Monetary System.

In this paper, we propose an empirical model of exchange rates that captures many salient features of target zones and allows some of the questions posed above to be addressed. In particular, our model of exchange rate changes accommodates occasional adjustments of the target zone band as well as jumps within the band. To do this, we condition the distribution of exchange rate changes on a jump variable. At each point in time, a jump may, or may not, occur. Conditional on no jump occurring, we model exchange rate changes as being drawn from a truncated normal distribution with time-varying moments. This distribution is truncated above and below, so that there is zero probability of observing an exchange rate change which would take the exchange rate outside the target zone. That is, we model the system as being perfectly credible in the absense of jumps. Jumps can occur within the existing target zone or, in the event of a realignment, the exchange rate may move outside the current band. The mean size and variance of the jump vary over time as a function of variables such as the position of the exchange rate in the band, the interest rate differential, cumulative inflation differentials, and the level of central bank foreign currency reserves. The probability of a jump occurring depends on the slope of the yield curve of the depreciating currency. Modeling jumps that can be accommodated within the band as well as realignments helps to identify the parameters of the model that are associated with jumps.

Our framework has three main advantages over the existing literature. First, our empirical model offers a very rich characterization of the (conditional) distribution of the exchange rate.[1] Krugman's credible-target-zone model implies strong restrictions on the conditional

[1]Previous studies focussing on the exchange rate distribution within a target zone include Beetsma and

distribution of exchange rate changes.[2] Svensson (1990) shows that the presence of the band should make the expected rate of currency depreciation negatively and non-linearly related to the level of exchange rates. Although mean reversion of exchange rates within a target zone has been often documented, previous empirical work such as Rose and Svensson (1993) fails to find substantial evidence of nonlinearities. In this paper, we document substantial non-linearities in the French Franc/Deutschemark (FF/DM) rate. We also examine the effects of target zones on the conditional volatility of exchange rates. In a credible target zone, the conditional volatility of exchange rate changes depends on the position of the exchange rate within the band. Volatility should decline when the exchange rate is near the edges of the band, as central bank intervention has a stabilizing effect on exchange rate movements. Our model, which incorporates the possibility of realignments, is more general than the credible-target-zone literature in two ways. First, in addition to dependence on the position of the exchange rate within the band, we also incorporate generalized autoregressive conditional heteroscedasticity (GARCH) effects into our volatility model. Second, the total conditional volatility of exchange rate changes also incorporates the possibility of jumps. Conditional volatility will be high if recent volatility has been high (via the GARCH process) or if there is high conditional probability of a large jump in exchange rates. We refer to the latter component of volatility as *jump risk*. This jump risk may substantially decrease the perceived volatility dampening ascribed to target zones. We find that on average 25% of total conditional volatility is accounted for by jump risk, but this proportion varies substantially over time.

The second contribution of our empirical framework, is to provide a better measure of the credibility of a target zone. We define a target zone to be perfectly credible if the probability of the exchange rate moving outside the band is zero. Since we specify the complete conditional distribution of exchange rate changes, we are able to directly compute this probability, conditional on available information. Whereas most of the current literature (see, for example, Rose and Svensson (1993) and Chen and Giovannini (1993)) relies on Uncovered Interest Rate Parity (UIRP) and interest differentials to infer market expectations of the exchange rate moving outside the band, we do not to take this route because UIRP is frequently violated.

The credibility of the target zone in our model depends crucially on the probability of a jump and its size, both of which vary over time. The jump size depends on the relative level of foreign currency reserves of the central bank of the weak currency, interest differentials, cumulative inflation differentials, and the position of the exchange rate within the band. The jump probability depends on the slope of the yield curve of the depreciating currency.[3]

van der Ploeg (1993), Chen and Giovannini (1993), Engel and Hakkio (1995), Flood, Rose and Mathieson (1990), and Nieuwland, Verschoor, and Wolff (1994).

[2]We follow the existing literature in referring to a target zone which has zero probability of realignment as being "credible".

[3]While it might be argued that some of these variables may influence both the probability of a jump and

This structure is more general and closer to actual practice than the exogenous realignment mechanisms that have been proposed in the literature by Bertola and Caballero (1993) and Bertola and Svensson (1993) and others. We document below the importance of allowing for within-the-band jumps in addition to realignment jumps.

The credibility issue has become more acute with the recent September 1992 and August 1993 crises in the EMS. It is often claimed that the 1987-1991 period, during which no realignments occurred, was an example of a credible target zone (see, for example, Ball and Roma (1994)) and that, consequently, the crises came as a complete surprise (see especially Rose(1993)). Our evidence is contrary to both claims. The fact that no realignments occur during a period does not imply that there is no realignment risk over that period. We find realignment probabilities to be quite substantial over the 1987-1991 period. We also formally examine whether our model has predictive (out-of-sample) power for the currency crises, and find that realignment probabilities are relatively high in the periods leading up to actual realignments. However the recent currency crises only lead to small increases in the realignment probabilities immediately before they occurred.

Finally, we consider how structural changes may have affected the credibility of the EMS. We focus on changes in monetary policy broadly defined, that is capital control changes in France over the sample period and the recent switch to the "franc fort" policy, and on the signing of the Maastricht Treaty. How did these policy changes affect the credibility of the system? This issue is important in considering future attempts at managing floating currencies. Padoa-Schioppa (1985), for instance, predicted that the EMS would not be sustainable when capital controls were abolished.

The third contribution of our approach is to examine the implied currency risk premia. Svensson (1990) has argued that risk premia in target zones ought to be small and most of the empirical literature has imposed Uncovered Interest Rate Parity (UIRP). However, the empirical evidence on UIRP in the EMS is mixed (see, for example, Bossaerts and Hillion (1991)).

We apply the model to the FF/DM rate from 1979 until July 1993. During that period the FF and DM were part of the EMS. We also compare the results to the Deutschemark/Dollar rate over the same period. Econometrically, we estimate the single-equation reduced-form model for exchange rate changes using maximum likelihood.

The remainder of the paper is organized as follows. The following section outlines the empirical models and their relationship with the current literature. Section 3 contains a

its size, adopting such a specification would result in identification problems. That is, it becomes difficult to differentiate between a large jump with small probability and a small jump with larger probability when the probability of a jump and its size both depend on the same set of instruments. The specification adopted in this paper, which is primarily empirically motivated, is discussed in some detail in the following section.

discussion of estimation issues. The fourth section reports the empirical results and examines the conditional distribution of exchange rates. Section 5 focusses on the credibility of the target zone and examines how structural changes may affect credibility. The sixth section discusses implied currency risk premia. The model is applied to the Deutschemark/Dollar rate in section 7 and the final section concludes.

2 Motivation and Econometric Model

2.1 Theoretical Target Zone Models

The theoretical target zone literature builds primarily on the stylized continuous-time model of Krugman (1991). The exchange rate is measured in domestic currency per unit of foreign currency and is in logs. Moreover the exchange rate is assumed to depend on market fundamentals and the expected exchange rate, as implied by the simple monetary model of exchange rate determination. One fundamental is assumed to follow a Brownian motion and the other fundamental is controlled to keep the exchange rate within a pre-specified band. Two important assumptions underlie the model: the target zone is perfectly credible and it is defended with marginal interventions only.

The Krugman model has strong empirical implications for exchange rates and interest rate differentials. First, the exchange rate is a non-linear function of fundamentals, hence exchange rate changes should exhibit non-linearities. In particular, the conditional volatility of exchange rate changes should be smaller near the edges of the band and the exchange rate should display a non-linear form of mean-reversion, even though fundamentals are Brownian motions. If UIRP is assumed to hold, the expected exchange rate change equals the interest rate differential and the particular form of mean reversion implied by the Krugman model induces a negative deterministic relationship between the exchange rate and interest rate differentials. Second, the unconditional distribution of the exchange rate should be U-shaped, with more observations near the edges of the band. Svensson (1991) notes that this implication is clearly refuted by the data. Since we focus on the conditional distribution of exchange rate changes, our interest is primarily in the first set of implications.

Direct tests of the Krugman model in Smith and Spencer (1991) and De Jong (1994) have delivered clear rejections of the model. In particular, the endogenous non-linearities are not sufficient to explain all of the leptokurtosis and ARCH effects in the data. Surprisingly, other studies such as Rose and Svensson (1991) and Flood, Rose and Mathieson (1991) do not detect significant non-linearities in EMS data. The history of repeated realignments and the preponderance of intra-marginal interventions in the EMS, described by Giavazzi and Giovannini (1989) and others, are also inconsistent with the Krugman model.

Extensions of the basic Krugman model have taken various forms. Two important modifications are the introduction of realignment risk and intramarginal interventions. Bertola and Caballero (1992) introduce the possibility of a devaluation at the edge of the exchange rate band. That is, when the exchange rate hits the upper boundary, there is a (fixed) probability of a devaluation. Bartolini and Bodnar (1992) show that this simple extension can generate realistic correlations between exchange rates and interest rate differentials. Bertola and Svensson (1993) introduce an additional exogenous stochastic process for the change in the central parity. Hence, a realignment can occur even if the exchange rate is within the band. To allow for intramarginal interventions Delgado and Dumas (1991) and Lindeberg and Söderlind (1992) introduce mean-reverting fundamentals. Beetsma and van der Ploeg (1993) stress the importance of this extension in addition to realignment risk. They document the empirical failures of the standard Krugman model for the Dutch guilder, the most credible of the exchange rates within the EMS, from 1987 to 1991, a period during which no realignments occurred and realignment risk for the guilder was negligible. Lewis (1995) presents an alternative model with similar implications, where the mean reversion arises from occasional interventions by the authorities when the exchange rate deviates from target levels.

We offer an empirical model that nests all of these extensions to the Krugman model and is more general in several directions. This generality permits the derivation of a detailed set of stylized facts, which should prove useful for future theoretical work. In weighing the lack of theoretical underpinnings, we note that the monetary exchange rate model was virtually abandoned on empirical grounds (see Meese and Rogoff (1983)) before it was picked up by target zone theorists, mainly for convenience. In the remainder of this section, we discuss and motivate the most important features of our model.

2.2 An Econometric Target Zone Model

Incorporating Jumps

Standard target zone models fail along two principal dimensions. First, conditional on the system being credible, the behavior of exchange rates within the target zone contradicts standard models. Second, the EMS has witnessed many realignments, and there have also been many large within-the-band exchange rate movements during speculative attacks, which sometimes lead to realignments themselves. These realignments indicate that, historically, the system has not been perfectly credible. While the target zone system has operated as intended for some periods, speculative attacks and other forces have caused the system to break down from time to time. To capture this feature, we begin by modeling exchange rates in a perfectly credible target zone, then we introduce the possibility of occasional jumps that may, or may not, take the exchange rate outside the band. A jump which would take the exchange rate outside the band is interpreted as a realignment, but we also allow for the possibility of within-the-band jumps. The reason we do not separately model within-the-band jumps and realignment jumps is twofold. First, many within-the-band jumps are of the same order of magnitude as realignment jumps, so both kinds of jumps can be parameterized in the same way. Second, there are relatively few realignment jumps, so including within-the-band jumps helps to identify the jump parameters.

Formally, we seek to model the distribution of changes in exchange rates, conditional on available information, $f(\Delta S_t|I_{t-1})$. ΔS_t represents log exchange rate changes, I_{t-1} denotes an information set, and $f(\cdot|\cdot)$ denotes a conditional density. We construct this conditional distribution by separately modeling (1) the conditional distribution in the absence of jumps, and (2) jumps in the exchange rate. The two pieces of this conditional distribution are defined, in turn, below. To this end, we define an indicator variable:

$$J_t = \begin{cases} 1 & \text{if the exchange rate jumps at time } t \\ 0 & \text{otherwise} \end{cases} .$$

Then the conditional distribution of exchange rate changes can be factored as:

$$f(\Delta S_t|I_{t-1}) = f(\Delta S_t|I_{t-1}, J_t = 0)\Pr(J_t = 0|I_{t-1}) + f(\Delta S_t|I_{t-1}, J_t = 1)\Pr(J_t = 1|I_{t-1}). \quad (1)$$

Note that in contrast to Bertola and Caballero (1992) and Bertola and Svensson (1993), we allow for *jumps*, rather than just *realignments*. Ball and Roma (1993) also formulate a jump process for the central parity (the center of the target zone) but do not allow for within-the-band jumps. Engel and Hakkio (1995) use a model that is similar to ours, however they model J_t as a Markov process and do not take the presence of the band explicitly into account. We illustrate below the empirical importance of within-the-band jumps, and describe the precise specification of the component pieces of our density.

A Model of a Credible Target Zone

First, we consider $f(\Delta S_t|I_{t-1}, J_t = 0)$, the distribution of exchange rate changes conditional on available information, and on there being no jump. This corresponds to the setting of a properly functioning target zone system where the exchange rate will never move outside the target zone, in which case exchange rate changes are bounded. The maximum possible change, Δ_U, takes the exchange rate to the upper boundary of the target zone, and the minimum possible change, Δ_L, takes the exchange rate to the lower boundary. In such a system, a bounded density is required to model exchange rate changes. In this paper, we use a truncated normal density which has a very flexible form, few parameters to estimate, and is defined only on $[\Delta_L, \Delta_U]$. While a number of alternative truncated distributions, such as the beta distribution, are available, we use the truncated normal for a number of reasons. First, most theoretical target zone models consider exchange rate changes to be normally distributed (an increment from a Brownian motion) in the absence of a target zone. When the exchange rate approaches a target zone boundary, however, the monetary authorities intervene to the extent required to keep the exchange rate within the band. A similar type of interpretation can be given to the truncated normal distribution used in this paper. In the absence of a target zone, we model exchange rate changes as being conditionally normal. In a credible target zone, however, there is zero probability of the exchange rate moving outside the band, so we truncate that part of the density. While the truncated normal is not equivalent to the transition density under regulated Brownian motion, there is a strong analogy. Second, the truncated normal density depends upon four parameters, the mean and variance of the underlying normal distribution and the truncation points. In modeling a target zone, the truncation points are predetermined and the mean and variance are economically-meaningful parameters. In particular, many target zone models imply restrictions on this mean and variance. Conversely, the beta distribution depends upon two shape parameters which can be converted to the mean and variance only by a complicated non-linear transformation.

The truncated normal distribution is:

$$f(\Delta S_t | I_{t-1}, J_t = 0) = \frac{\phi\left(\frac{\Delta S_t - \mu_{t-1}}{\sqrt{\sigma^2_{t-1}}}\right)\frac{1}{\sqrt{\sigma^2_{t-1}}}}{\Phi\left(\frac{\Delta_{U_{t-1}} - \mu_{t-1}}{\sqrt{\sigma^2_{t-1}}}\right) - \Phi\left(\frac{\Delta_{L_{t-1}} - \mu_{t-1}}{\sqrt{\sigma^2_{t-1}}}\right)}$$

where $\phi(\cdot)$ denotes the standard normal probability density function and $\Phi(\cdot)$ represents the standard normal cumulative distribution function and μ_{t-1} and σ^2_{t-1} are the conditional mean and variance of the normal distribution which is to be truncated. That is, ΔS_t is modeled as being normally distributed with conditional mean μ_{t-1} and variance σ^2_{t-1}, with any probability mass falling outside the range of $[\Delta_L, \Delta_U]$ being truncated and added back in proportion to the density within this range. Consequently, there is zero probability of the exchange rate moving outside the target zone, consistent with the credibility of the target zone.

We parameterize the conditional mean, μ_{t-1}, to incorporate mean reversion by letting exchange rate changes depend on the position in the band: $\mu_{t-1} = \beta_8 + \beta_9 PB_{t-1}$, where PB_{t-1} takes a value on $[-1, 1]$ indicating the relative position of the exchange rate within the target zone. When $PB_t = 0$, the exchange rate is at the center of the target zone, when $PB_t = 1$, the exchange rate is at the upper boundary of the target zone, and so on. Hence, the expected change toward the center of the target zone is stronger when the exchange rate is near the edge of the band. This is consistent with the predictions of a Krugman-type model and also with the presence of intra-marginal interventions, which we address below. For example, central banks may defend an implicit exchange rate target within the band. Although there is no official record of such an implicit target for the French Franc, narrower band were maintained by both the Dutch and Belgian central banks for parts of the sample period.

The conditional variance, σ^2_{t-1}, follows a GARCH (1,1) process, augmented to allow for dependence on the position within the band:

$$\sigma^2_t = \beta_{10} + \beta_{11}(1 - RD_{t-1})\epsilon^2_{t-1} + \beta_{12}\sigma^2_{t-1} + \beta_{13}|PB_{t-1}|. \tag{2}$$

In this specification, $\epsilon_t = \Delta S_t - \mathrm{E}_{t-1}[\Delta S_t]$, as is standard, and RD_t is a realignment dummy variable which takes the value 1 when a realignment of the target zone occurred in week t and zero otherwise. This variable is included to capture the effects of "pressure relieving" shocks. It is common in the EMS for realignments to be preceeded by periods of above-average volatility, often caused by speculative attacks and fears of a sudden depreciation in the value of a currency. The period immediately after a realignment is usually characterized by below-average volatility, as the weak currency's competitive position has been restored, the exchange rate is usually near the center of the band, and the probability of another realignment in the near future is small. Since realignments often cause a large one-time shock to the exchange rate, ϵ_{t-1}^2 is large and a standard GARCH model would predict very high volatility after a realignment – the opposite of what is expected. We therefore model realignment shocks as being non-persistent.

This specification also enables us to test the relative importance of GARCH effects, which Jorion (1988) shows are significant in the Deutschemark/Dollar rate, and the position in the band, which is the sole determinant of conditional volatility in standard target zone models such as Krugman (1991). Cai (1994) and Gray (1995) have noted that the often-documented persistence of conditional variances is substantially reduced in models which accommodate changes in the unconditional variance. Similarly, we are able to test whether the persistence produced by a standard GARCH model is affected by (1) incorporating dependence on the position in the band in the conditional variance model, and (2) allowing for jumps in the exchange rate process.

Modeling Jumps
Next, we consider the possibility that the exchange rate may jump, in which case the relevant piece of the density is $f(\Delta S_t | I_{t-1}, J_t = 1)$. The jump may take the exchange rate outside the current target zone (in the case of a realignment), but jumps may also occur within the target zone, as the exchange rate jumps from near the lower band to near the upper band, for example.

One motivation for including the possibility of jumps is the work of Jorion (1988), who found evidence of jumps in floating exchange rates. Furthermore, in the EMS, discontinuities in the bilateral exchange rate may occur naturally for a number of reasons. First, and most obviously, a realignment of the EMS target zone may cause a jump in the exchange rate. Indeed a discontinuity is inevitable when, as is usually the case, the new target zone and the old target zone do not overlap. Second, a jump in the exchange rate may occur within the target zone. For example, a pronounced change in the fundamental value of a currency can be caused by announcements of changes in central bank policy or by sudden speculative attacks on a weak currency. Consider the case of a speculative attack: If the bilateral rate in question is in the lower half of the band when the speculative attack begins, there is room for a large and sudden depreciation in the bilateral rate to be accommodated within the band. A prolonged attack may, or may not, subsequently lead to a realignment. Since both hedgers and speculators are concerned primarily with movements in exchange rates rather than movements in the EMS central parity, the models presented below focus primarily on the predictability of all jumps rather than just realignments. We will examine the predictability of realignments in section 5, in the context of a discussion of the credibility of target zones.

Empirically, while the largest jumps in bilateral rates are associated with realignments, there are many within-the-band jumps which are of the same order of magnitude as the realignment jumps. Table 1 documents the ten largest increases and the ten largest decreases in the FF/DM rate over the sample period. This period contains the six realignments of the FF/DM central parity that have occurred since the inception of the EMS. While three of those realignments drive the three largest changes in the bilateral rate, the other three realignments do not rank in the top ten changes in the bilateral rate. That is, several within-the-band jumps are larger than several realignment jumps. Two of the within-the-band jumps appear to be associated with speculative attacks leading up to a realignment. Over the sample period, jumps in the bilateral rate are more likely to take the form of a depreciation of the franc than an appreciation of the franc. There are nine increases in the FF/DM rate that are larger than the largest decrease in the FF/DM rate.

Since there is no a priori reason to impose an upper or lower limit on the magnitude of a jump, we model jumps in the exchange rate as being drawn from a normal distribution. We allow the moments of the jump distribution to be state-dependent (i.e. dependent on I_{t-1}, the information set). The form of this state-dependence renders the conditional mean proportional to the conditional standard deviation. For example, if the conditional mean of the jump distribution is small and positive we constrain the conditional variance to be small. This assumption limits parameter proliferation and avoids identification problems in situations where a positive jump is expected (the conditional mean jump size is positive), while at the same time there is a significant probability of a negative jump (the conditional variance of the jump size is large). In particular, when the exchange rate jumps, we model changes in exchange rates (ΔS_t) as being (conditionally) normally distributed with conditional mean ρ_{t-1} and conditional variance $\rho_{t-1}^2\delta^2$ where δ^2 is a scaling parameter to be estimated and

$$\rho_{t-1} = \beta_3 + \beta_4 LR_{t-1} + \beta_5|PB_{t-1}| + \beta_7 ID_{t-1} + \beta_8 CID_{t-1}.$$

These conditioning variables, which are defined precisely in table 2, are:

1. The relative level of foreign currency reserves of the weak currency's central bank, LR_{t-1}. The position of the exchange rate within the band is unlikely to be a sufficient statistic to gauge the strength of a currency. As indicated above, intra-marginal

interventions have been commonplace in the EMS. Hence, efforts of the central bank to defend the currency may signal a higher probability of either a realignment or a swift movement to the edge of the band. Although in the EMS intervention is only mandatory when the exchange rate hits the boundary of the band, central banks that foresee speculative pressures, might, and do, intervene intramarginally.[4] Therefore, changes in the level of reserves might signal future speculative pressures. To capture the potential information effect of interventions, we employ the difference between the level of French reserves and a moving average of previous reserve levels.[5] Speculative attacks may also drive reserves to a critically low level beyond which the target zone becomes unsustainable and a realignment becomes inevitable.[6] We use this moving average specification for two reasons. First, the level of reserves is measured with error. By measuring reserves relative to a moving average, we capture the depletion of reserves that occurs during a speculative crisis without regard to the level of reserves. Second, in the lead-up to a realignment it is common for reserves to be depleted quite dramatically in the month before the realignment (see Collins (1992)). Therefore, examining reserves relative to a moving average is likely to provide a strong signal of impending realignments, which are manifest in our model as large jumps that take the exchange rate outside the target zone.

2. The position of the exchange rate within the band, $|PB_{t-1}|$. Larger jumps are expected near the edges of the band. At the lower boundary, a larger jump can be accommodated within the band, and at the upper boundary, the only kind of jump which is possible is a realignment jump, which tend to be relatively large.

3. The interest differential with German interest rates, ID_{t-1}. Speculative tensions and the ensuing actions of monetary authorities to defend the currency are reflected rapidly in interest rates. In particular, the yield curve will typically invert and the differential with the German interest rate will increase. Both the slope of the yield curve and short-term interest rate differentials can serve as jump predictors, and they are highly correlated. In this model, we try to disentangle the size and probability of jumps. When UIRP holds, the interest rate differential equals expected exchange rate changes reflecting both the size and probability of jumps. Empirically, however, the slope of the yield curve is a better jump predictor while the interest differential is a better jump size indicator (see below).

4. The cumulative inflation differential between Germany and France, CID_{t-1}. This is the cumulative difference in inflation between Germany and France, since the most

[4] Giavazzi and Giovannini (1989) discuss the evidence of intra-marginal interventions within the EMS.

[5] We need not concern ourselves with German reserve levels, since the Bundesbank has never intervened intra-marginally, see Giavazzi and Giovannini (1989)).

[6] Bertola and Caballero (1991) present a stylized Krugman type model in which the realignment probability depends on the level of reserves. The relationship between the large literature on speculative attacks on fixed rate systems and target zone models is explored in Flood and Garber (1991).

recent realignment. Larger jumps are expected when the CID is large. Since Germany has consistently achieved lower inflation than most other EMS countries, an unchanged EMS-band gradually erodes the competitiveness of these countries as their real exchange rates appreciate. In the early years of the EMS, the realignments typically restored competitiveness. From 1983 onwards, however, realignments, although still highly correlated with cumulative inflation differentials, no longer fully compensated for lost competitiveness so that inflationary policies were punished (see Giavazzi and Pagano (1988)). Our model allows us to assess whether the cumulative inflation differential has any ex-ante bearing on the size of jumps. We can also examine whether this predictive ability changed after 1983.

The conditional probability of Jumps

The only piece of the model left to be specified is the time-varying probability of a jump, $\lambda_{t-1} = \Pr(J_t = 1|I_{t-1})$. Since this is a true probability, we constrain $0 < \lambda_{t-1} < 1$ using the normal cumulative distribution function, as in a probit model. In this paper we model the jump probability as being a function of the slope of the yield curve, SYC_{t-1}: $\lambda_{t-1} = \Phi(\beta_1 + \beta_2 SYC_{t-1})$. It is likely that the jump probability will be influenced by a number of macro-economic variables. Within the band, monetary policy has some independence of pursuing other goals. When macro-economic developments, such as poor GNP-growth and high unemployment, create tensions between exchange rate and other macro-economic goals, the jump probability may rise. However, the relationship between macro-economic data and jump probabilities is likely to be noisy and it is difficult to construct weekly macro-economic data that were actually in the information sets of economic agents. The slope of the yield curve, through the forward looking nature of market determined interest rates, may better reflect such effects than poorly measured macro-economic data.

Of course, the variables that determine the mean and variance of the jump, described above, may also affect the jump probability. Hoewever, we found them to be statistically and economically insignificant jump predictors in the presence of the slope of the yield curve variable.[7] This model is an extension of the jump-diffusion models of Ball and Torous (1985) and Jorion (1988). In both of these models, which deal with stocks and floating exchange rates respectively, the jump probability is assumed to be constant. The endogeneity of the jump probability makes our model also more general than the target zone models of Ball and Roma (1993) and Bertola and Svensson (1993), who generate realignments through an exogenous jump process with constant intensity.

The Complete Model

[7] For example, when λ_{t-1} is allowed to depend on the level of reserves, its coefficient is insignificantly different from zero and of the wrong sign.

Combining the two components of the conditional density yields the following model:

$$f(\Delta S_t|I_{t-1}) = \begin{cases} TN(\mu_{t-1}, \sigma^2_{t-1}, \Delta_{L_{t-1}}, \Delta_{U_{t-1}}) & \text{w.p. } (1-\lambda_{t-1}) \\ N(\rho_{t-1}, \rho^2_{t-1}\delta^2) & \text{w.p. } \lambda_{t-1} \end{cases} \tag{3}$$

where

$$\begin{aligned} \lambda_{t-1} &= \Phi(\beta_1 + \beta_2 SYC_{t-1}) \\ \rho_{t-1} &= \beta_3 + \beta_4 LR_{t-1} + \beta_5|PB_{t-1}| + \beta_6 ID_{t-1} + \beta_7 CID_{t-1} \\ \mu_{t-1} &= \beta_8 + \beta_9 PB_{t-1} \\ \sigma^2_{t-1} &= \beta_{10} + \beta_{11}(1 - RD_{t-1})\epsilon^2_{t-1} + \beta_{12}\sigma^2_{t-1} + \beta_{13}|PB_{t-1}|, \end{aligned}$$

and the other terms are as defined in the text above. The precise definitions of the variables used in the model are summarized in Table 2.

3 Estimation

The model described above is written in terms of the conditional distribution of exchange rate changes and is a reduced-form model. Full information maximum likelihood requires that we model the joint density of exchange rate changes *and* the conditioning variables, which is beyond the scope of this paper. In empirical work in this area, it is customary to proceed by maximizing the *conditional* likelihood function $\sum_{t=2}^{T} \mathcal{L}(\Delta S_t|I_{t-1})$. While this approach produces consistent estimates of the parameters of our model, some degree of efficiency is sacrificed by parameterizing only part of the full likelihood function. To show this, we define Z_t to be a vector consisting of all of our conditioning variables, and let $\tilde{Z}_t = \{Z_t, Z_{t-1}, ..., Z_1\}$. Let $\Delta\tilde{S}_t$ be defined in similar fashion. The information set is made up of these two components so that $I_t = \{\Delta\tilde{S}_t, \tilde{Z}_t\}$. Finally, define θ to be the vector of parameters affecting the joint distribution $f(\Delta\tilde{S}_t, \tilde{Z}_t)$.

Full maximum likelihood estimation requires maximization of the likelihood function based on the joint density of the data, ΔS_t, and the conditioning variables, Z_t:

$$\mathcal{L}(\Delta\tilde{S}_T, \tilde{Z}_T; \theta) = \ln\left[f(\Delta\tilde{S}_T, \tilde{Z}_T; \theta)\right]. \tag{4}$$

A series of conditioning arguments can be used to establish that, up to an initial condition,

$$f(\Delta\tilde{S}_T, \tilde{Z}_T; \theta) = \Pi_{t=1}^{T} f(Z_t|\Delta S_t, I_{t-1}; \theta) f(\Delta S_t|I_{t-1}; \theta). \tag{5}$$

Conditioning also on our jump variable, J_t, yields

$$f(\Delta\tilde{S}_T, \tilde{Z}_T; \theta) = \Pi_{t=1}^{T} \sum_{i=0}^{1} f(Z_t|\Delta S_t, J_t = i, I_{t-1}; \theta) f(\Delta S_t|J_t = i, I_{t-1}; \theta) \Pr(J_t = i|I_{t-1}). \quad (6)$$

We then assume that once we condition on the exchange rate, the conditioning variables are independent of the jump variable. That is

$$f(Z_t|\Delta S_t, J_t = i, I_{t-1}; \theta) = f(Z_t|\Delta S_t, I_{t-1}; \theta). \quad (7)$$

Clearly, the conditioning variables are not independent of the contemporaneous exchange rate changes in our setting. For example, when ΔS_t is large as a result of a speculative attack, it is quite likely that LR_t and SYC_t will be low and ID_t will be high. The assumption which is made above merely posits that after conditioning on the change in exchange rates, the jump variable is not informative about the distribution of the conditioning variables. That is, knowledge of the actual change in exchange rates is at least as informative as knowing whether there was a jump in exchange rates. If a large change in the exchange rate is observed, it is not possible to determine (ex post) whether this was the result of a jump or a draw from the tail of the no-jump distribution. Therefore, the effect of this change in the exchange rate in the model is the same, regardless of the cause. Alternatively, a realignment is observable (ex post) since the change in the target zone boundaries will appear in the information set, and the dynamics of the variables change immediately after a realignment. Even in this case, however, conditioning on the jump variable (J_t) is uninformative when the change in exchange rate (ΔS_t) and target zone boundaries ($\Delta_{L_{t-1}}$) and ($\Delta_{U_{t-1}}$) are observable. This is because when ΔS_t moves the exchange rate outside the existing band, it can only be due to a realignment. This allows us to write the log-likelihood function as

$$\mathcal{L}(\Delta S_T, \tilde{Z}_T; \theta) = \sum_{t=2}^{T} \ln\left[f(Z_t|\Delta S_t, I_{t-1}; \theta_2)\right] + \sum_{t=2}^{T} \ln\left[\sum_{i=0}^{1} f(\Delta S_t|J_t = i, I_{t-1}; \theta_1) \Pr(J_t = i|I_{t-1}).\right] \quad (8)$$

where θ_1 is the vector of parameters affecting the conditional distribution of exchange rate changes and θ_2 is the vector of parameters affecting the conditional distribution of the instruments. We proceed by parameterizing only the second piece of this log-likelihood function. Since this second piece allows identification of θ_1, our maximum likelihood estimates will be consistent. While the first piece of the log-likelihood function may contain potentially relevant information, parameterization of this joint density is not feasible given the number of conditioning variables and the size of our data set. Since consistent estimates of all of our parameters can be obtained by focusing exclusively on the second piece, this is the procedure we employ. This amounts to using maximum likelihood to estimate the parameters of a reduced-form model, which has become a popular method of estimation in empirical work in this area.

4 Results

4.1 Data

Our data were obtained from Datastream, *The Financial Times* and the International Monetary Fund publications *Exchange Arrangements* and *International Financial Statistics*. The sample consists of weekly data from March 1973, with the implementation of the ERM within the EMS, through to July 1993, a total of 749 observations. We use Euro-currency interest rates in the empirical analysis, because they are true market-determined rates. The presence of capital controls in France, for most of the sample period, implies that there can be a significant wedge between domestic rates and true market rates.

Figure 1 plots the FF/DM exchange rate and EMS bounds over the sample period. Figure 2 contains time-series graphs of the key variables in the models – the position in the band, the relative level of reserves of the Banque de France, the slope of the yield curve, the interest differential, and the cumulative inflation differential.

4.2 Results

The econometric model in equation (3) was estimated by maximum likelihood using the GAUSS MAXLIK and CML modules. The parameter estimates reported have been verified by using two optimization algorithms, BHHH and BFGS, and several different sets of starting values. While the likelihood functions are highly non-linear and may admit several local optima, this procedure provides some degree of confidence that the parameter estimates reported below are at the global maximum. In all cases, asymptotic standard errors are based on heteroskedastic consistent standard errors. We also report results for a model in which we use normal distributions for both $J_t = 1$ (jumps) and $J_t = 0$ (no jumps) (Model 2). We only use this model to provide for a comparison with standard models, which ignore the possibility of jumps and are based on a single conditionally normal distribution.

The parameter estimates for the model in equation (3) are reported in table 3. The model confirms much of the intuition reviewed above, with most parameters taking the hypothesized sign, and many reaching statistical significance. We first examine whether our model replicates some of the basic intuition from the target zone literature for the behavior of exchange rates within the band.

Mean Reversion

In our truncated normal model, the mean-reversion parameter β_9 is negative, but not statistically significant. In the truncated normal distribution, however, $\mu_{t-1} = \beta_8 + \beta_9 PB_{t-1}$ represents the conditional mean of the underlying normal distribution which is truncated, and not the conditional mean of the resulting truncated distribution. When the exchange rate is near the top of the band, the right half of the distribution is truncated more severly than the left, leaving a negatively skewed distribution. Whereas μ_{t-1}, defined above, denotes the peak of this distribution, the mean of the distribution will be lower, further towards the center of the band. Symmetrically, when the exchange rate is near the lower boundary, the left half of the distribution will be more severly truncated, resulting in positive skewness.

More formally, the conditional mean of the truncated distribution is:

$$\mathrm{E}[\Delta S_t | I_{t-1}, J_t = 0] = \mu_{t-1} + \frac{\phi\left(\frac{\Delta_{L_{t-1}} - \mu_{t-1}}{\sigma_{t-1}}\right) - \phi\left(\frac{\Delta_{U_{t-1}} - \mu_{t-1}}{\sigma_{t-1}}\right)}{\Phi\left(\frac{\Delta_{U_{t-1}} - \mu_{t-1}}{\sigma_{t-1}}\right) - \Phi\left(\frac{\Delta_{L_{t-1}} - \mu_{t-1}}{\sigma_{t-1}}\right)} \sigma_{t-1}. \tag{9}$$

Figure 3 plots this conditional expectation for each observation in the sample, ordered by the position of the exchange rate within the target zone. The mean reversion is evident from the fact that when the exchange rate is close to the boundaries, movements of over 0.5% are expected. Since this mean reversion is computed as a non-linear function of the data and a number of parameters, it is difficult to construct confidence intervals. However, an expected one-week change in exchange rates of this magnitude is clearly of economic significance.

When the exchange rate is near the lower boundary, μ_{t-1} is closer to $\Delta_{L_{t-1}}$ than $\Delta_{U_{t-1}}$ and the numerator is positive, resulting in a positively skewed distribution, and conversely when the exchange rate is near the upper boundary. These results are consistent with intramarginal central bank intervention, and are inconsistent with the regulated Brownian motion assumption of the standard Krugman model where interventions only occur at the edges of the band. Nevertheless, the non-linear nature of the mean reversion is broadly consistent with the predictions of Krugman-type models. Svensson (1992b) reports evidence inconsistent with this prediction of many theoretical target zone models by examining the relationship between the interest differential and the position of the exchange rate within the band. This evidence, however, depends on two auxilliary assumptions not imposed on our model: uncovered interest rate parity and a fully credible target zone. Note also, that in Model 2 where within-the-band changes are modeled as being normally distributed, β_9 is significantly less than zero, indicating strong mean reversion.

Conditional Heteroscedasticity

In contrast to the predictions of Krugman-type models, we find that the conditional volatility of exchange rates does not decrease as the exchange rate approaches the boundaries of the target zone. Whereas a negative value of β_{13} would be consistent with volatility being lower near the boundary of the target zone, our maximum likelihood estimates of β_{13} are positive, although not significant. Moreover, there are also very significant GARCH effects (β_{11} and β_{12}) which is also inconsistent with the assumption of regulated Brownian motion in Krugman-type models. The existence of GARCH effects is consistent with Jorion's (1988) evidence relating to floating exchange rates. Furthermore, the persistence of conditional variance shocks has been reduced by the introduction of jumps and dependence on the position of the exchange rate in the band, and by modeling realignment shocks as being non-persistent. In our model, the effects of conditional variance shocks die out relatively quickly, with $\beta_{11} + \beta_{12} = 0.6471$. Contrast this with (1) a standard GARCH (1,1) model where $\sigma_t^2 = \beta_{10} + \beta_{11}\epsilon_{t-1}^2 + \beta_{12}\sigma_{t-1}^2$ and (2) an augmented GARCH model which is a no-jump version of Model 2 (i.e. $\lambda_t \equiv 0\ \forall t$) where $\sigma_t^2 = \beta_{10} + \beta_{11}(1 - RD_{t-1})\epsilon_{t-1}^2 + \beta_{12}\sigma_{t-1}^2 + \beta_{13}|PB_{t-1}|$. In the standard GARCH model $\beta_{11} + \beta_{12} = 0.9977$ and in the augmented GARCH model $\beta_{11} + \beta_{12} = 1.0244$, although the hypothesis that $\beta_{11} + \beta_{12} = 1$ cannot be rejected by a likelihood ratio test at the 5% level of significance. Consistent with Jorion (1988), allowing for jumps has dramatically decreased the persistence of shocks to exchange rates.[8]

Jumps

Next, we turn to the impact of jumps on the conditional distribution of exchange rates. Unfortunately, it is difficult to test for the absence of jumps, since under the null the parameters governing the jump are not identified. Hansen (1992) discusses this issue and proposes a computer-intensive simulation method that allows testing in this case. However, Hansen's method requires a series of optimizations over a grid of the nuisance parameters. Given the size of our paramater space, the series of optimizations that would be required is prohibitive. The issue of testing the statistical significance of jumps and regime switches remains an open question in the econometrics literature. The LRT statistic comparing our Model 2 with the nested no-jump model ($\lambda_t \equiv 0\ \forall t$), calculated in the standard manner, is 734.3436 which is exceptionally large by any benchmark. Despite the fact that we have not adjusted the χ^2 distribution of this LRT statistic to reflect the presence of parameters which are not identified under the null, we do gain some degree of confidence in the statistical significance of jumps from this exercise.

We can, however, formally test whether the jump probability is state-dependent or constant. The jump probability (λ_t) is negatively related to the slope of the yield curve in

[8]Bollerslev (1986) shows that a GARCH (1,1) process can be written as an ARMA(1,1) process in squared residuals, with autocorrelation parameter $\beta_{11} + \beta_{12}$. Whereas the half-life of a shock is over 5 years in a standard GARCH (1,1) model, in our model it is less than 2 weeks.

France ($\beta_2 < 0$) – when the yield curve inverts, the jump probability increases. Although the coefficient is not statistically significant, it is economically significant. What matters is the ability of the slope of the yield curve to predict large movements in exchange rates. For the majority of our sample, the jump probability does not show much variation, but spikes occur when speculative crises are expected. Hence, the identification of the coefficient comes primarily from those few observations where the yield curve experiences dramatic changes during speculative crises. Such a pattern can be fit in the current model because the derivative of the jump probability with respect to the slope of the yield curve is steeply decreasing in its magnitude. Figure 4 graphs this derivative as a function of the level of the slope of the yield curve. When the yield curve is upward sloping, a 10% drop in the slope raises the jump probability by less than 0.025, but when the yield curve inverts the sensitivity to slope changes rises dramatically. Figure 5 plots the jump probabilities which increase noticeably, prior to most realignments. The jump probability increases at other times to reflect the probability of non-realignment jumps.

The expected size of a jump, conditional on one occurring, (ρ_{t-1}) also varies substantially over time. A larger jump is expected when the level of reserves runs low ($\beta_4 < 0$), when the French interest rate differential with Germany increases ($\beta_6 > 0$) and the expected size of a jump is also higher when the cumulative inflation differential between the two countries is high ($\beta_7 > 0$). This indicates that weak-currency countries have their competitive position restored, at least partially, by realignments. Although the coefficient is not statistically significant, it is large in an economic sense. The effect of the position in the band on the expected jump size is not statistically significant. The time-variation in the expected jump size (ρ_t) is plotted in figure 6. Here the model indicates that the size of jumps is predictable. The expected mean jump size increases noticably before the three large realignment jumps in the early 1980's and non-realignment jumps are expected to be of relatively smaller magnitude, which is also consistent with the observed data.

Finally, we consider the impact of jumps on exchange rate volatility by introducing two measures of jump risk. First, note that the conditional variance of exchange rate changes can be written as:

$$h_{t-1} = \mathrm{VAR}[\Delta S_t | I_{t-1}] = [(1-\lambda_{t-1})\sigma_{t-1}^2 + \lambda_{t-1}\rho_{t-1}^2\delta_{t-1}^2] + (1-\lambda_{t-1})\lambda_{t-1}[\mu_{t-1} - \rho_{t-1}]^2.$$

That is, jump risk consists of a variance term, $\lambda_{t-1}\rho_{t-1}^2\delta_{t-1}^2$, which is directly increasing in λ_{t-1} and ρ_{t-1}, and a conditional mean term. Since ρ_{t-1} can be significantly greater than μ_{t-1}, the latter can be quite important. We compute two measures of the relative importance of jump risk:

$$VR_{1_{t-1}} = 1 - \frac{(1-\lambda_{t-1})\sigma_{t-1}^2}{h_{t-1}}$$

and

$$VR_{2_{t-1}} = \frac{(1-\lambda_{t-1})\lambda_{t-1}[\mu_{t-1} - \rho_{t-1}]^2}{h_{t-1}}.$$

From the results reported in Table 3, VR_2 is high when the mean jump size is higher than the expected exchange rate change within the band. Naturally, the ratio peaks before realignments but it never exceeds 25%. VR_1 adds a term that is increasing in the variance and probability of a jump. Interestingly, just before realignments virtually all of the exchange rate's conditional volatility is accounted for by jumps. Even in quiet periods, a significant portion of the total conditional volatility can be attributed to jump risk, in fact the sample mean of VR1 is 0.62. Note that jump risk was still substantial after 1987, a period often described as the most stable and credible period in EMS history. We discuss the credibility issue in more detail below.

5 The Credibility of Target Zones

5.1 Credibility and Realignment Probabilities

Several authors have studied the credibility of the European Monetary System. Rose and Svensson (1991, 1993), Frankel and Phillips (1992) and Chen and Giovannini (1992) rely on (1) uncovered interest rate parity and (2) an estimate of the expected exchange rate change within the band, to infer realignment expectations. The consensus result in the literature seems to be that the credibility of the EMS increased considerably after 1987, when no further realignments took place. Consequently, the crises in September 1992 following the signing of the Maastricht Treaty in December 1991, and the eventual break-down of the system came as a surprise. In this section, we examine whether our model implies a similar increase in credibility after 1987.

Recall that we define a target zone to be "perfectly credibile" if there is zero probability that it will be realigned or, equivalently, that there is zero probability that the exchange rate will move outside the target zone. Let p_{t-1} denote the realignment probability at time t-1 which is $\Pr[S_t > \ln(U_{t-1})|I_{t-1}]$. This is the probability, conditional on available information, that the exchange rate will move above the upper boundary of the target zone. A target zone is perfectly credible when p_{t-1} is zero. A necessary, but not sufficient, condition for the target zone to be non-credible, is that the jump probability (λ_{t-1}) is positive. Of course, our jump probabilities cannot be construed as true realignment probabilities because it is possible that there is a high probability of a very small jump within the target zone. However, since our model fully specifies the conditional distribution of the exchange rate, we can compute the conditional probability that the exchange rate moves outside the band, p_{t-1}. Interestingly, unlike the papers listed above, we can disentangle the magnitude and probability of a realignment. For example, we can compute the probability that next week's exchange rate will be 5% above the current upper band. Of course, the model only makes predictions about exchange rate movements, not the central parity rate per se.

The realignment probabilities are plotted in figure 7. The realignment probability spikes noticeably before all six realignments. Interestingly, the mean realignment probability appears to be higher in the period since 1988. We interpret this as evidence of the predictability of the eventual breakdown of the system. That is, in the post-1988 period, conditions which would previously have caused a realignment, caused no change to the system. This resulted in a sustained build up of realignment pressure. When no pressure-relieving realignments were forthcoming, the entire system eventually broke down.

The two potential criticisms of this argument, are addressed in turn below. First, our analysis is within-sample and the apparent realignment predictability is potentially spurious. In the next sub-section, we conduct a true out-of-sample analysis of the predictive power of the model. Second, structural changes may have occurred during our sample, including changes in capital controls and the signing of the Maastricht Treaty. These changes may have affected the structural parameters of the unspecified, underlying model and hence, our reduced form parameter estimates may be unstable. We deal with each of these issues below.

5.2 Predictability of Realignments

Although the variables that we use in predicting realignments have been used before, we argue that our analysis does not amount to data-snooping because most previous work has not found any evidence that these variables hold any predictive power. Moreover, we are also careful to allay concerns about some form of "model-snooping". That is, the model specified in equation (3) relies on a thorough analysis of how the EMS operated during the sample period. In 1979, it is unlikely that somebody could have formulated such a model. For example, the EMS had a number of mechanisms (such as the divergence indicator) that should have made it a symmetric system, rather than the DM-anchored system that it eventually became. Consequently, we attempt to construct a series of true ex-ante realignment probabilities, noting that our econometric model could only have been formulated after a number of realignments had occurred, clarifying the role of the DM, the effect of speculative crises on interest rates, and the importance of real exchange rate changes. Therefore, we use data from 1979 to 1983 and focus on the predictive power of the model for further realignments. To do so, we re-estimate the model every week adding new observations and use these parameters to compute the realignment probability one week ahead, conditional on observable information. These probabilities are plotted in Figure 8.

The root mean square error (RMSE) from using our model to predict the exchange rate one week ahead is 0.2976 compared to 0.3124 and 0.2977 for the RMSE of a simple random walk model $\mathrm{E}[S_{t+1}|I_t] = S_t$ and the unbiasedness model $\mathrm{E}[S_{t+1}|I_t] = S_t + i_t^{ff} - i_t^{ge}$, respectively. Although this improvement in out-of-sample fit seems small, Meese and Rogoff (1983) note that most empirical and structural exchange rate models fail to beat the random walk model. Moreover, we did not attempt to reduce the number of parameters in our model in order to maximize out-of-sample fit.

5.3 Credibility and Structural Changes

In this section, we examine whether changes in the policy and institutional environment had any effect on the realignment probabilities. The first issue here is the impact of capital controls. Controls on international capital flows can protect domestic interest rates from the large fluctuations associated with expectations of discrete exchange rate realignments. Moreover, a central bank may experience large changes in its reserves, when holders of domestic high-powered money try to avoid losses by selling the domestic currency to the central bank in exchange for foreign currency just before a devaluation is expected. To some, capital controls were an essential ingredient of the stability of the EMS (see, for example, the famous Padoa-Schioppa report of 1985), to others, capital controls prevented optimal allocation of resources and may have been largely circumvented anyway.

France has a long history of capital controls. From 1971 to 1981, the purchase of foreign financial assets was unrestricted but French residents were forbidden to lend French francs to non-residents. In 1981, foreign exchange controls were tightened both through additional limits on foreign exchange transactions for banks and French residents and through strict regulations on trade credits to prevent importers and exporters from exerting pressure on reserves through "leads and lags".[9] After 1984, but especially in 1986, foreign exchange regulations were gradually eased whereas at the same time the monetary policy operating procedures were changed and financial markets were reorganized and deregulated (see Melitz (1990) and Icard (1994)). In the context of the move towards a Single Market by the end of 1992, a June, 1988 EC decision called for the complete elimination of the remaining capital controls within Europe. France was given a deadline of July 1, 1990. Moreover, the French central bank, following the Netherlands and Belgium, had recently introduced a "franc fort" policy, thereby giving up the limited amount of monetary independence that a target zone allows.

Hence, during our sample period, various changes in controls on portfolio investment and trade financing and other policy changes occurred that could have had an effect on the credibility of the target zone. Examining how these policy changes may have affected the credibility of the system may hold important lessons for future attempts at managing floating currencies. As mentioned above, Padoa-Schioppa (1985) predicted that the EMS would not be sustainable when capital controls were abolished. Our empirical framework can be used to examine whether these structural changes indeed led to a decrease of the credibility of the system.

Second, we examine more closely the behavior of the realignment probabilities after the signing of the Maastricht Treaty and during the turbulent period afterwards, with the rejection of the Treaty in the Danish referendum, which eventually led to the Currency Crises of September 1992 and August 1993.

A lot has been said, both in the academic world and in the financial press, about whether the Maastricht Treaty was credible or not. Some have argued that creating a Monetary Union in Europe makes little economic sense (Feldstein (1993), Krugman (1994)), whereas others have argued that the Treaty's time table and practical implementation of the movement towards monetary union were not fully credible (Fratianni and von Hagen (1993)). Ultimately, this question is an empirical one. In the context of our model, if the Maastricht Treaty was fully credible, the realignment probability should have decreased after (or even before) the Treaty was signed.

The currency crises have been the subject of even more debate, particularly the September 1992 crisis which led to both the British pound and Italian lira exiting the system. Was the crisis anticipated by the markets? It is interesting to re-examine this question in the context of our model, since Rose and Svensson (1993) have concluded from a quite different framework that "both private-sector agents as well as policy makers appear to have been taken by surprise by the events and the aftermath of mid-September."[10]

[9] See, for example, Claassen and Wyplosz (1983), Giavazzi and Giovannini (1988).

[10] One disadvantage of our framework is that our model does not specify the full dynamics of all variables used to predict exchange rates. Hence, we can only look one week ahead and cannot sketch the evolution of

We summarize the policy changes in France and the events described above in Table 4. Since the majority of these events are most likely to have affected the credibility of the system, their effects would be most visible in the parameters governing the size and probability of a jump. Unfortunately, this makes it virtually impossible to construct meaningful tests for structural change. Note that the important dates are typically after 1985. Unfortunately, no major realignments occurred after 1985, making it impossible to identify the jump probabilities and size with post-1985 data. When estimating realignment probabilities from post-1985 data only, one is bound to find low realignment probabilities. However, although no major realignments occurred, this need not mean agents did not expect them, that is, the post-1985 data suffer from a classic peso problem. Consequently, it is critical to use the early, more turbulent, period to estimate the jump parameters.

Although this prevents us from conducting formal econometric tests, in figure 8 we study the behavior of the out-of-sample realignment probabilities around the dates of potential structural changes. The first issue is whether the relaxation of capital controls after 1987 affected the credibility of the system. Many doubted the sustainability of the EMS in light of the classic argument of the impossibility of pursuing independent monetary policy in a system of fixed exchange rates and perfect capital mobility. However, most empirical studies find that the credibility of the EMS increased considerably after 1987. Frankel and Phillips (1992) suggest that the EMS may be "Credible at Last" and their results have been supported by Chen and Giovannini (1992), Rose and Svensson (1993), and others. Hence, these studies seem to indicate that capital controls are not a necessary condition for a credible EMS. The currency crises in 1992, however, and the ensuing reimposition of capital controls by Spain, casts doubt on this conclusion.[11] Our results have somewhat different implications. As Figure 8 shows, realignment probabilities remain high after 1987 and there is no downward trend. This is all the more surprising, since inflation differentials, one of the underlying macro-economic causes of tensions, had substantially narrowed over time. Interestingly, one period of relative turbulence occurs shortly after the June 1988 decision to remove all capital controls. This indicates that the post 1987 period may have been less stable than previously thought.

The second issue is the impact of the Maastricht Treaty on credibility. There is a clear increase in realignment probabilities in November 1991, which is reversed by January 1992. This may reflect the speculation of market participants about the possibility of one last realignment before the process towards Economic and Monetary Union (EMU) was started, or general uncertainty about the feasibility of the Treaty. In fact, since German reunification in 1990 many economists felt that a revaluation of the DM was warranted and that a failure

longer-term expectations.

[11] Interestingly, Ireland endured a 10% devaluation in January 1993, one month after its capital controls were lifted, despite having strong fundamentals. The exit of the British pound was a major factor in the pressure on the Irish punt, but it is striking that the devaluation could no longer be averted once capital controls were lifted.

to do so may put strains on the movement towards EMU. In contrast to previous studies (see especially Rose and Svensson (1993)), we find evidence of such strains. For example, after the fall of the Berlin Wall in November 1989 and the December 1989 Strasbourg Summit, in which a date for the Maastricht Conference was agreed upon, realignment probabilities increased significantly reaching 5.5% at year-end.

Surprisingly, there is no increase in realignment probabilities during 1992 and our model does not show any effect of the rejection of the Maastricht Treaty by the Danes on the credibility of the FF/DM band. One week before the French referendum on September 20, there was an increase in the realignment probability. The turbulent period afterwards with devaluations of the peseta and the escudo, and the suspensions of the ECU links by Sweden and Norway, generated little loss of credibility for the French Franc, except in December 1992. In 1993, realignment probabilities are close to zero, consistent with the credibility of the FF/DM target zone. This coincides with a period in which French short and long-term interest differentials virtually converged to German levels, and some market observers talked about the "franchor", the French Franc replacing the DM in the anchor role of the EMS. There is a marked increase in the realignment probability in the week of July 23, 1993, which is large by historical standards. This is the week prior to the August 2, crisis when the parity band were widened to 15% on either side of the central rate. Hence, our model would have produced a useful warning signal of the trouble ahead.

In conclusion, our results partially confirm the findings of Rose and Svensson (1993) who conclude that the currency crisis in September 1992 came as a surprise to market participants and governments alike. They also find that macro-economic variables do not have any impact on realignment probabilities. Whereas our empirical results demonstrate that macroeconomic variables can be used to forecast realignments, we do not conclude that 1992 was a "turbulent" year, relative to historical averages. This may indeed mean, as Rose and Svensson (1993) argue, that "the currency crisis may have been caused by phenomena without long gestation lags of the sort that characterize most macroeconomic and political events."

One structural change, however, does not suffer from a peso problem and can be formally tested. The Basle-Nyborg Agreement may affect the way intra-marginal intervention is conducted, potentially affecting the reversion of exchange rates towards the center of the band. We formally test this by allowing the conditional mean parameters, β_8 and β_9, to take different values before and after the agreement. Neither of these extra parameters is individually significant and the LRT of their joint significance, which is χ^2_2 under the null, is 0.5986 which is not significant at any usual level. We conclude from this that the Basle-Nyborg Agreement merely formalized the practice of intramarginal intervention which was already common in the EMS.

6 Implied Foreign Exchange Risk Premia

Svensson (1990) argues that the foreign exchange risk premium in a target zone is small. His analysis is based on a simple optimizing model with exchange rate uncertainty arising from exchange rate movements inside the band and occasional realignments which are assumed to follow a Poisson process. He concludes that risk premia arising from exchange rate movements within narrow band, as are in place in the ERM, are insignificant whereas risk premia arising from devaluation risks may be considerably larger but are still relatively small in comparison with the expected rate of devaluation. His results are important because they have motivated a large literature on the computation of realignment probabilities (see above), which imposes Uncovered Interest Rate Parity and ignores risk premia.

The model developed in this paper provides a challenge for these results and the methodologies on which they are based. Since we model the complete conditional distribution of exchange rate changes, we can compute the implied risk premium on FF investments for German investors as $i_t^{ff} - i_t^{gg} - 52\mathrm{E}[\Delta S_{t+1}|I_t]$. In annualized percentage terms, the risk premium has a mean of 3.02% with a standard deviation of 3.28% and a first order autocorrelation coefficient of 0.867. The risk premium, graphed in Figure 9, varies between -3.30% and 31.45%. Svensson claims that the risk premium can never exceed 4.5%. What the graph shows is that the risk premium seems to satisfy these band most of the time, but increases substantially in times of speculative crises before realignments. This suggests that most of the jump risk we discussed earlier may be priced. In fact, when we regress the risk premium on the variance ratios VR_{1_t} and VR_{2_t}, which measure the importance of jump risk, we find highly significant positive slope coefficients.[12] When speculative crises hit, both the expected rate of devaluation and the uncertainty about future exchange rate movements increase dramatically. However, whereas Svensson (1990) claims that the resulting increase in the interest differential between French and German deposits is primarily due to the increase in the expected rate of devaluation, we find that a substantial part of the increase in the interest differential reflects currency risk.

This debate parallels the debate on the size of the foreign exchange risk premium for floating currencies. One interpretation of the empirical evidence on UIRP, implies the existence of highly variable risk premia. For example, Bekaert (1995) uses a vector autoregressive framework to empirically derive lower bounds on the variability of risk premia on yen, pound and mark investments for U.S. investors (and all cross-rate investments). He finds the variability of these premia to be of the order of 10%, three times as large as our estimate for

[12]Because both the risk premium and the variance ratios contain measurement errors that may be correlated, this analysis is only suggestive.

the FF/DM risk premium. Moreover, the risk premium changes sign and is often quite large. Although here too it is often claimed that the risk premium is small (see Frankel (1988)), these claims are always model based. Many fundamentals simply do not show the required variability to explain the empirical evidence on UIRP deviations.[13] Similarly, it is not surprising that Svensson's theoretical model fails to generate the required variability. For example, he assumes that the exchange rate volatility within the band only depends on the position in the band as in the Krugman (1991) model. We have shown above that volatility within the band exhibits marked GARCH effects and that the dependence on the band is contrary to what is predicted by the Krugman model.

While in the presence of unsatisfactory theoretical models, one may be tempted to rely on empirical estimates of the risk premium, there are dangers in this approach as well. The reduced-from estimation of the conditional distribution of the exchange rate is subject to small sample problems and the existence of peso problems may generally make it difficult to infer the correct probability distribution actually used by agents from a finite data set. Nevertheless, our empirical results and the out-of-sample analysis discussed above instill some degree of confidence in our risk premium estimates. Moreover, there are few alternative empirical approaches. The regressions of exchange rate changes onto forward premia and other information variables so often conducted in the floating exchange rate literature do not easily extend to (partially) credible target zones. In fact, although prevalent in the empirical literature (see e.g. Bossaerts and Hillion (1991)), they are likely to yield biased and inconsistent estimates. A more promising alternative approach is to use options data to infer the exchange rate's conditional distribution as in Campa and Chang (1995).

Our findings have a number of implications. First, the variability of risk premia within a target zone is considerably smaller than empirical estimates of the variability of risk premia for floating exchange rates. Second, the risk premia are sizable and should not be ignored. Hence, the practice in the new literature on target zones (e.g. Rose and Svensson (1993), Chen and Giovannini (1992)) of relying on UIRP and disregarding the risk premium may yield unreliable empirical estimates of realignment probabilities.

7 Application to the Deutschemark/Dollar Rate

7.1 Motivation and Model

This section discusses the application of our target zone model to the Deutschemark/Dollar (DM/$) rate. Although this bilateral rate is, in principle, freely floating, central banks

[13]See Bekaert (1994) for the analysis of the foreign exchange risk premium in a monetary general equilibrium model.

occasionally intervene in the foreign exchange markets and both the Federal Reserve and the Bundesbank have done so extensively in the past. Whereas the Federal Reserve has no formal exchange rate policy, the Bundesbank is known to have implicit external targets. Dudler (1983) shows that although the primary goal of the Bundesbank is to maintain price stability through monetary targeting, the Bundesbank has always taken exchange rate considerations into account and has on occasion not met its target growth path for money because of these external constraints. Moreover, since the Plaza and Louvre Accords, international policy coordination aimed at controlling exchange rate movements among the major currencies, has gained visibility. More recently, the continued appreciation of the yen relative to the dollar in 1994 and early 1995 led to a number of coordinated intervention efforts. Hence, there may exist an implicit target zone for the DM/$ rate, maintained by the Bundesbank and/or internationally coordinated interventions from several central banks.

Further, even if such an implicit target zone does not exist, an issue that deserves investigation is whether the properties of the conditional exchange rate distribution documented above are specific to an explicit target zone such as the EMS. Jorion (1988) found evidence of jumps in floating currencies, and Flood, Rose and Mathieson (1990) have difficulty clearly distinguishing between the properties of floating and target zone exchange rates.

To estimate the model in equation (3) for the DM/$ rate, a number of changes are required. First, we drop the level of reserves variable from the specification - that is, we set $\beta_4 = 0$. Since no interventions are formally required or enforced, it is unlikely that this variable will be a useful jump indicator. Second, we now include the slope of the yield curve in both the U.S. and Germany in the expression for the probability of a jump. Third, the band L_t and U_t are now not given by a formal arrangement and the Bundesbank releases no official information on its implicit exchange rate target. However, there is a consensus that the Bundesbank cares both about erratic short-run exchange rate movements and about excessive variability of the real Deutsche mark exchange rate.[14] Given the large and prolonged deviations from Purchasing Power Parity (PPP), we do not pursue a target zone model based on the PPP value of the exchange rate. Instead, we focus on the "smoothing" operations of the Bundesbank and define a exchange rate target in terms of moving averages of past exchange rates. In particular, where X_t is a 20 week moving average of past exchange rates, we set $L_t = 0.9X_t$ and $U_t = 1.1X_t$.[15]

[14]See, for example, Dudler (1983) and Neumann (1984).

[15]We are unable to estimate this bandwidth due to problems in simultaneously identifying the bandwidths and other model parameters. Experimentation with other values led to poorly behaved estimation for narrower bandwidths and lower log-likelihood values for wider bandwidths.

7.2 Empirical Results

This section briefly summarizes the empirical results for the DM/$ model.[16]. First, there is no significant time-variation in the jump probability and mean. A likelihood ratio test for constancy of both the probability and mean of the jump yields a value of 3.178 with a p-value of 0.5284. The remaining results are based on the model with a constant jump probability and jump mean. Second, the LRT comparing the likelihood values for the model without jumps to the model with jumps has a quasi-p-value of 0.1003. As noted above, while this test makes no adjustment for the presence of nuisance parameters under the null, it is clear that in the case of the FF/DM, the relative difference in likelihood values was much more dramatic. That is, the DM/$ rate exhibits less jumps than the FF/DM rate. Although Jorion (1988) finds evidence of jumps in the DM/$ rate, his model does not feature mean reversion, and uses an ARCH(1) process to describe the conditional variance in the no jump case, whereas we specify a full GARCH model with dependence on the position in the band. Further, Jorion models jumps as a Poisson process, whereas our jump model allows for a single jump per period. Third, we find no evidence of mean reversion within the band. In fact, the mean-reversion parameter is significantly positive indicating that the DM/$ rate exhibits a tendency to move towards the edges of the band. There is no evidence of any smoothing efforts of central banks. When conducting an out-of-sample forecasting experiment analogous to that described in Section 5.2, we find that both the random walk and unbiasedness model outperform the jump-model. We conclude that many of the features we documented for the FF/DM rate cannot be detected in the DM/$rate, for which the target zone model provides a poor description of the data. This suggests that the EMS has had a real effect on exchange rate behavior relative to a system of quasi-floating exchange rates. Using a differnet methodology, Lewis (1995) also finds little support for target zone behavior in the DM/$ rate in the late 1980's.

8 Conclusions and Future Work

This paper developed an empirical model of exchange rates in a target zone which nests most theoretical and empirical models in the existing literature. A series of econometric tests on the FF/DM rate highlight the strengths and weaknesses of the various models. In contrast to some recent empirical analyses, we detect substantial non-linearities in the behavior of the FF/DM rate. We also find that, in addition to realignments of the target zone itself, exchange rates exhibit a tendency to jump within the target zone. Our model is able to predict the likelihood and size of jumps in the exchange rate. Furthermore, by modeling the entire conditional distribution of exchange rates, we are able to isolate the probability of target zone realignments. In contrast to previous work, we show that realignments and the

[16]More detailed results are available upon request

eventual breakdown of the system are predictable and that the credibility of the EMS did not increase after 1987. Moreover, the popular practice of computing realignment probabilities imposing UIRP is shown to be unreliable because foreign exchange risk premia are likely to be large before realignments.

Our work has implications that extend beyond the realm of the European Monetary System. The recent proposals to limit the variability of floating exchange rates by means of target zones implicitly assume that target zones effectively reduce the variability of exchange rates, and hence limit the costs of exchange rate uncertainty. Our findings indicate that when a target zone is imperfectly credible, exchange rate variability can remain substantial because of the presence of jump risk. Moreover, this risk seems to be priced leading to enormous yield differentials between currencies before a realignment is expected. Even barring arguments about the true costs of exchange rate uncertainty, it is not clear to us that replacing a system of floating exchange rates, exhibiting high variability, with a target zone system, with lower variability on average, but occasional extreme volatility, is welfare improving.

There exist a number of avenues for future research which could be undertaken to further flesh out the behavior of exchange rates within a target zone. First, we have only considered a bilateral exchange rate in isolation. In a system such as the ERM, movements in third currencies can put pressure on the FF/DM rate, that is, there are effective bilateral band which are narrower than the actual band (see Pill (1994)). Unfortunately, it is likely to prove numerically infeasible to extend our techniques to an entire system of exchange rates. In this sense, the realignment probabilities we compute may under-estimate the true realignment probabilities. Second, a bivariate model of exchange rates and interest rates could be developed in order to examine UIRP in the context of our dynamic setting. Such an analysis is fruitful for several reasons. In a credible target zone, unbiasedness cannot be tested by a linear regression since the interest differential is likely to be correlated with the error term. Moreover, the possibility of infrequent but large realignments makes the EMS an ideal laboratory for the analysis of peso problems.

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Table 1A
The ten largest one-week decreases in the French Franc/Deutschemark (FF/DM) exchange rate (i.e. appreciation of the Franc) over the period 23 March 1979 to 23 July 1993, a total of 749 observations.

Rank	Date	Percentage Change	Weeks Since Last Realignment[a]	Weeks Until Next Realignment[b]	Position in Band[c]
1	790615	-1.30	13	14	0.73
2	820205	-1.26	17	18	-0.36
3	920918	-1.22	296	--	0.86
4	800321	-1.17	25	80	-0.48
5	800516	-1.10	33	72	-0.05
6	810522	-1.08	86	19	0.89
7	861205	-0.91	34	5	0.72
8	810710	-0.80	93	12	0.71
9	831007	-0.57	28	130	0.04
10	810626	-0.56	91	14	0.62

[a] The number of weeks since the last realignment of the FF/DM target zone in the European Monetary System (EMS).
[b] The number of weeks between the current change and the next realignment of the FF/DM target zone in the EMS.
[c] The position of the FF/DM exchange rate within the EMS target zone before the current change. The difference between the current exchange rate and the center of the band as a proportion of half the width of the band. Values of -1, 0, and 1 correspond to exchange rates at the bottom edge, center, and top edge of the band, respectively.

Table 1B
The ten largest one-week increases in the French Franc/Deutschemark (FF/DM) exchange rate (i.e. depreciation of the Franc) over the period 23 March 1979 to 23 July 1993, a total of 749 observations.

Rank	Date	Percentage Change	Weeks Since Last Realignment[a]	Weeks Until Next Realignment[b]	Position in Band[c]	
1	820611	5.61	35	0	0.97	[d]
2	811002	4.32	105	0	0.85	[d]
3	830318	3.52	39	0	0.91	[d]
4	860328	2.60	157	1	0.18	[e]
5	830304	2.05	37	2	0.05	[f]
6	820312	1.70	22	13	0.02	
7	871023	1.68	40	--	-0.18	
8	790608	1.45	12	15	0.09	
9	810508	1.40	84	21	0.36	
10	820212	1.29	18	17	0.91	

[a] The number of weeks since the last realignment of the FF/DM target zone in the European Monetary System (EMS).
[b] The number of weeks between the current change and the next realignment of the FF/DM target zone in the EMS.
[c] The position of the FF/DM exchange rate within the EMS target zone before the current change. The difference between the current exchange rate and the center of the band as a proportion of half the width of the band. Values of -1, 0, and 1 correspond to exchange rates at the bottom edge, center, and top edge of the band, respectively.
[d] Realignment.
[e] One week before realignment.
[f] Two weeks before realignment.

Table 2
Definitions of the Variables Used in the Model.

Exchange Rate Changes: ΔS_t
Continuously compounded exchange rate change: $\ln\left(\frac{S_t}{S_{t-1}}\right)$ where S_t represents the French Franc/Deutschemark exchange rate at time t.

Position In Band: PB_t
The relative position of the French Franc/Deutschemark (FF/DM) exchange rate within the European Monetary System (EMS) target zone band: $\frac{S_t - C_t}{\frac{1}{2}(U_t - L_t)}$. S_t is the FF/DM exchange rate, C_t is the center of the EMS target zone, U_t is the upper boundary of the target zone, and L_t is the lower boundary of the target zone. $-1 < PB_t < 1$, with $PB_t > 0$ if the franc is in the weak half of the band.

Level of Reserves: LR_t
The level of foreign currency reserves of the Banque de France, relative to a four-week moving average: $\frac{Reserves_t}{\frac{1}{4}\sum_{i=1}^{4} Reserves_{t-i}}$. When $LR_t < 1$, foreign currency reserves have been depleted relative to their recent average level.

Slope of Yield Curve: SYC_t
The slope of the yield curve for French franc-denominated instruments: $i_t^{F12} - i_t^{F1}$, where i_t^{F12} is the one-year rate and i_t^{F1} is the one-month rate and both rates are nominal eurocurrency yields.

Cumulative Inflation Differential: CID_t
The cumulative inflation differential between France and Germany: $\frac{CPI_t^F}{CPI_{0t}^F} - \frac{CPI_t^G}{CPI_{0t}^G}$. CPI_{0t}^F represents the CPI level in France at the time of the last realignment of the French Franc/Deutschemark target zone and CPI_t^F represents the CPI level in France at time t. The corresponding terms relate to CPI level in Germany. This variable measures the difference between inflation in France and inflation in Germany since the most recent realignment.

Interest Differential: ID_t
The interest differential between France and Germany: $i_t^{FW} - i_t^{GW}$. This is the difference between one-week Eurocurrency rates in France and Germany.

Table 3
Maximum Likelihood Parameter Estimates

Parameter	Model 1		Model 2	
β_1	-1.2891	*	-1.2046	*
	(0.1607)		(0.1666)	
β_2	-0.0129		-0.0150	
	(0.0120)		(0.0133)	
β_3	0.8111	*	0.7414	*
	(0.3204)		(0.2974)	
β_4	-0.6264	*	-0.5719	*
	(0.2772)		(0.2584)	
β_5	-0.0896		-0.0740	
	(0.0868)		(0.0800)	
β_6	0.0371	*	0.0329	*
	(0.0126)		(0.0117)	
β_7	0.8924		0.8665	
	(0.7830)		(0.7440)	
β_8	-0.0099		-0.0049	
	(0.0095)		(0.0100)	
β_9	-0.0157		-0.0476	*
	(0.0195)		(0.0169)	
β_{10}	0.0031		0.0040	
	(0.0022)		(0.0030)	
β_{11}	0.2957	*	0.2523	*
	(0.1060)		(0.0936)	
β_{12}	0.3514	*	0.3904	*
	(0.1639)		(0.1723)	
β_{13}	0.0190		0.0121	
	(0.0102)		(0.0081)	
δ^2	2.8104		3.2715	
	(1.5836)		(1.7731)	

The sample contains weekly data from 23 March 1979 to 23 July 1993, a total of 749 observations. **Model 1** denotes the model in which exchange rate changes are assumed to be conditionally distributed as a truncated normal, with conditionally normal jumps. **Model 2** denotes the model in which exchange rate changes are assumed to be conditionally normal, with conditionally normal jumps. * = significant at the 5% level. Model 1 is described in equation (3).

Table 4
Structural Changes in the EMS and France

May-June, 1981
Tightening of foreign exchange controls in France.

1984-1986
Easing of French foreign exchange controls, reorganization and deregulation of bond and money markets in France, and movement of French monetary policy towards interest rate targeting.

December, 1985
Establishment of MATIF futures market in France.

February, 1986
Single Europen Act sets December 31, 1992 as the date for the completion of the single market.

September, 1987
Basle-Nyborg Agreement intended to strengthen the ERM by providing for intra-marginal intervention and more liberal short-term financing of interventions.

June 13, 1988
Agreement to free capital movements in the EC.

March, 1990
Start of French "franc fort" policy.

July 1, 1990
Removal of capital controls in all EMS countries except Ireland, Spain, Greece, and Portugal.
Complete removal of capital controls in France.

December 11, 1991
Maastricht Treaty signed.

June 2, 1992
Denmark rejects Maastricht Treaty.

September 16-17, 1992
Pound and Lira exit the EMS.

August 2, 1993
Parity band are widened to 15%.

This table outlines the critical events in France and the EMS which may have had an impact on the structural relationship of the variables in a target zone model. The events which relate primarily to the French franc appear in bold font.

Titles/Legends for Figures

Fig 1: French Franc/Deutschemark (FF/DM) spot rates and European Monetary System target zone boundaries: March 1973 to July 1993. The dashed lines indicate realignments of the FF/DM target zone.[a]

[a] The data set consists of weekly observations from 23 March 1973 to 23 July 1993, a total of 749 observations.

Fig 2: This figure contains a time-series plot of weekly observations of the variables used in the econometric target zone model. The **Log Exchange Rate Change** is the one-week log difference in the French Franc/Deutschemark (FF/DM) exchange rate. The **Slope of the Yield Curve** is the difference between the Eurocurrency rate on one-year and one-month Franc denominated bonds. The **Position in the Band** indicates the position of the bilateral rate relative to the target zone. A positive value indicates that the bilateral rate is in the top half of the band where the Franc has depreciated against the Mark. The **Cumulative Inflation Differential** measures the cumulative difference between inflation in France and inflation in Germany between target zone realignments. The **Foreign Currency Reserves** measures French foreign currency reserves against a four-week moving average. The **Interest Differential** is the difference between the one-month Eurocurrency interest rates for Franc and Mark denominated bonds. The precise definitions of these variables are contained in table 2. The dashed lines indicate realignments of the FF/DM target zone.[a]

[a] The data set consists of weekly observations from 23 March 1973 to 23 July 1993, a total of 749 observations.

Fig 3: This figure shows the expected change in the French Franc/Deutschemark exchange rate over the following week - conditional on available information and on no jump occurring - as a function of the position of the exchange rate within the European Monetary System target zone. This is a measure of reversion towards the center of the band.[a]

[a] The data set consists of weekly observations from 23 March 1973 to 23 July 1993, a total of 749 observations.

Fig 4: This figure shows the absolute increase in the jump probability as a result of a 10% drop in the slope of the yield curve as a function of the initial slope of the yield curve. The parameters of the jump probability are estimated using the entire data set.[a]

[a] The data set consists of weekly observations from 23 March 1973 to 23 July 1993, a total of 749 observations.

Fig 5: This figure shows the probabilitity, conditional on available information, of a jump in the French Franc/Deutschemark (FF/DM) exchange rate in the following week (λ_{t-1}). The parameters of the model of the conditional distribution and the jump probabilities are estimated using the entire data set. The dashed lines indicate realignments of the FF/DM target zone.[a]

[a] The data set consists of weekly observations from 23 March 1973 to 23 July 1993, a total of 749 observations.

Fig 6: This figure shows the expected size of a jump in the French Franc/Deutschemark (FF/DM) exchange rate in the following week, conditional on available information and on a jump occurring, (ρ_{t-1}). The parameters of the model of the conditional distribution and the jump means are estimated using the entire data set. The dashed lines indicate realignments of the FF/DM target zone.[a]

[a] The data set consists of weekly observations from 23 March 1973 to 23 July 1993, a total of 749 observations.

Fig 7: This figure shows the probabilitity, conditional on available information, that the French Franc/Deutschemark (FF/DM) exchange rate will move outside the European Monetary System target zone during the following week. This conditional probability is computed by integrating the area of the conditional distribution which is outside the target zone, and is interpreted as the realignment probability. The parameters of the model of the conditional distribution and the realignment probabilities are estimated using the entire data set. The dashed lines indicate realignments of the FF/DM target zone.[a]

[a] The data set consists of weekly observations from 23 March 1973 to 23 July 1993, a total of 749 observations.

Fig 8: This figure shows the probabilitity, conditional on available information, that the French Franc/Deutschemark (FF/DM) exchange rate will move outside the European Monetary System target zone during the following week. This conditional probability is computed by integrating the area of the conditional distribution which is outside the target zone, and is interpreted as the realignment probability. In computing the realignment probability at time t, the parameters of the model of the conditional distribution are estimated using data up to time $t-1$ only. The dashed lines indicate realignments of the FF/DM target zone.[a]

[a] The data set consists of weekly observations from 23 March 1973 to 23 July 1993, a total of 749 observations.

Fig 9: This figure shows the implied risk premium for the French Franc/Deutschemark (FF/DM) exchange rate. This is computed as the difference between the interest differential and the expected exchange rate change, and is reported in annualized percentage terms. The parameters of the model of the conditional distribution and the jump means are estimated using the entire data set. The dashed lines indicate realignments of the FF/DM target zone.[a]

[a] The data set consists of weekly observations from 23 March 1973 to 23 July 1993, a total of 749 observations.

FIGURE 1

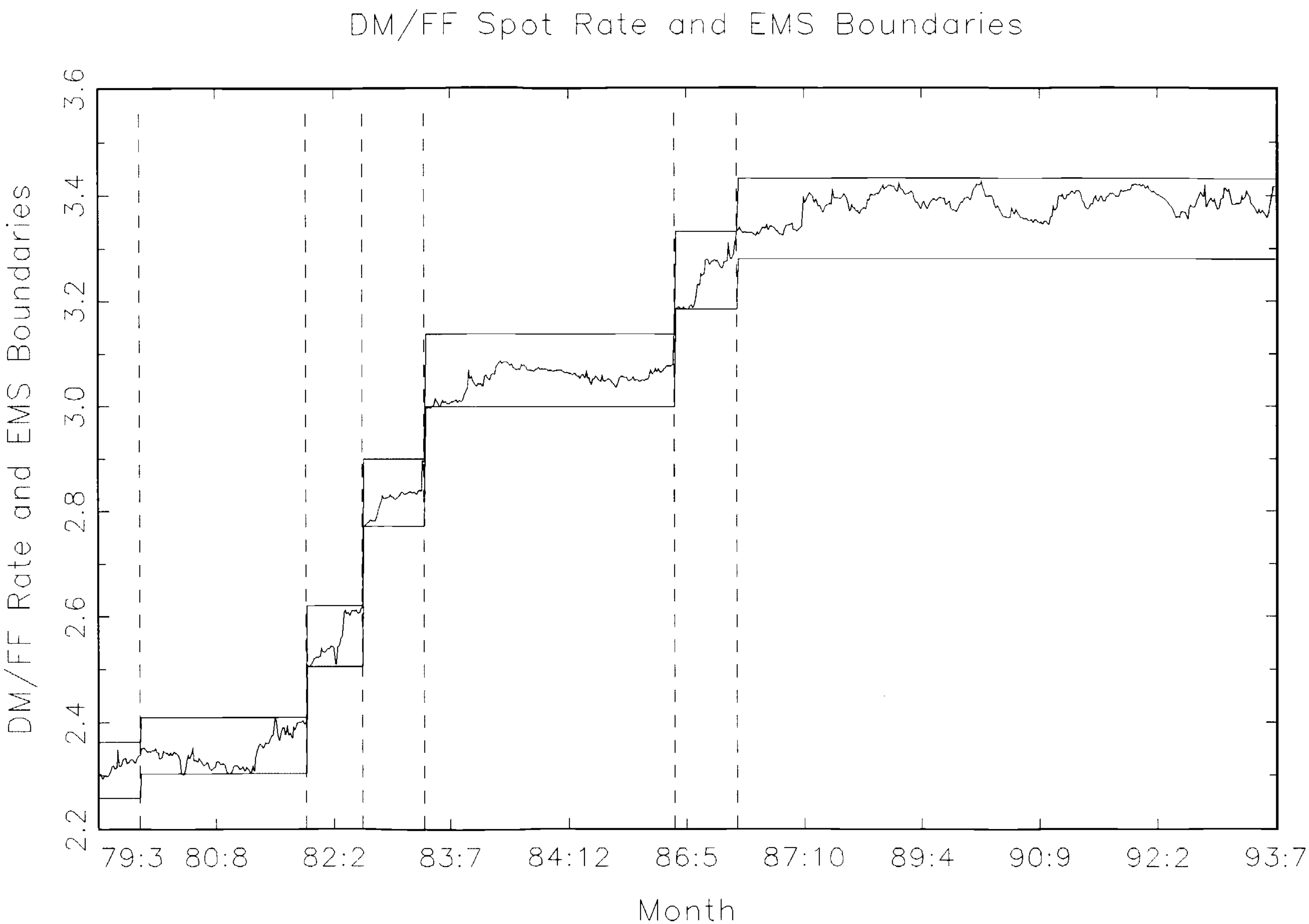

DM/FF Spot Rate and EMS Boundaries
DM/FF Rate and EMS Boundaries
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
79:3
80:8
82:2
83:7
84:12
86:5
87:10
89:4
90:9
92:2
93:7
Month

FIGURE 2

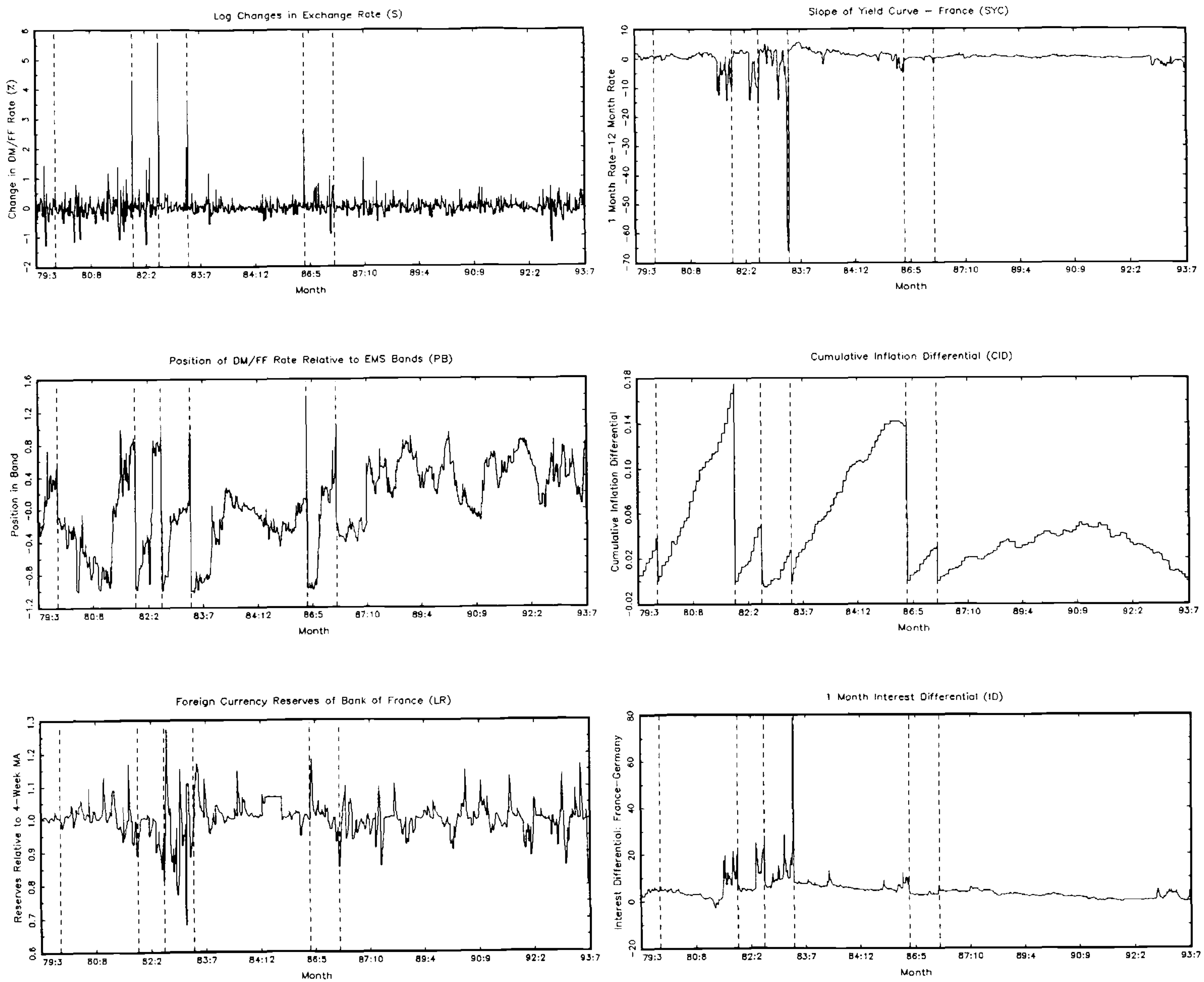
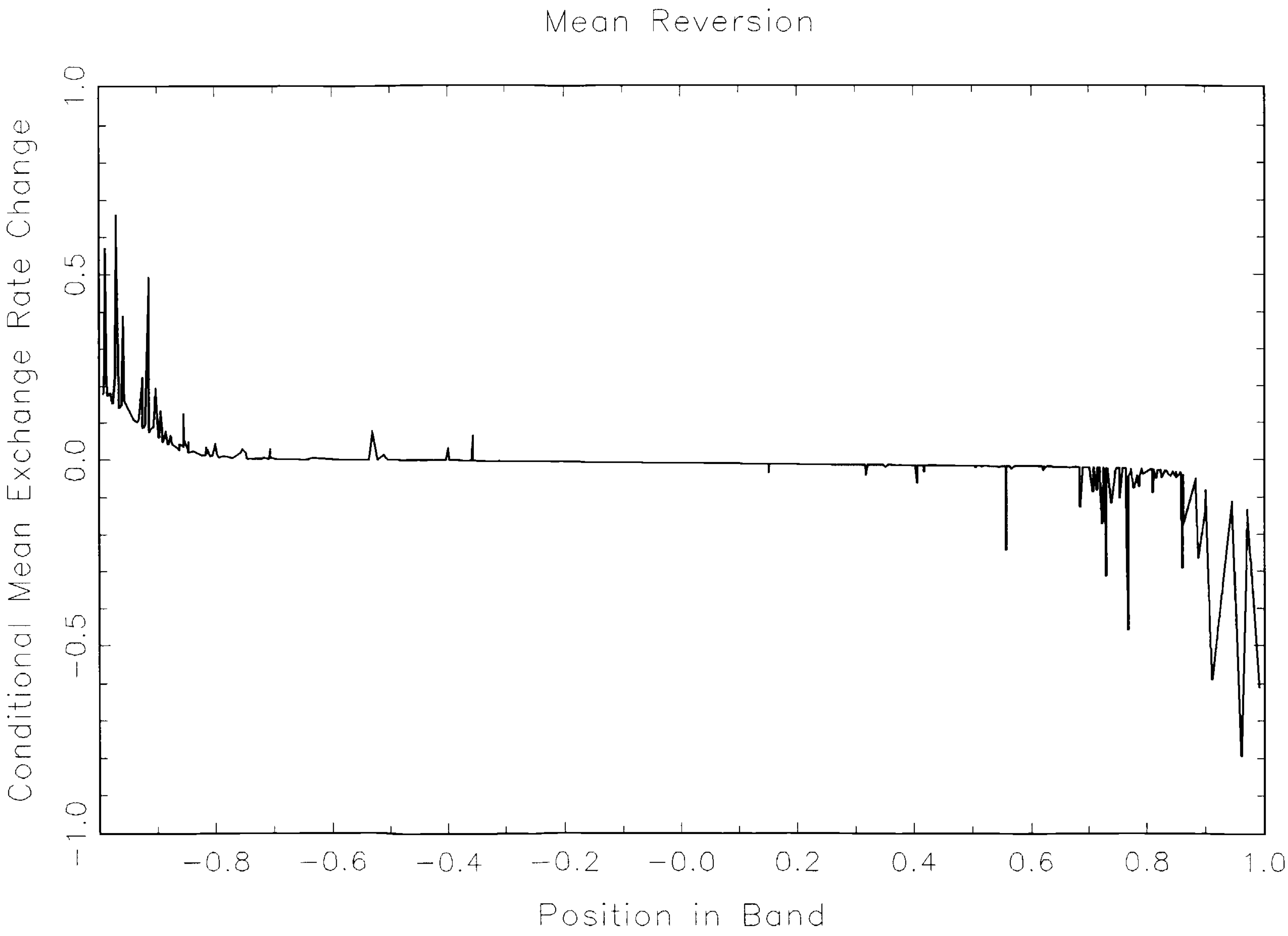

Log Changes in Exchange Rate (S)
Change in DM/FF Rate (%)
6
5
4
3
2
1
0
-1
-2
79:3
80:8
82:2
83:7
84:12
86:5
87:10
89:4
90:9
92:2
93:7
Month
Slope of Yield Curve – France (SYC)
1 Month Rate-12 Month Rate
10
0
-10
-20
-30
-40
-50
-60
-70
79:3
80:8
82:2
83:7
84:12
86:5
87:10
89:4
90:9
92:2
93:7
Month
Position of DM/FF Rate Relative to EMS Bands (PB)
Position in Band
1.6
1.2
0.8
0.4
-0.0
-0.4
-0.8
-1.2
79:3
80:8
82:2
83:7
84:12
86:5
87:10
89:4
90:9
92:2
93:7
Month
Cumulative Inflation Differential (CID)
Cumulative Inflation Differential
0.18
0.14
0.10
0.06
0.02
-0.02
79:3
80:8
82:2
83:7
84:12
86:5
87:10
89:4
90:9
92:2
93:7
Month
Foreign Currency Reserves of Bank of France (LR)
Reserves Relative to 4-Week MA
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
79:3
80:8
82:2
83:7
84:12
86:5
87:10
89:4
90:9
92:2
93:7
Month
1 Month Interest Differential (ID)
Interest Differential: France-Germany
80
60
40
20
0
-20
79:3
80:8
82:2
83:7
84:12
86:5
87:10
89:4
90:9
92:2
93:7
Month

FIGURE 3



Mean Reversion
Conditional Mean Exchange Rate Change
1.0
0.5
0.0
-0.5
-1.0
-1
-0.8
-0.6
-0.4
-0.2
-0.0
0.2
0.4
0.6
0.8
1.0
Position in Band

FIGURE 4

Derivative of Jump Probability w.r.t. Slope of the Yield Curve

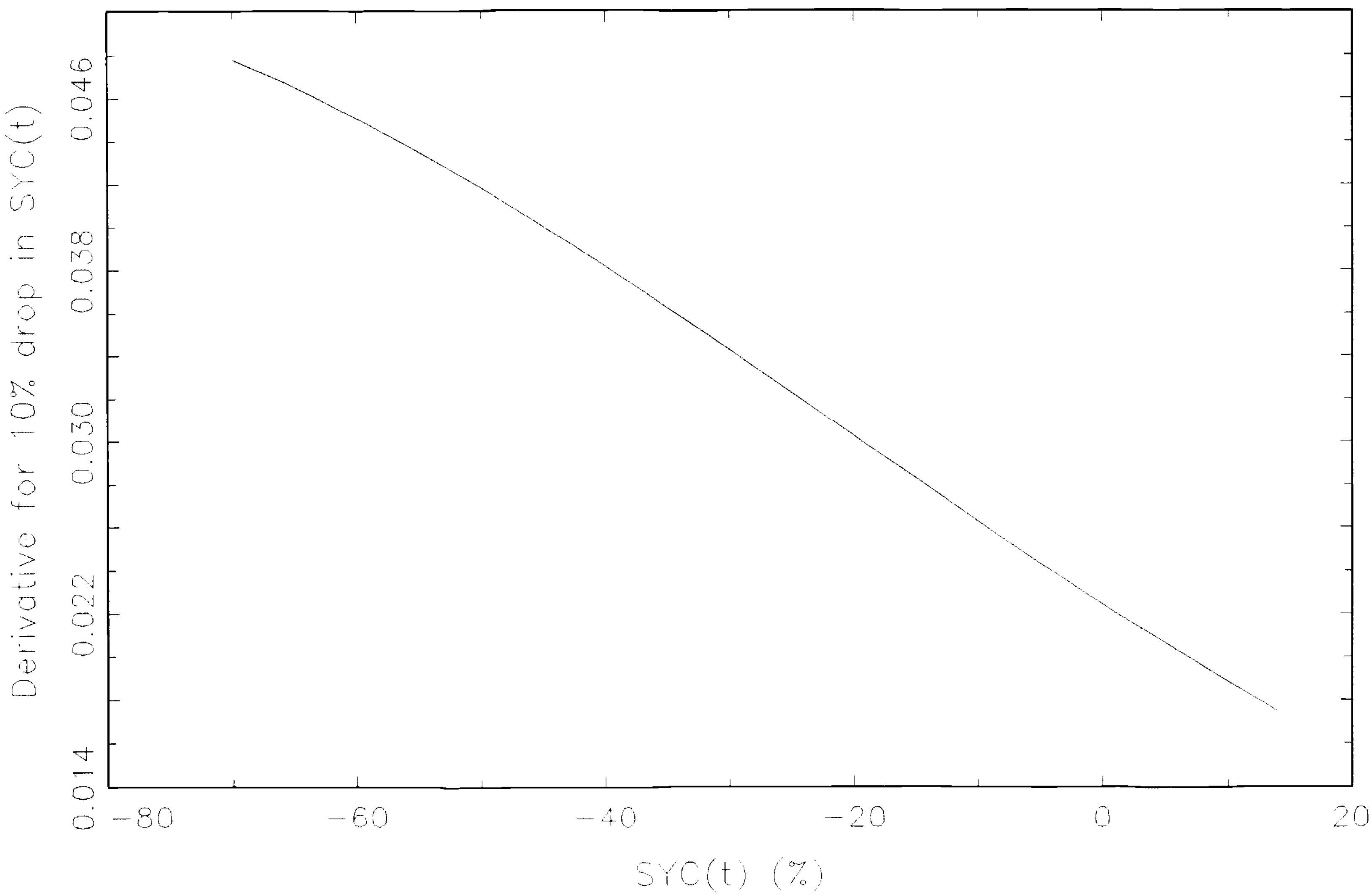


FIGURE 5

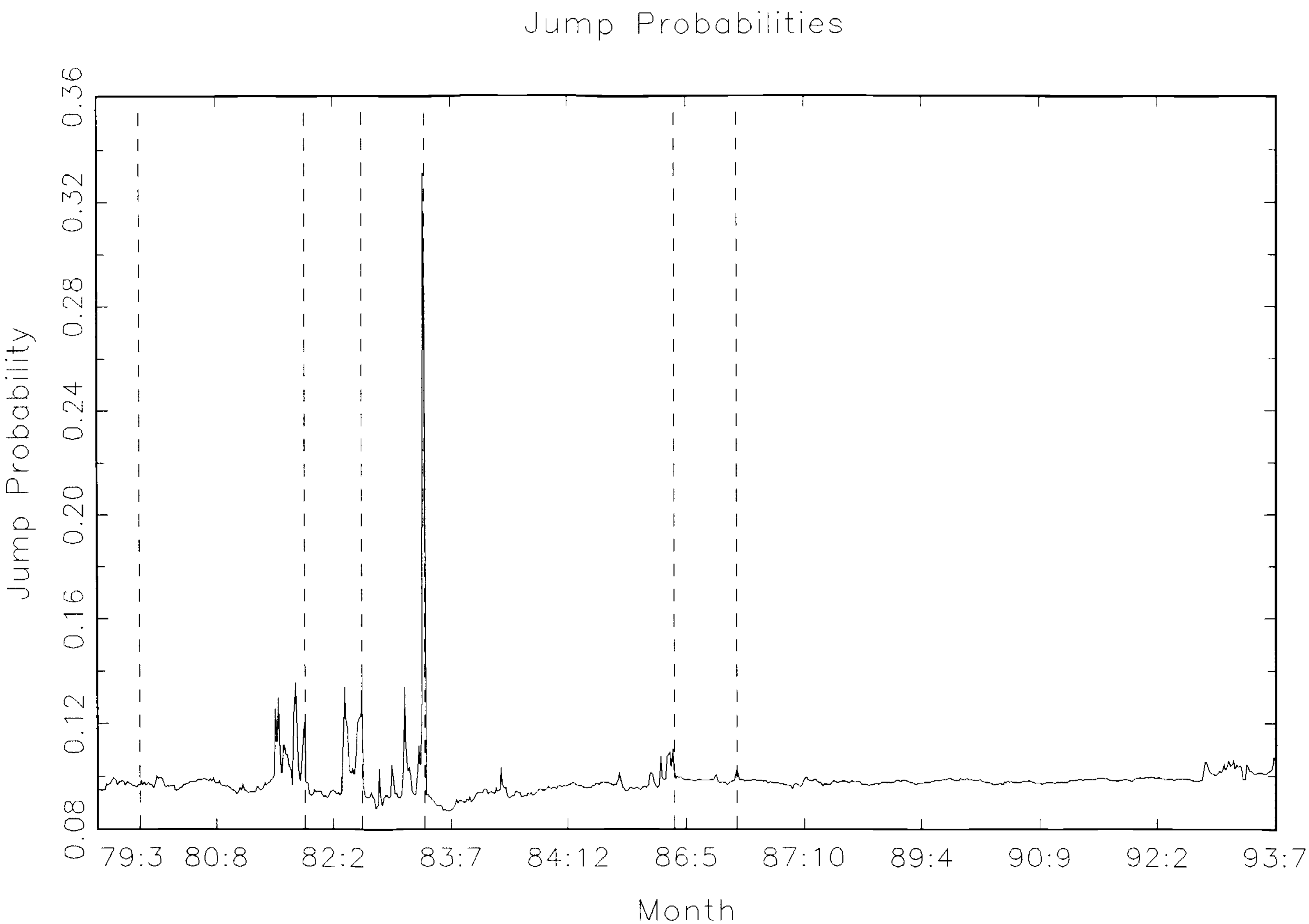

Jump Probabilities
Jump Probability
0.08
0.12
0.16
0.20
0.24
0.28
0.32
0.36
79:3
80:8
82:2
83:7
84:12
86:5
87:10
89:4
90:9
92:2
93:7
Month

FIGURE 6

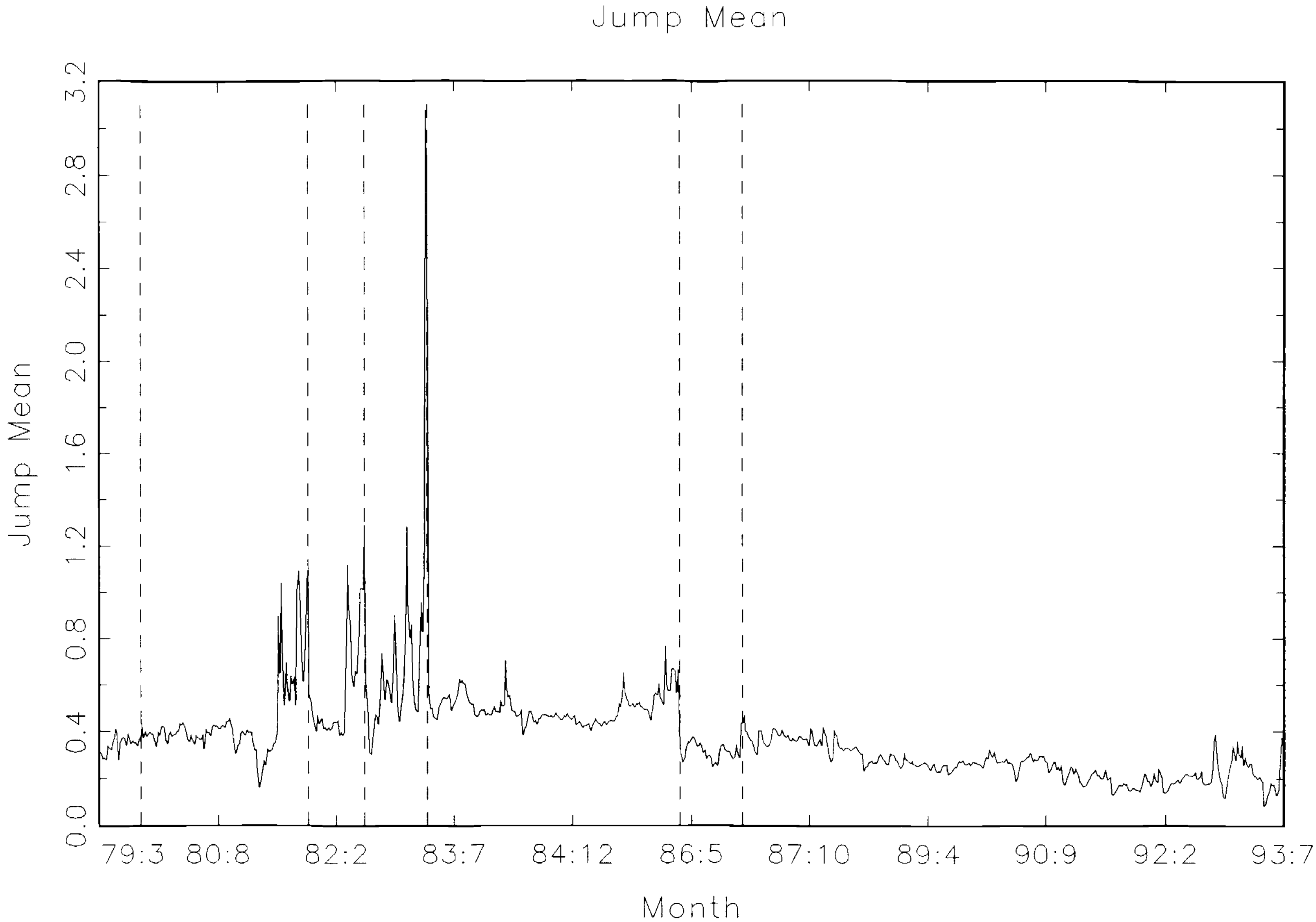

Jump Mean
Jump Mean
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
79:3
80:8
82:2
83:7
84:12
86:5
87:10
89:4
90:9
92:2
93:7
Month

FIGURE 7

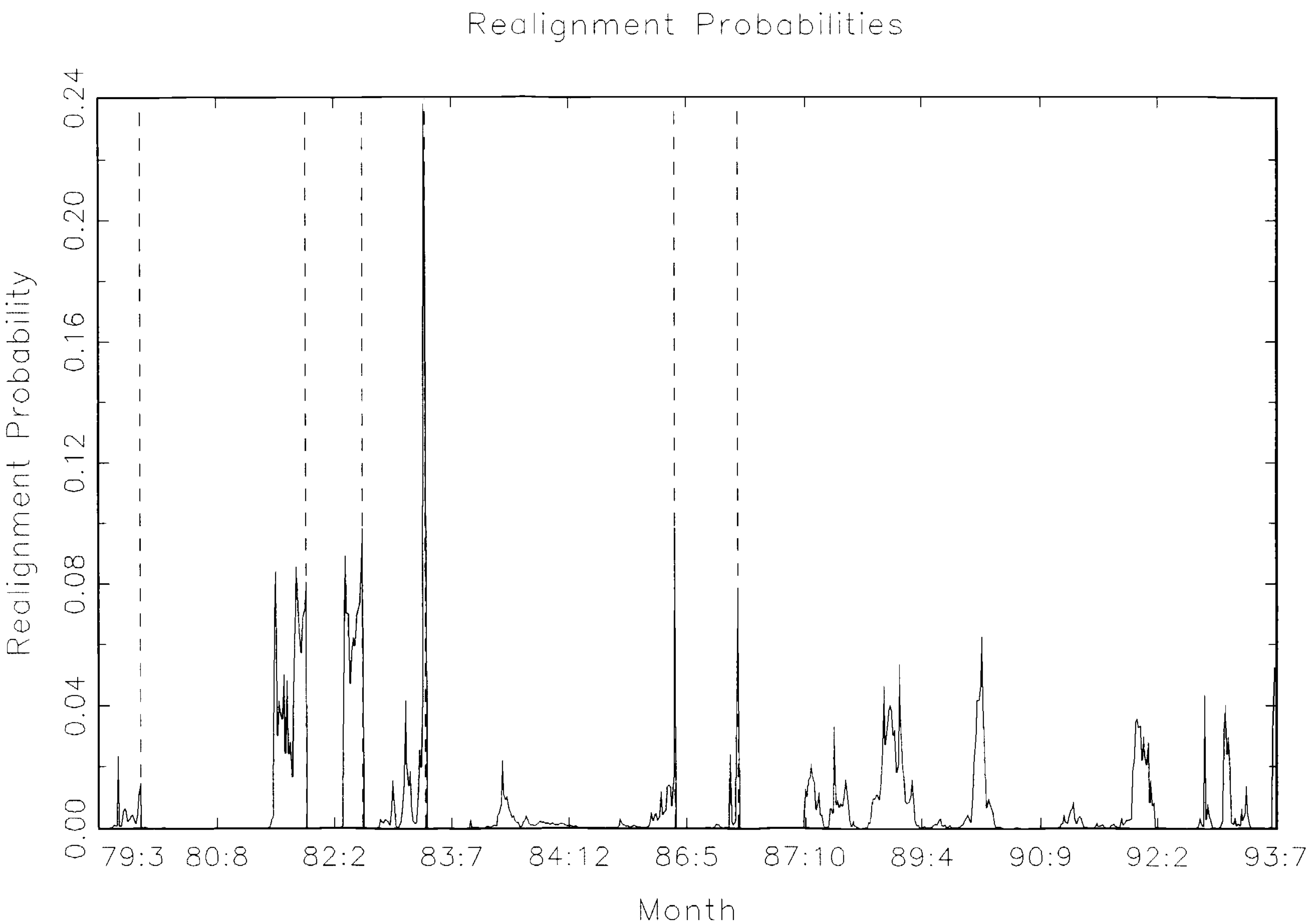

Realignment Probabilities
Realignment Probability
0.24
0.20
0.16
0.12
0.08
0.04
0.00
79:3
80:8
82:2
83:7
84:12
86:5
87:10
89:4
90:9
92:2
93:7
Month

FIGURE 8

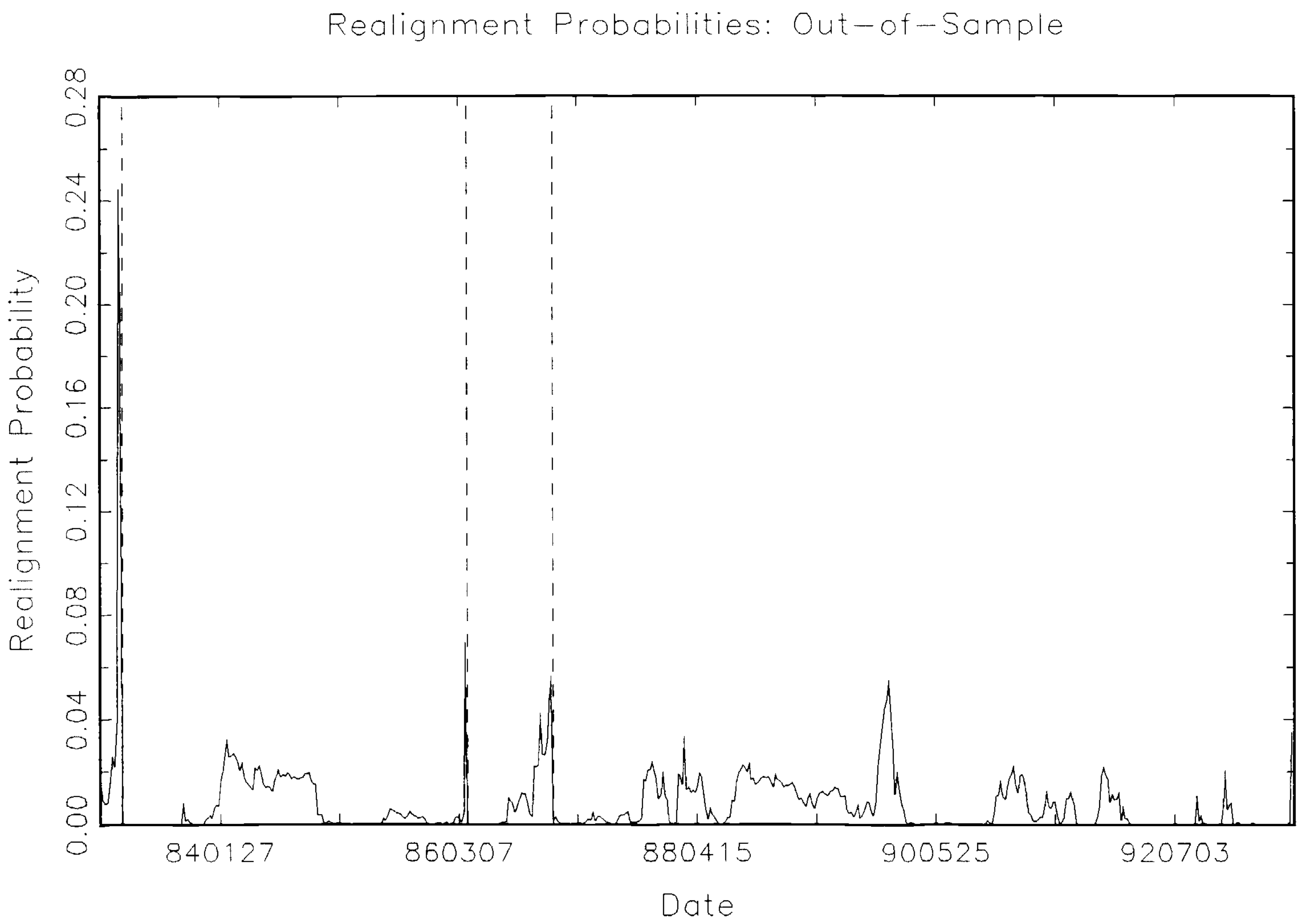
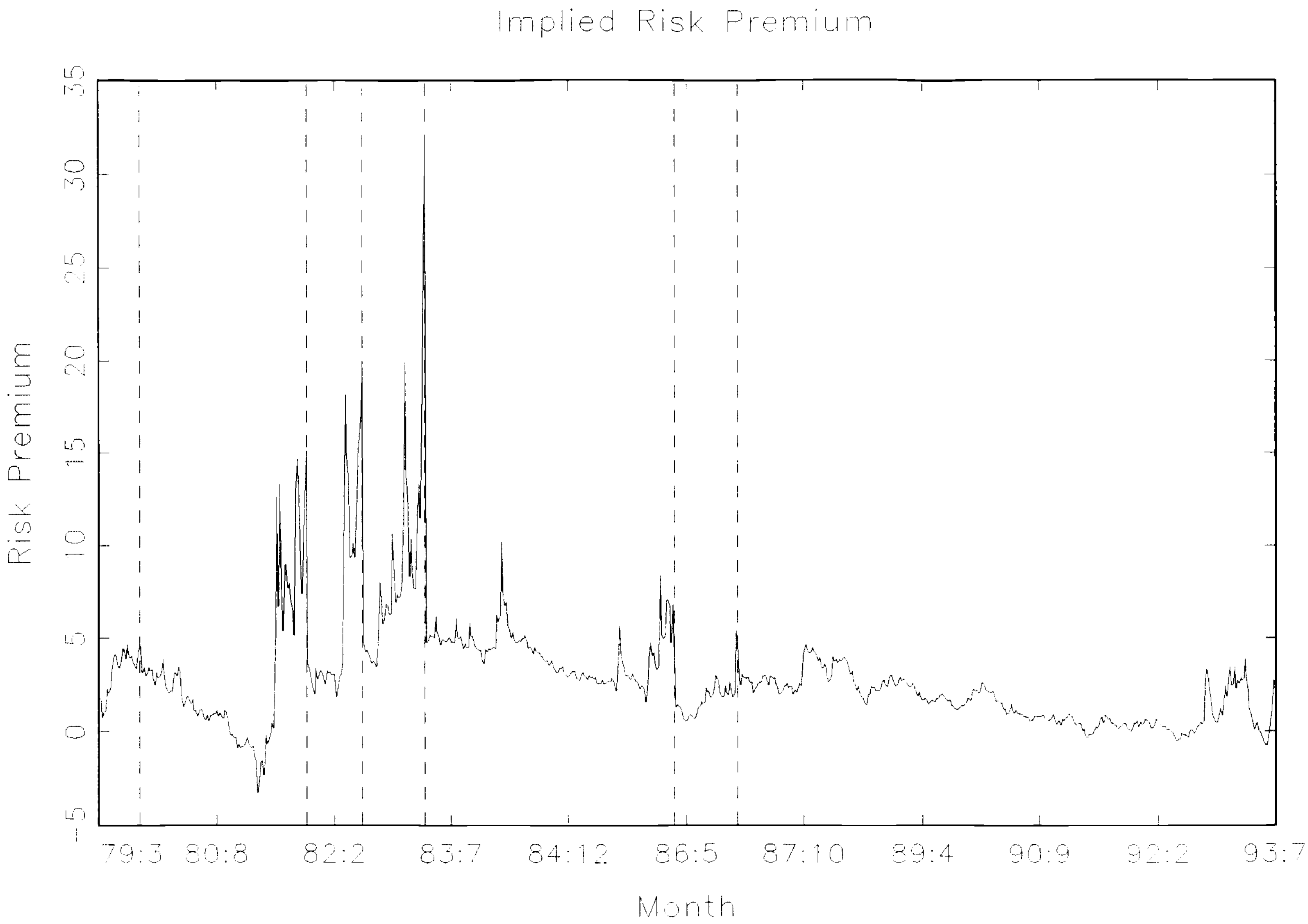

Realignment Probabilities: Out-of-Sample
Realignment Probability
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
840127
860307
880415
900525
920703
Date

FIGURE 9


Implied Risk Premium
Risk Premium
-5
0
5
10
15
20
25
30
35
79:3
80:8
82:2
83:7
84:12
86:5
87:10
89:4
90:9
92:2
93:7
Month