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EXPECTED AND PREDICTED REALIGNMENTS:
THE FF/DM EXCHANGE RATE DURING THE EMS

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ABSTRACT

An empirical model of time-varying realignment risk in an exchange rate target zone is developed. Expected rates of devaluation are estimated as the difference between interest rate differentials and estimated expected rates of depreciation within the exchange rate band, using French Franc/Deutsche Mark data during the European Monetary System. The behavior of estimated expected rates of depreciation accord well with the theoretical model of Bertola-Svensson (1990). We are also able to predict actual realignments with some success.

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I. Introduction

An important feature of fixed exchange rate regimes is that parities are usually imperfectly credible and not permanent. There have been numerous realignments of central parities during the life of the Exchange Rate Mechanism (ERM) of the European Monetary System (EMS). In this paper we attempt to provide an empirical model of imperfect credibility in a system of limited exchange rate flexibility. We estimate market expectations of future realignments of the French Franc/Deutsche Mark exchange rate during the ERM. We then use these estimates to examine the empirical content of the theoretical model developed by Bertola and Svensson (1990); we also attempt to predict actual realignments.¹

Although we often couch our discussion in terms of the Bertola-Svensson model, most of our analysis does not test or rely upon a specific model of exchange rate determination. Our paper relies only on the assumption of uncovered interest rate parity, which we argue is a reasonable assumption for relatively narrow target zone exchange rate regimes; thus our technique is fairly general. The assumption of uncovered interest rate parity implies that the interest rate differential reflects the *total* expected rate of exchange rate depreciation. The total expected rate of exchange rate depreciation is the sum of two components: the expected rate of *depreciation* of the exchange rate *within* the exchange rate band, and the expected rate of *devaluation* (the expected rate of change of the central parity). (By convention a negative expected devaluation is an expected revaluation.) Hence, with an estimate of the expected rate of depreciation within the currency band, an estimate of the expected rate of devaluation can be found by subtracting the estimate of the expected rate of depreciation within the band from the interest rate differential. Empirically, we find substantial mean reversion in the exchange rate within the band,

¹ For alternative empirical approaches to target zone credibility see for instance Bartolini and Bodnar (1991), Bertola and Caballero (1990), Bodnar (1991), Collins (1986), Fratianni and von Hagen (1990), Giovannini (1990), Svensson (1990b,c) and Weber (1990).

which we exploit in forming estimates of expected rates of depreciation.

This paper has six sections. In section II the theoretical model of expected rates of devaluation is summarized. Section III presents the data and our estimation of the expected rate of depreciation within the band and the expected rate of devaluation. Section IV presents the resulting empirical exchange rate function. Section V uses the estimated expected rates of depreciation to forecast actual realignments and conducts a few tests of the model. Section VI summarizes and concludes.

II. Model of Expected Rates of Devaluation

Bertola and Svensson (1990) present a theoretical target zone model with a stochastic time-varying devaluation risk and argue that the existence of such devaluation risk can in principle explain empirical patterns of exchange rates and interest rate differentials. Bertola-Svensson also suggest an empirical method to extract implicit devaluation risk from data on exchange rates and interest rate differentials. In this section we briefly outline this empirical method; Bertola-Svensson provide full theoretical treatment and technical details.

We let $\delta_t \equiv i_t - i_t^*$ denote the home country's interest rate differential at time t , the difference between a default-free home currency interest rate i_t and a default-free foreign currency interest rate i_t^* , both of maturity $\Delta t > 0$. Furthermore, we let s_t denote the natural log of the exchange rate, measured as units of domestic currency per foreign currency. Then we can express uncovered interest rate parity as

$$(2.1) \quad \delta_t = E_t[\Delta s_t]/\Delta t,$$

where E_t denotes expectations conditional upon information available at time t . That is, the interest rate differential reflects the expected average rate of depreciation of the home currency during a time interval corresponding to the maturity. Uncovered interest rate parity is a good approximation if the foreign exchange risk premium is small. Svensson (1990a) argues that the foreign exchange risk premium is likely to be small in exchange

rate target zones, even when there is devaluation risk.² There is also empirical support for uncovered interest rate parity for the FF/DM during the EMS.³ Consequently we rely on uncovered interest rate parity.

Let c_t denote the log of central parity, and let $x_t \equiv s_t - c_t$ denote the deviation of exchange rate from central parity. We shall informally refer to x_t as the exchange rate within the band. We can then separate the right-hand side of (2.1), the expected rate of depreciation of the home currency, into two components,

$$(2.2) \quad E_t[\Delta s_t]/\Delta t \equiv E_t[\Delta x_t]/\Delta t + E_t[\Delta c_t]/\Delta t,$$

the expected rate of depreciation within the band and the expected rate of change of central parity.

Central parities remain constant except at realignments. We think of central parities as being stochastic jump processes. During the next small time interval Δt the central parity remains constant with probability $1 - \nu_t \Delta t$, whereas it takes a jump of independent random size z_t with probability $\nu_t \Delta t$. Here ν_t can be seen as the probability intensity of a jump, the probability of a jump per unit time. It follows that the expected change in central parity can be written

$$(2.3) \quad E_t[\Delta c_t] = (1 - \nu_t \Delta t) \cdot 0 + \nu_t \Delta t \cdot E_t[z_t] = \nu_t \bar{z}_t \Delta t,$$

where $\bar{z}_t = E_t[z_t]$ denotes the expected size of the realignment (positive if expected devaluation, negative if expected revaluation). The expected rate of realignment can consequently be written as

² Svensson (1990a) shows that the foreign exchange risk premium has two components: one arising from exchange rate uncertainty due to exchange rate movements within the band, and the other arising from exchange rate uncertainty due to realignments of the band. The first component is likely to be very small, since conditional exchange rate variability inside the band is smaller than conditional exchange rate variability in a free float, and since foreign exchange risk premia even in a free float appear to be fairly small. The second component is likely to be much larger than the first, but still of moderate size: Even with a coefficient of relative risk aversion of 8 and expected size of devaluations of 10 percent, the foreign exchange risk premium is no more than 20 percent of the total interest rate differential.

³ See footnote 10 below.

$$(2.4) \quad E_t[\Delta c_t]/\Delta t = \nu_t \bar{z}_t$$

the product of the probability intensity of a realignment and the expected size of a realignment.

We use "devaluation" to mean the *actual jump in the exchange rate* at the time of a realignment, as opposed to "realignment" which denotes the *jump in the central parity*. The size of the devaluation will differ from the size of the realignment if the exchange rate's position within the band (x_t) jumps at realignments.⁴

For simplicity, assume that the position of the exchange rate within the band remains the same immediately before and immediately after a realignment (the complications that arise when this assumption does not hold will be dealt with in section V). Furthermore, let g_t denote the expected rate of devaluation. In this case, we may identify the expected rate of devaluation with the expected rate of realignment,

$$(2.5) \quad g_t \equiv E_t[\Delta c_t]/\Delta t.$$

It follows that we may express the expected rate of devaluation as the difference between the interest rate differential and the expected rate of depreciation within the band,

$$(2.6) \quad g_t \equiv \delta_t - E_t[\Delta x_t]/\Delta t.$$

As observed by Bertola-Svensson, equation (2.6) has obvious empirical implications. Even though the expected rate of devaluation is not directly observable, it can be extracted from the data if one forms an estimate of the expected rate of depreciation within the band and then subtracts this estimate from the interest rate differential.

Equation (2.6) holds regardless of the direction of causality. In the Bertola-Svensson model, the causality direction is specified so that the expected rate of devaluation is an exogenous stochastic process which, together with another exogenous stochastic process (the traditional "fundamental" in the standard exchange rate model), determine the

⁴ This is often the case: often the exchange rate for the weak currency is in the upper (weak) half of the band immediately before a realignment and near the lower (strong) edge of the band immediately after a realignment. In that case the size of the devaluation is less than the size of the realignment.

endogenous exchange rate. In this case the exchange rate is a sufficient statistic for, and hence the only determinant of the expected exchange rate depreciation within the band.⁵ The interest rate differential is then the sum of the endogenous expected rate of depreciation within the band and the exogenous expected rate of devaluation. The interest rate differential hence depends separately also on the expected rate of depreciation. The expected rate of depreciation within the band and the determination of the interest rate differential is illustrated in Figure 1. The expected rate of depreciation is shown as the lower downward sloping curve in the Figure; it is a decreasing function of the exchange rate within the band. This is easily understood since the exchange rate band introduces a powerful element of mean reversion to the exchange rate within the band: at the lower (strong) edge of the band the exchange rate cannot appreciate any further, only remain constant or depreciate back into the band. Hence there is positive expected depreciation. Conversely, at the upper (weak) edge of the band, the exchange rate cannot depreciate any further, only remain constant or appreciate back into the band. Hence there is negative expected depreciation. The precise curvature of the expected rate of depreciation within the band need not concern us here; we only note that the theory predicts a nonlinear shape with the curve being convex towards the strong edge of the band and concave towards the weak edge of the band.

The interest rate differential as a function of the exchange rate within the band (for a given expected rate of devaluation) is given by the upper downward-sloping curve in Figure 1. It is simply the curve corresponding to the expected rate of devaluation, shifted up by the expected rate of devaluation. With fluctuating exchange rates and expected

⁵ The exchange rate is a sufficient statistic for the expected exchange rate depreciation within the band only if the the stochastic processes of the expected rate of devaluation and the "fundamental" has constant parameters.

The Bertola-Svensson framework can also incorporate a feedback from the exchange rate within the band to the expected rate of devaluation, by allowing the expected rate of devaluation to be the sum of two components: one exogenous and one a monotonic function of the exchange rate within the band.

rates of devaluation, the interest rate differentials will be generated by corresponding shifting curves in the Figure. Conversely, with observations of exchange rates and interest rate differentials, and a given estimated expected rate of depreciation within the band in the form of a curve as in Figure 1, the expected rates of devaluation can be extracted by taking the vertical differences between each observation and the curve corresponding to the expected rate of depreciation.⁶

III. Estimation of Expected Rates of Devaluation

In this section we first estimate the expected average rate of depreciation within the band, $E_t[\Delta x_t]/\Delta t \equiv E_t[x_{t+\Delta t} - x_t]/\Delta t$, conditional upon information available at time t , where we set Δt to one month. Then we examine the extracted estimates of expected rates of devaluation. In Section V we use these to predict actual realignments.

Estimating the expected rate of depreciation over a finite time interval is equivalent to estimating the expected future exchange rate. We choose for convenience to discuss the problem in terms of the expected future exchange rate.

The theory in Svensson (1990c) derives expected future exchange rates within the band for different time intervals as in Figure 2. Although the precise calculation of the expected future exchange rate requires the solution of a second-order partial differential equation, similar to those arising in option theory, the intuition for Figure 2 is straight-forward. Roughly, there is more reversion towards the mean the longer the time

⁶ Bertola-Svensson clarify in detail the determination of the term structure of interest rate differentials with time-varying devaluation risk, and the distinction between the expected *instantaneous* expected rate of devaluation and the expected *average* rate of devaluation for *finite* maturities. Depending upon the precise properties of the stochastic process of the expected instantaneous rate of devaluation, the expected average rate of devaluation for finite maturities may be a complicated nonlinear function of the expected instantaneous rate of devaluation. These complications need not concern us here. It is enough in this paper to interpret the expected rate of devaluation as the expected average rate of devaluation during the maturity considered, which in our data will be one month.

The expected rate of *depreciation* within the band over a finite time interval has been computed by Svensson (1990c) for the standard target zone model, and the theory predicts that the corresponding curve in Figure 1 would be less sloped and less curved the longer the time interval. The slope should be negative, except for an infinite maturity when it should be zero.

interval, with proper adjustment for the drift of the exchange rate. The relationship is nonlinear and S-shaped, although for typical parameters the relationship is almost linear.⁷

Although the Bertola-Svensson model predicts that the expected future exchange rate will depend *only* on the current exchange rate (in a non-linear fashion), we take an eclectic view in our empirical estimation and allow other determinants of the expected future exchange rate as well. Although some of the other determinants are *statistically* significant, they end up being *economically insignificant*; the dominating determinant of the expected future exchange rate remains the current exchange rate.

Data

We apply the model to the French Franc/Deutsche Mark (FF/DM) nominal exchange rate during the Exchange Rate Mechanism (ERM) of the EMS.⁸ ERM data is a natural choice, both because of intrinsic interest, and because the ERM has experienced a number of realignments since its inception in March 1979. However, the FF/DM exchange rate is the only obvious possibility, since the Bertola-Svensson model is designed to explain exchange rate jumps which are coincident with realignments. Most other ERM exchange rates do not actually jump at realignments, since exchange rate bands before and after realignments typically overlap. Indeed, only four of the six realignments of the FF/DM central parity rate actually involve a jump in the exchange rate.

Our daily BIS data were used and described by Flood, Rose and Mathieson (1990). The period covered is March 13, 1979, through May 19, 1990.⁹ The exchange rates are

⁷ The parameters for both Figures 1 and 2 are drift and rate of variance of the aggregate fundamental equal to 2 percent/year and 1 percent/year, respectively (the latter corresponding to an instantaneous standard deviation of 10 percent/ $\sqrt{\text{year}}$), and a semi-elasticity of money demand (α) equal to 1 year.

⁸ The bandwidth of the FF/DM rate is ± 2.25 percent throughout the ERM.

⁹ Data and programs are available from the authors upon receipt of one 3.5-inch diskette.

recorded at the daily "official fixing"; interest rates are annualized bid rates for 1 month Euro-market bills at around 10am Swiss time. Figure 3a contains a time-series plot of the spot exchange rate, along with the ERM bands; Figure 3b provides a comparable graph of the interest differential.¹⁰ (Disregard Figure 3c at the moment.) The six realignments in Figure 3a define seven regimes, which we will refer to as Regimes 1-7. Table 1 reports the precise dates of realignments.

Estimation of Expected Future Exchange Rates within the Band

Figure 4a can be used to illuminate the problem of estimating the expected future exchange rate. The top left panel in the Figure, labeled "Theory", reproduces Figure 2, the theoretical plot of expected future exchange rates within the band against the current exchange rate within the band, except that only the 1-month expected exchange rate and the 45-degree line is shown. The dots in the other panels, labeled "Regime 1", etc., in Figure 4a show for each regime a scatter plot of the actual realized 1-month future exchange rates (measured in percent deviation from central parity) within the band plotted against the current exchange rate within the band (realizations across a realignment are not shown.) (Disregard the S-shaped curves in the regime plots for a moment.) While there is no theoretical reason to presume that the stochastic process of the exchange rate within the band remains the same through all regimes, completely unrestricted estimation (allowing the process to vary regime by regime) potentially runs

¹⁰ We note that there is empirical support for uncovered interest rate parity for FF/DM exchange rates and interest rate differentials during the ERM period. An OLS regression of the equation $\Delta s_t / \Delta t = a + b\delta_t + u_{t+22}$ (where $s = \log(\text{FF}/\text{DM})$, $\Delta s_t \equiv s_{t+22} - s_t$ and $\Delta t = 1/12$) results in (rates of depreciation and interest rate differentials in percent per year; Newey-West standard errors with 22 lags):

		(s.e.)	<i>N</i>	2542
<i>a</i>	-1.70	(1.14)	R-squared	.18
<i>b</i>	.94	(.24)	σ	11.0

This result seems to be unique to the FF/DM rate. The result is robust to inclusion of lags of δ , other ERM δ s and division of the sample. Regressions of other ERM/DM cross rates result in values of *b* ranging from -1.04 to .33. See Hodrick (1987) and Froot and Thaler (1990) for a discussion of many years of failed attempts to estimate similar equations for different exchange rates and sample periods.

into serious small sample problems. The use of daily data does not obviate small sample problems, since the data is highly persistent; further, the relevant observation interval is the expected time for the exchange rate to hit the edge of the band (starting from the middle). (Svensson (1990c) shows that for typical parameters, that time is on the order of magnitude of a year.)

The theory panel in Figure 4a suggests that a restriction to linearity may be reasonable, although it seems safer to include nonlinear terms (but see Meese and Rose (1990)). However, it would seem (from inspection of Figure 4a) that unrestricted nonlinear regression of future exchange rates against current exchange rates would give rather bizarre results, especially for regimes 3 and 4.¹¹ The latter regimes are also rather short, so that small sample problems may be severe. We have chosen to handle these problems by introducing quadratic and cubic functions of the exchange rate and imposing constancy across regimes on all coefficients except the intercept, which is allowed to vary across regimes. Alternatively, one may restrict quadratic and cubic terms to be zero but allow both slopes and intercepts to vary across regimes; we will also discuss and report results from that restriction.

The regressions estimated are of the form:

$$(3.1) \quad \Delta x_t / \Delta t = \sum_i \beta_{0i} d_i + \beta_1 x_t + \beta_2 x_t^2 + \beta_3 x_t^3 + \sum_j \gamma_j x_{t-j} + \sum_k \varphi_k x_{kt} + \varepsilon_{t+22},$$

where: t is in daily observations; $\Delta x_t \equiv x_{t+22} - x_t$; $\Delta t = 1/12$; $i = 1, \dots, 7$ refers to regime i ; d_i is a dummy for regime i ; $j = 1, \dots, 5$; the x_{kt} terms denote the log of the bilateral DM exchange rates for the five other long-term participants in the ERM (Belgium-Luxembourg, Denmark, Netherlands, Ireland and Italy); and the random disturbances ε_{t+22} are uncorrelated with information available at time t by the assumption of rational expectations. All exchange rates within the band are measured in percent deviation from

¹¹ In regime 4 it is easy to see from Figure 4a that out of sample forecasts of future exchange rates for current exchange rates in the strong part of the band will lie outside the band. This is clearly inadmissible, since what is being forecasted is the exchange rate within the band! Also see footnote 12.

central parity; rates of depreciation are measured in percent per year. This equation allows the future rate of depreciation to depend on the current exchange rate, as well as its square and cube; the latter terms are included to pick up any non-linear dependency which may exist. Lags of x , and levels of other ERM exchange rates are included as specification checks; the latter may be relevant in a multilateral exchange rate target-zone (the Bertola-Svensson model is of a unilateral target-zone).^{12 13}

Estimation of (3.1) is complicated by the well-known "overlapping observations" problem (see Hansen and Hodrick (1980)); in addition, ε_t is likely to be heteroskedastic. We use ordinary least squares, but compute standard errors using a Newey-West covariance estimator (with the number of off-diagonal bands in the error covariance matrix equal to 22 ($\Delta t = 1/12$ year corresponds to 22 daily observations)).

Estimation of (3.1) is equivalent to estimation of

$$(3.2) \quad x_{t+22} = \sum_i \bar{\beta}_{0i} \bar{d}_i + (\bar{\beta}_1 + 1)x_t + \bar{\beta}_2 x_t^2 + \bar{\beta}_3 x_t^3 + \sum_j \bar{\gamma}_j x_{t-j} + \sum_k \bar{\varphi}_k x_{kt} + \bar{\varepsilon}_{t+22},$$

where $\bar{\beta}_{0i} \equiv \beta_{0i} \Delta t$, $\bar{\beta}_i \equiv \beta_i \Delta t$, etc. We choose to discuss the estimation in terms of (3.2). Figures 4a-c show estimated expected future exchange rates within the band (that is, fitted values of (3.2)) under different sets of restrictions (all exchange rates are expressed in percent deviation from central parity).

Recall that the dots in the regime panels in Figure 4a show for each regime the actual realized 1-month future exchange rates within the band plotted against the current

¹² The restrictions that β_1 , β_2 and β_3 do not vary across regimes are statistically rejected at a low level of significance. This can be intuitively understood from Figure 4a. Regime 4 results in a highly significant large positive coefficient for the cubic term, whereas Regime 3 results in a highly significant negative coefficient for the cubic term.

¹³ In the Bertola-Svensson model the current exchange rate is the only determinant of the expected rate of depreciation of within the band. As mentioned, this requires the assumption of constant parameters of the exogenous stochastic processes of the "fundamental" and the interest rate differential. If that assumption does not hold, the interest rate differential may also affect the expected rate of depreciation within the band. Therefore we have also done regressions of (3.1) with the DM/FF interest rate differential as an explanatory variable. Interestingly, and in consistency with the Bertola-Svensson model, the coefficient of the interest rate differential is not significantly different from zero.

exchange rate within the band (realizations across a realignment are not shown.) The S-shaped curves in the regime panels show expected future exchange rates within the band (fitted values of equation (3.2)) under the most restrictive non-linear estimation. Only the current FF/DM exchange rate, its square, and its cube are used as regressors (as well as the intercepts); the coefficients $\bar{\gamma}_j$ and $\bar{\varphi}_k$ are restricted to be zero. Estimates are reported in Table 2, column (2). This is the estimation suggested by the theory, except that the nonlinearity need not necessarily be a cubic function. Comparing the regime panels with the theory panels we see a fairly remarkable consistency with the theory: The estimates display mean reversion as the theory predicts, and the curvature is correct, with concavity to the right and convexity to the left.

The dots in the regime panels in Figure 4b show the expected future exchange rates within the band (fitted values of (3.2)) when 5 lags of FF/DM are included among the right-hand side variables (that is, the coefficients $\bar{\gamma}_j$ are no longer restricted to zero). (Since the current exchange rate within the band is no longer the only right-hand side variable, the fitted values no longer form a curve when plotted against the current exchange rate within the band. The actual realized future exchange rates within the band are not shown in Figures 4b and c.) The regression is reported in Table 2, column (3). The hypothesis that the coefficients of the lags are zero is only rejected at a marginal significance level of 10 percent. The relationship between the expected future exchange rates and the current exchange rate is a bit fudged compared to the case with no lags in Figure 4a. Even so it is clear that the current exchange rate has a dominating influence on the expected future exchange rate.

The dots in the regime panels in Figure 4c show expected future exchange rates within the band when the other current ERM exchange rates are also included, that is, when the coefficients $\bar{\varphi}_k$ are no longer restricted to equal zero. The regression is reported in Table 2, column (4). The hypothesis that those coefficients are zero is rejected only at a marginal significance level of 8 percent. We see in Figure 4d that the relationship

between the expected future exchange rate is blurred further, but that the current FF/DM rate still has the dominating influence.

We interpret these results as implying that although determinants other than the current FF/DM rate are of marginal *statistical* significance, they are *economically insignificant*. The current exchange rate remains the dominating determinant, and the error made in disregarding the other determinants seems minor. We nevertheless choose as our base case the intermediate one in Figure 4c and column (3), Table 2, where lags of the FF/DM rate are included.

Estimation of Expected Rates of Devaluation

In accordance with equation (2.6) the expected rates of devaluation can now be estimated by subtracting from each observed interest rate differential the corresponding estimate of the expected rate of depreciation. In order to see more clearly what is involved, in Figure 5 we show a scatter plot of the interest rate differentials (measured in percent per year) against the exchange rate within the band (measured in percent deviation from central parity). The curved line shows the expected rate of depreciation resulting from the most restricted estimation without lags and other exchange rates (Table 2, column (2)). The consistency with the theoretical Figure 1 is striking. We also see that the expected rate of depreciation and the interest rate differentials are often of the same order of magnitude. In regime 2, for instance, the interest rate differentials are between 5 and 20 percent per year in the weak third of the exchange rate band, whereas the expected rate of depreciation is between -5 and -15 percent per year. The difference between the interest rate differential and the expected rate of devaluation is considerable in these cases.

As mentioned, we do not use the most restrictive estimate of expected rates of depreciation within the band as our benchmark, but the intermediate one illustrated in Figure 4c (Table 2, column (3)). The expected rates of depreciation in Figure 5 would then be accordingly fudged, although the expected current exchange rate would remain

the main determinant of the expected rate of depreciation. The resulting time series of the expected rate of depreciation is depicted in Figure 3c.

The expected rate of devaluation in Figure 3c (measured in percent per year) is (naturally) highly correlated with the interest rate differential in Figure 3b, especially when the interest rate differential takes extreme values in the first half of the ERM period. But the expected rate of devaluation is certainly not identical to the interest rate differential. For instance, the interest rate differential is always positive and fairly stable in the second half of the ERM period, but the expected rate of devaluation fluctuates quite a bit, and occasionally indicates zero or even negative expected rates devaluation (positive expected rates of revaluation).

The overall variability of the expected rate of devaluation is less in the later regimes than in the earlier regimes. The average expected rate of devaluation is also lower in the later regimes. In line with conventional wisdom, the average credibility of the FF/DM band appears to have increased in the later regimes. However, we see that expected rates of devaluation still fluctuates quite a bit in later regimes, normally between 0 and +10 percent per year. At the beginning of Regime 6 there is evidence of an expected revaluation.

In order to interpret what an expected rate of devaluation of 10 percent means, recall that the expected rate of devaluation by (2.4) is the product of the expected size of a devaluation and the probability intensity of a devaluation. Suppose the expected *size* of a devaluation is 5 percent. Then the probability *intensity* of a devaluation is 200 percent per year (5 percent \times 200 percent/year = 10 percent/year). This can be interpreted as the probability of a devaluation occurring within the next month being 200 percent/12 = 1/6, or that the expected time to a devaluation (if the probability intensity is expected to remain constant) is .5 year (= 1/(200 percent/year)).

In the Bertola-Svensson model, the expected rate of devaluation is assumed to be a Brownian motion. It is therefore interesting to see whether the estimated expected rate of

devaluation has a unit root and is consistent with the Bertola-Svensson assumption. We have done Dickey-Fuller unit root tests on a number of different estimates of the expected rate of devaluation, and the unit-root hypothesis cannot be rejected.

Restriction to Linearity

The discussion above and Figures 3c and 4a-c concern the nonlinear estimation of the expected rate of depreciation within the band which includes the square and the cube of the exchange rate as explanatory variables in (3.1) (column (2)-(4) in Table 2). As mentioned we impose constancy across regimes of all coefficients except the intercept. This restriction is certainly a bit controversial.

It is therefore relevant to consider also the alternative restriction to linearity: to restrict the coefficients in (3.1) of the square and the cube of the exchange rate within the band to zero. There are several reasons for considering this restriction. First, the theoretical Figure 2 suggest that the relationship may be nearly linear. Second, the coefficients of the quadratic and cubic terms in column (2)-(4), Table 2, are only marginally significant. Third, the restriction to constancy across regimes of the coefficients for the quadratic and cubic term, required in the nonlinear case, implies an implicit assumption that some parameters and possible unofficial bands within the official band have remained similar across regimes.

An estimation of a linear version of (3.1) without imposing any constancy of coefficients across regimes results in negative slopes (coefficients for the current exchange rate) which are very similar. The hypothesis that the slopes are equal across regime cannot be rejected. Column (1), Table 1, shows the result of the estimation without lags and other exchange rates when slopes but not intercepts are (non-bindingly) restricted to be equal across regimes. Column (1) shows a strong rejection of a unit root, and strong support for mean reversion in the exchange rate.

In order to reduce the number of figures, the graphs for the linear case are not shown. It is easy to imagine in Figures 4a and 5 what they look like, though. In Figure 4a the

estimated future exchange rates would be straight lines with slopes less than unity and different intercepts, similar to the theory panel. In Figure 5 the estimated expected rates of depreciation would be straight lines with slopes equal to -2 and different intercepts .

It is apparent from Figure 5 that the expected rate of depreciation within the band will be of less magnitude at the edges of the band for the linear case, compared to the nonlinear case. As a result the variability of the expected rate of devaluation will be somewhat less in situations when the exchange rate within the band is near the edge. This can be seen in Figures 6a and b. Figure 6a shows the expected rate of devaluation estimated in the nonlinear case (column (2), Table 2). Figure 6b shows the expected rate of devaluation estimated in the linear case (column (1), Table 2). (Since no lags are used here, there are fewer missing values than in Figure 3c, corresponding to column (3), Table 2.) The variability of the expected rate of depreciation is clearly less after 1986 for the linear case.

IV. The Exchange Rate Function

As mentioned, our method of estimating the expected rate of devaluation does not depend on whether the Bertola-Svensson model or any other target zone model is a correct representation of actual exchange rate regimes. Nevertheless, in this section we look more closely at the relations between our estimates and some results of the rapidly growing target zone theory.

The standard target zone model in Krugman (1990) starts from an assumption that the (log of the) exchange rate depends on a "fundamental" and the expected instantaneous rate of depreciation according to

$$(4.1) \quad s_t = f_t + \alpha E_t[ds_t]/dt.$$

Here $\alpha > 0$ is a constant (which may in some specifications be interpreted as the interest rate semi-elasticity of money demand), and f_t , the fundamental, includes (the log of) relative domestic and foreign money supplies, velocity shocks, etc. For given assumptions

about the stochastic processes of the exogenous components of f_t and the rules of intervention in the central-bank controlled components of f_t , the exchange rate can be solved as a function of f_t ,

$$(4.2) \quad s_t = S(f_t),$$

with a characteristic S-shape. Flood, Rose and Mathieson (1990) observed that under the assumption of uncovered interest rate parity (2.1), and given an estimate (or guess) $\hat{\alpha}$ of α , a direct estimate of the fundamental is given by

$$(4.3) \quad \hat{f}_t = s_t - \hat{\alpha}\delta_t.$$

A plot of s_t against \hat{f}_t should then result in the graph of the S-shaped function (4.2). Flood, Rose and Mathieson constructed a number of those plot for the different ERM countries and for different regimes between realignments. The results were disappointing, in the sense that no deterministic relation between s_t and \hat{f}_t were found, and both nonlinear and nonparametric regressions of s_t on \hat{f}_t resulted in a wide variety of shapes, unless $\hat{\alpha}$ is very small (in which case the scatter plot is trivially close to a 45-degree line).

The Bertola-Svensson model offers an explanation to these results. In the Bertola-Svensson model the exchange rate is a function of two "fundamental" variables, the traditional f_t in (4.1) and the expected rate of devaluation g_t . In particular, the exchange rate within the band can be written as a function

$$(4.4) \quad x_t = X(\tilde{f}_t, g_t) \equiv X(h_t),$$

where \tilde{f}_t equals $f_t - c_t$ and the aggregate fundamental h_t equals $\tilde{f}_t + \alpha g_t$, a linear function of the two primitive fundamentals. Subtracting c_t from both sides of (4.1) and manipulating results in

$$(4.5) \quad x_t = \tilde{f}_t + \alpha E_t[dx_t]/dt + \alpha E_t[dc_t]/dt.$$

Using (2.5) we can then write

$$(4.6) \quad x_t = (\tilde{f}_t + \alpha g_t) + \alpha E_t[dx_t]/dt \equiv h_t + \alpha E_t[dx_t]/dt.$$

Equation (4.6) has the same form as (4.1). The solution to (4.6) will be identical to the Krugman solution to (4.1), except that f_t in (4.2) will be replaced by the aggregate

fundamental h_t .

Plots of x_t against \hat{f}_t will not reveal the underlying exchange rate function, when the expected rate of devaluation fluctuates. In order to graph the exchange rate function one should instead plot x_t against an estimate of h_t . Such an estimate is easy to construct according to

$$(4.7) \quad \hat{h}_t \equiv \hat{f}_t - c_t + \hat{\alpha} \hat{g}_t,$$

where \hat{f}_t is given by (4.3) and \hat{g}_t is an estimate of the expected rate of devaluation.

Figure 7a and 7b correspond to $\hat{\alpha} = 1$ year and $\hat{\alpha} = 0.1$ year, respectively.^{14 15} The theory panel shows the theoretical relation between x_t and h_t (the right curve), and the corresponding relation between x_t and $\hat{f}_t - c_t$ for a given level of g_t (the left curve). The horizontal difference between the curves is $\hat{\alpha} g_t$. The curves in the regime panels are plots of the actual x_t against the estimates \hat{h}_t . We see the characteristic S-shape, emphasized in the theory (the S-shape is more pronounced with larger $\hat{\alpha}$). We also see Krugman's "honeymoon" effect; the band for the aggregate fundamental is wider than the exchange rate band (this is more pronounced with larger $\hat{\alpha}$). The dots in the regime panels show the actual x_t plotted against the estimate $\hat{f}_t - c_t$. These scatters can be understood as generated by horizontal shifts of the curve depicting the exchange rate function. Put differently, the horizontal distance between an observation $(\hat{f}_t - c_t, x_t)$ and an observation (\hat{h}_t, x_t) on the curve is equal to $\hat{\alpha} \hat{g}_t$. The regime panels in Figure 7a and 7b are remarkably similar to the theory panels and the theoretical and simulated graphs in Bertola-Svensson.

¹⁴ There is considerable uncertainty in the literature about the appropriate value of α (cf. Flood, Rose and Mathieson (1990)), but hopefully the true value is not too far from this interval.

¹⁵ We use the one-month interest rate differentials as proxies for instantaneous interest rate differentials.

V. Prediction of Realignment

In this section we examine how well the estimated expected rates of depreciation predict actual rates of realignment. In view of (2.5) and (2.6) we write our model as

$$(5.1) \quad E_t[\Delta c_t]/\Delta t \equiv g_t \equiv \delta_t - E_t[\Delta x_t]/\Delta t.$$

It is therefore natural to estimate and do hypothesis testing on the coefficients ψ_0 , ψ_1 and ψ_2 in the equation

$$(5.2) \quad \Delta c_t/\Delta t = \psi_0 + \psi_1 \delta_t + \psi_2 \hat{E}_t[\Delta x_t]/\Delta t + \eta_{t+22},$$

where $\hat{E}_t[\Delta x_t]/\Delta t$ denotes the estimate of the expected rate of depreciation. The model suggests the null hypothesis $H_0: \psi_0 = 0, \psi_1 = -\psi_2 = 1$.

Estimation of (5.2) is complicated by two factors, in addition to the overlapping observation problem. First, $\hat{E}_t[\Delta x_t]/\Delta t$ is a generated regressor, and has associated measurement error problems. Pagan (1984) shows that an instrumental variable procedure delivers correct estimates of the covariance matrix.¹⁶ The second problem is that the dependent variable in (5.2) is a jump process and not Normal; thus η_{t+22} will not be Normal. Consistent (but inefficient) estimates are available through OLS. Maximum likelihood estimation would produce efficient results but underlying distributions are unknown. Reliance on an assumption of underlying normality is questionable (Flood, Rose and Mathieson (1990)) and may yield inconsistent estimates. We prefer OLS as an estimator, since it delivers consistent estimates of the coefficients of interest, ψ_0 , ψ_1 and ψ_2 , but are wary of over-interpreting our results.^{17 18}

¹⁶ Pagan (1984) shows that there is no efficiency gain to estimating the expected rate of depreciation and prediction equations simultaneously.

¹⁷ The difficulties with a maximum likelihood estimations seems formidable. They involve simultaneously handling non-Normal disturbances, overlapping observations, generated regressors and missing values, each of which is a considerable complication.

¹⁸ As the parameters of interest in (5.2) are not country-specific, data for other currencies or exchange rate regimes could, in principle, be pooled with the FF/DM data in estimating (5.2). Adding more data is potentially important given the relatively few realignments experienced by the FF/DM rate during the ERM. However, it is not clear how to pool such data in practice (given the sample selection issues induced by the long spells without realignments). Further, the empirical results indicate that at least some of the hypotheses can be tested with enough precision to be rejected.

The actual size of devaluations (meaning the actual jump of the exchange rate at a realignment) usually differs from the size of realignments (meaning the jump of the central parity), since the exchange rate's position within the band often jumps at realignments (typically from the weak part of the band before the realignment to the strong part of the band after the realignment). Therefore, actual devaluations are less than actual realignments (usually by about half). For some overlapping realignments, there is no clear devaluation at all. When the size of devaluations differ from the size of realignments, the Bertola-Svensson model applies to devaluations rather than realignments. Therefore we also examine a variant of (5.2) where the left-hand variable is replaced by the actual rate of devaluation $\Delta \bar{s}_t / \Delta t$, where \bar{s}_t is defined to be constant except at each date of realignment where it jumps by the actual jump of the exchange rate that date.

Results

Estimates of (5.2) with $\Delta c_t / \Delta t$ and $\Delta \bar{s}_t / \Delta t$ are reported in Table 3. The coefficients have the right signs, although the coefficients on the expected rate of depreciation within the band are not significantly different from zero. The magnitude of the coefficient for the interest rate differential is too large with the regressand $\Delta c_t / \Delta t$ and about right with the regressand $\Delta \bar{s}_t / \Delta t$. The magnitude of the coefficient for the expected rate of depreciation within the band is too small with the regressand $\Delta c_t / \Delta t$ and even lower with the regressand $\Delta \bar{s}_t / \Delta t$. The constants are large and negative but imprecisely estimated. The estimates and the standard errors with the regressand $\Delta \bar{s}_t / \Delta t$ are about half of the estimates with the regressand $\Delta c_t / \Delta t$ (since the the actual devaluations are about half the realignments).

A number of chi-square hypothesis tests are also reported in Table 3. Consider first tests with the regressand $\Delta c_t / \Delta t$. The most important hypothesis, (1), $\psi_0 = 0$, $\psi_1 = -\psi_2 = 1$ (the overall model), is rejected only at the relative low marginal significance level

of 9 percent (this is unusual for any model that involves exchange rates.) Hypothesis (2), that the expected rate of devaluation enters with the right sign and value, is only rejected at a marginal significance level of 20 percent. In contrast, hypothesis (3), that only the expected rate of devaluation matters, is rejected at a lower marginal significance level of 7 percent. Hypothesis (4), that only the interest rate differential matters, is rejected at a marginal significance level of 22 percent. Hypothesis (5), that the interest rate of differential enters with a unit coefficient, is rejected at marginal significance level of 19 percent. Finally, hypothesis (6), that the expected rate of depreciation within the band enters with a coefficient of minus one, is rejected at a marginal significance level of 26 percent. This is obviously a mixed result. We are pleased by a rather high marginal significance level for the overall model, but it is disturbing that the hypothesis that only the interest rate differential matters cannot be rejected except at a very high marginal significance level.^{19 20}

As mentioned, the estimates and the standard deviations with the regressand $\Delta \bar{s}_t / \Delta t$

¹⁹ Andrews (1991) and Andrews and Monahan (1990) report Monte Carlo simulations according to which the Newey-West estimator (which uses a Bartlett kernel) of the covariance matrix is biased downwards. They propose an alternative estimator with a Quadratic Spectral kernel with an optimally chosen lag truncation parameter. This estimator is less downward biased in their simulations. We have found that estimates with both kernels are insensitive to the lag length, so the choice of an optimal lag truncation parameter does not seem important for our sample. If the covariance matrix is estimated with a Quadratic Spectral kernel, its elements are about 10 percent larger in magnitude than with the Bartlett kernel. Use of the Quadratic Spectral estimates in Table 3 would therefore improve our results somewhat. For instance, hypothesis (1) in column (1) (the complete model) would be rejected at a marginal significance level of 12 percent rather than 9 percent.

²⁰ We have also predicted realignments with two alternative techniques. First, we have estimated probit regressions where the dependent variable is an indicator variable marking actual realignments. Both the interest rate differential and the expected depreciation within the band (estimated in any of a variety of ways) enter these regressions significantly, as does the expected rate of devaluation on its own; the equations fit well, although relatively few realignments are predicted successfully. Second, there is a significant positive relationship between realized devaluations (either central parity realignments or the actual jump in the exchange rate) and the expected rate of devaluation during episodes of actual realignments. These encouraging results reinforce the potential value of our measure of expected devaluations.

are about half of those with the regressand $\Delta c_f/\Delta t$. As a consequence most of the hypotheses are clearly rejected, except that hypothesis (3), that only the expected rate of devaluation matters, is rejected at about the same marginal significance level as with the regressand $\Delta c_f/\Delta t$ (7 percent). Hypothesis (4), that only the interest rate differential matters, is rejected at about the same marginal significance as with the regressand $\Delta c_f/\Delta t$. Hypothesis (5), that the interest rate differential enters with a unit coefficient is now rejected at a marginal significance level of 51 percent.

VI. Summary and Conclusions

In this paper we demonstrate and use a simple and operational method, suggested by Bertola and Svensson, to extract implicit expected rates of devaluation from FF/DM data during the ERM. The method relies on uncovered interest rate parity; for a variety of theoretical and empirical reasons we believe this is a reasonable assumption.

The method to extract expected rates of devaluation consists of adjusting the interest rate differential by the expected rate of depreciation within the band. Estimating the adjustment term is equivalent to forecasting the future exchange rate within the band.

We find strong evidence of statistically and economically significant mean reversion of the exchange rate within the band. The current exchange rate is the dominant determinant of the expected rate of depreciation. The adjustment term is of the same order of magnitude as typical interest rate differentials.

The method used to extract expected rates of devaluation is general and does not rely on the specific Bertola-Svensson target zone model, or any other particular exchange rate model. Nevertheless, a remarkable consistency is observed between the data and many assumptions and predictions of the Bertola-Svensson model. These include the mean reversion of the exchange rate within the band, the sign pattern of nonlinear terms, the shape of the exchange rate function, and a unit-root in estimated expected rates of devaluation.

The performance of expected rates of devaluations to predict actual realignments is also examined, with mixed success. The prediction model performs relatively well both absolutely and relative to other exchange rate models.

One reason why the prediction model does not perform even better may be that private agents actually mispredicted actual realignments. Another might be that the interest rate differentials in some instances take extreme values immediately before realignments, in which case the adjustment term does not matter. The adjustment term may be more important for assessing the expected rate of devaluation in normal times with smaller interest rate differentials.

Further research can be undertaken in several directions. The extracted expected rates of devaluation can be compared with other information about devaluation expectations and economic or political events. One can also test for dependence of expected rates of devaluation on macroeconomic variables such as inflation differentials, real exchange rates, unemployment, and reserves. Some of those extension are being pursued on data on the Swedish target zone exchange rate regime by Lindberg, Svensson and Söderlind (1991). It would also be interesting to use measures of devaluation risk to test the Bertola-Svensson model more rigorously, perhaps using the techniques of Flood, Rose and Mathieson (1990).

Table 1. Regimes between Effective Realignments of the FF/DM Exchange Rate

Regime	Start Date	End Date
1	79:03:13	79:09:23
2	79:09:24	81:10:04
3	81:10:05	82:06:13
4	82:06:14	83:03:20
5	83:03:21	86:04:06
6	86:04:07	87:01:11
7	87:01:12	90:05:16

Table 2. Estimation of Expected Exchange Rate Depreciation within the Band (3.1)

	(1)	(2)	(3)	(4)
<u>Intercepts</u>	(s.e.)	(s.e.)	(s.e.)	(s.e.)
Regime 1	3.72 (.88)	3.59 (.90)	3.08 (.89)	-.22 (2.54)
Regime 2	-.18 (1.45)	.69 (1.62)	.30 (1.87)	4.03 (2.26)
Regime 3	5.55 (2.51)	6.68 (2.78)	7.39 (3.38)	5.27 (4.27)
Regime 4	2.83 (1.37)	3.24 (1.47)	3.03 (1.59)	.98 (2.18)
Regime 5	-.06 (.55)	.29 (.59)	.22 (.66)	-2.65 (1.76)
Regime 6	3.95 (2.06)	3.77 (2.27)	4.36 (2.48)	.65 (2.62)
Regime 7	1.62 (.89)	1.92 (1.03)	2.06 (1.22)	-.38 (1.57)
<u>Coefficients</u>				
FF	-1.98 (.49)	-.35 (1.03)	-2.48 (1.75)	-5.58 (2.16)
FF ²		-.45 (.33)	-.32 (.39)	-.10 (.43)
FF ³		-.59 (.28)	-.61 (.33)	-.47 (.33)
p-value (FF ² =FF ³ =0)		.05	.13	.35
FF ₋₁			1.07 (.56)	1.25 (.63)
FF ₋₂			1.11 (.51)	1.15 (.56)
FF ₋₃			.46 (.55)	1.14 (.58)
FF ₋₄			-.51 (.57)	-.79 (.64)
FF ₋₅			-.27 (.88)	-.36 (.83)
p-value (FF ₋₁ =...=FF ₋₅ =0)			.10	.03
BF				2.36 (1.27)
DK				.28 (.61)
IP				.16 (.82)
IL				.30 (.34)
NG				.46 (1.17)
p-value (BF=...=NG=0)				.08
<u>Diagnostics</u>				
N	2426	2426	1878	1799
R-squared	.15	.17	.19	.23
σ	6.2	6.1	6.4	6.3

OLS; regressand is $(x_{t+22}-x_t)/\Delta t$ (%/yr); $\Delta t=1/12$ yr; $x = \log(\text{FF}/\text{DM})$ (%); regressors are $x, x^2, x^3, x_{-1}, \dots, x_{-5}, \log(\text{BF}/\text{DM}), \dots, \log(\text{NG}/\text{DM})$, where BF, ..., NG denote, respectively, Belgian Franc, Danish Krone, Irish Pound, Italian Lire and Netherlands Guilder; Newey-West standard errors (22 lags); Chi-Square hypothesis tests.

Table 3. Prediction of Realignment (5.1)

	Regressand	$\Delta c_t / \Delta t$	$\Delta \bar{s}_t / \Delta t$
	<u>Coefficient Estimates</u>		
ψ_0	Constant	-4.41	-2.52
	(s.e.)	(2.01)	(1.08)
ψ_1	δ_t	1.58	.84
	(s.e.)	(.43)	(.24)
ψ_2	$\hat{E}_t[\Delta x_t] / \Delta t$	-.52	-.28
	(s.e.)	(.43)	(.22)
	<u>Diagnostics</u>		
	N	2102	2102
	σ	14.7	7.9
	R-squared	.30	.29
	<u>Chi-Square Hypothesis Test</u>		
(1)	$\psi_0=0, \psi_1=-\psi_2=1$	6.6	32.6
	p-value	.086	.000
(2)	$\psi_1=-\psi_2=1$	3.2	10.9
	p-value	.20	.004
(3)	$\psi_1=-\psi_2$	3.2	3.2
	p-value	.074	.073
(4)	$\psi_2=0$	1.5	1.6
	p-value	.22	.21
(5)	$\psi_1=1$	1.7	.43
	p-value	.19	.51
(6)	$\psi_2=-1$	1.2	10.6
	p-value	.26	.001

Regressand and regressors in percent per year. Coefficients are OLS estimates; Newey-West standard errors (22 lags) from instrumental variables estimation; instrumental variables are regressors in Table 2, column (3).

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Figure 1. Expected future exchange rate and interest rate differential

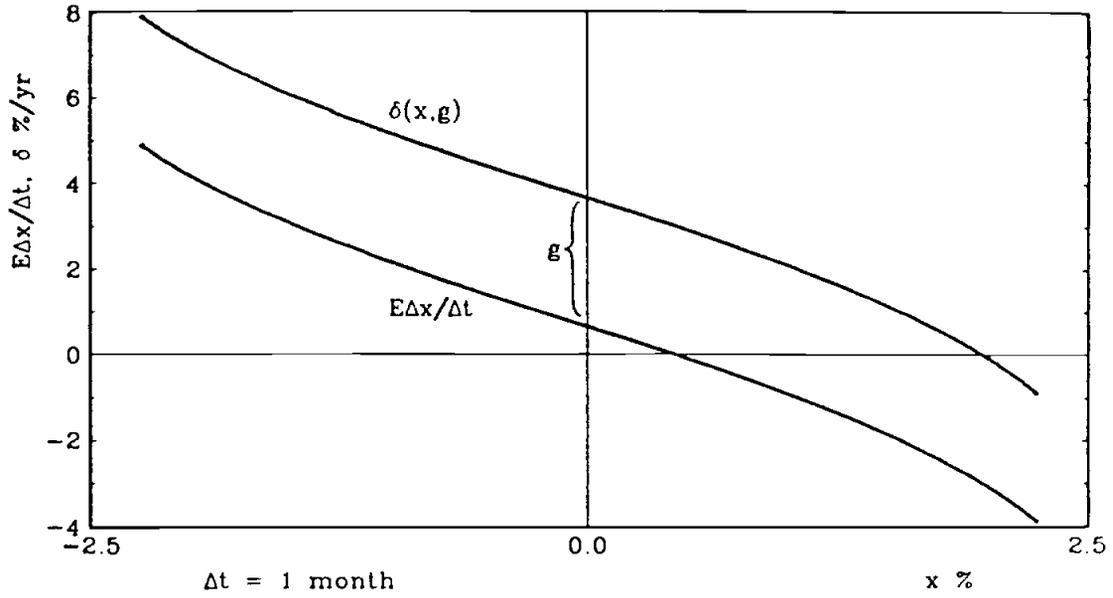


Figure 2. Expected future exchange rate

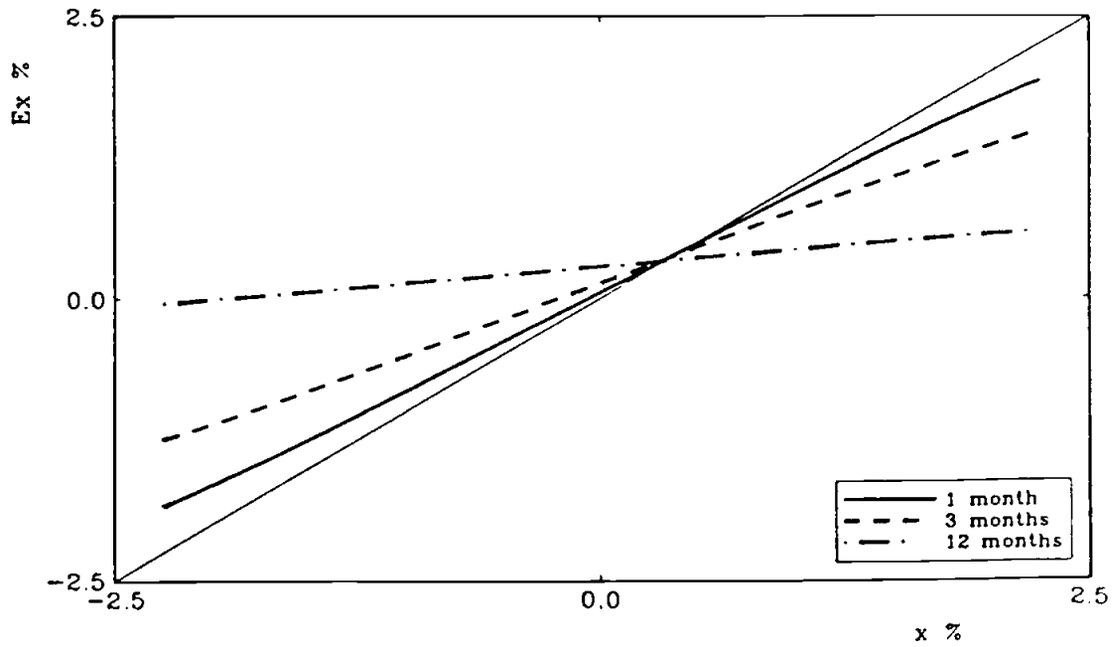


Figure 3a. Log of FF/DM exchange rate

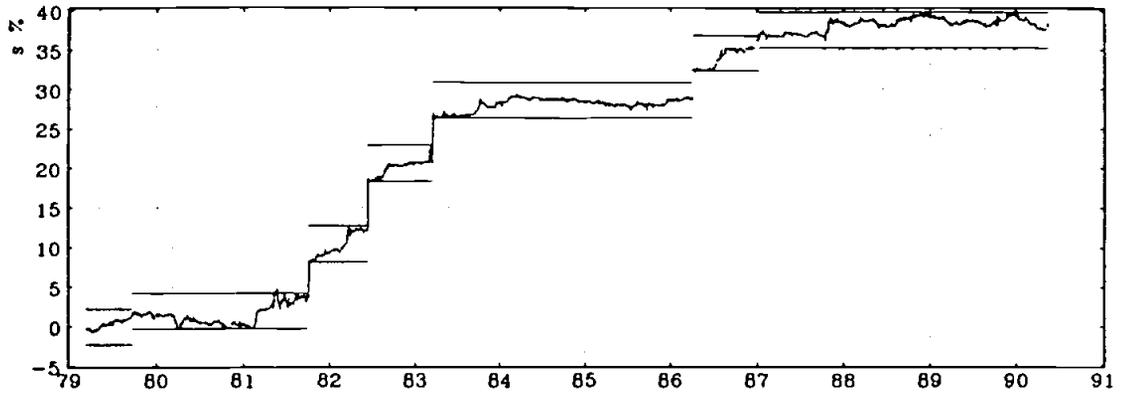


Figure 3b. One-month interest rate differential

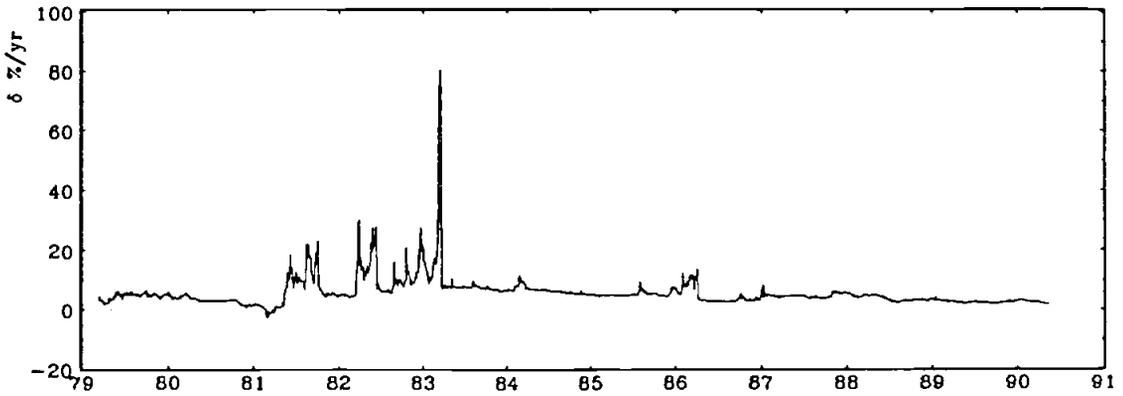


Figure 3c. Expected rate of devaluation

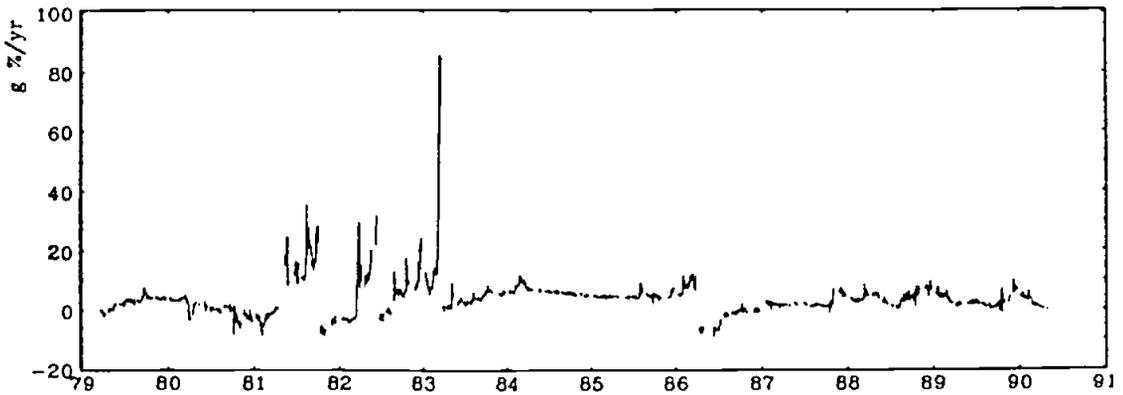


Figure 4a. Expected and actual future exchange rates

Thin line is 45-degree line
Thick curve is fitted values from cubic regression
Dots are actual future exchange rates

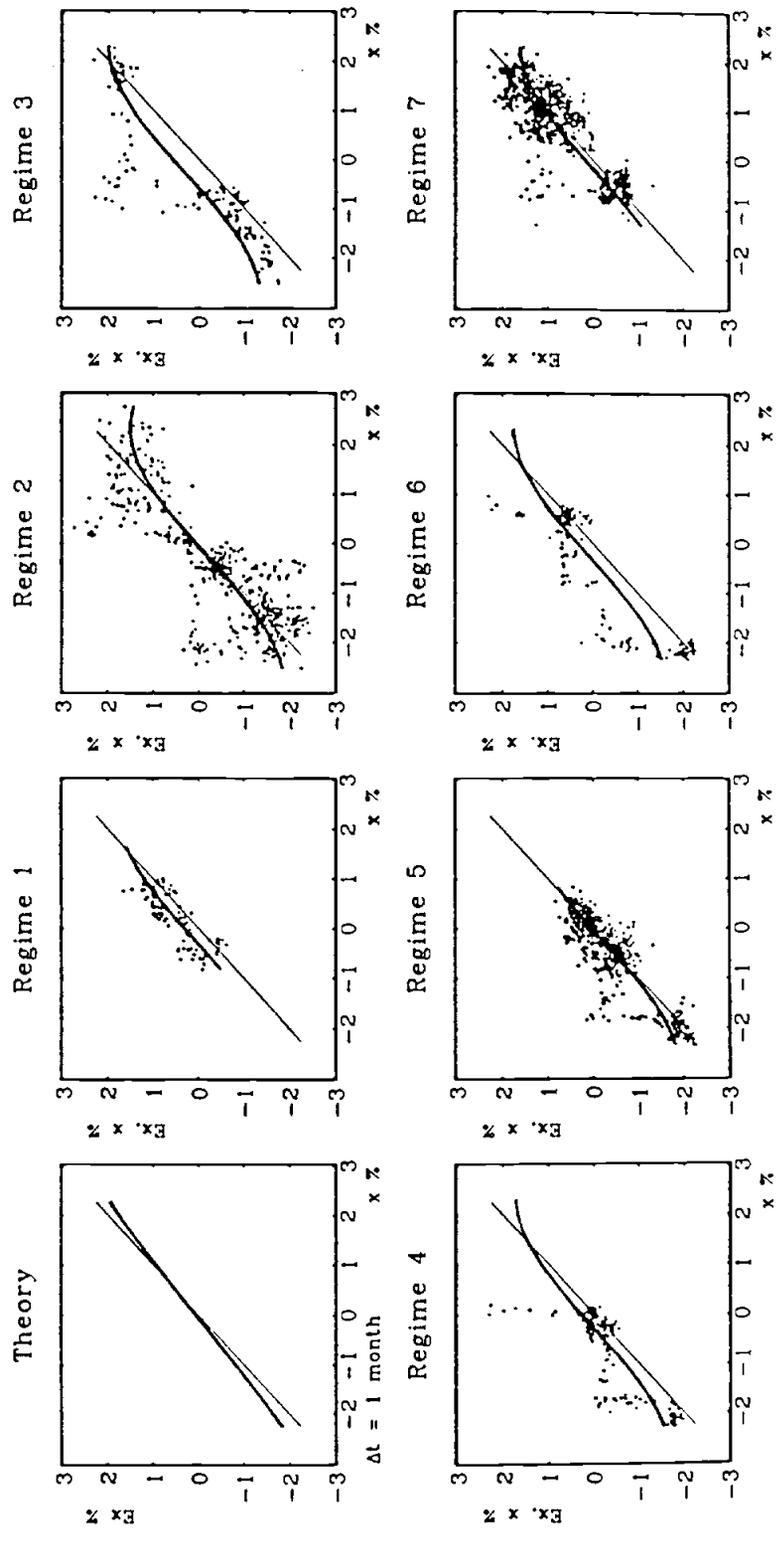


Figure 4b. Expected future exchange rates

Thin line is 45-degree line

Dots are fitted values from cubic regression with lags

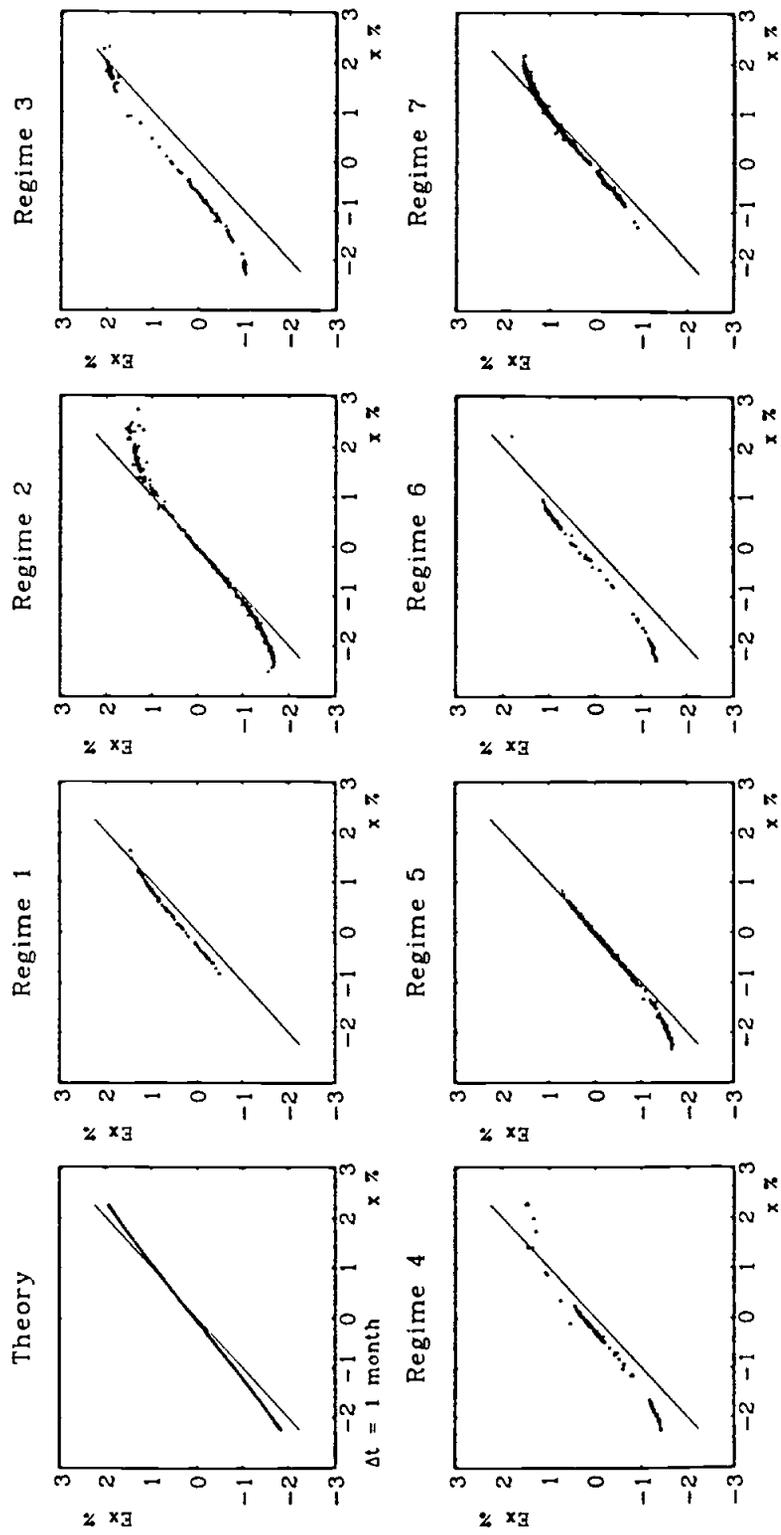


Figure 4c. Expected future exchange rates

Thin line is 45-degree line
Dots are fitted values from cubic regression with lags and other ERM exchange rates

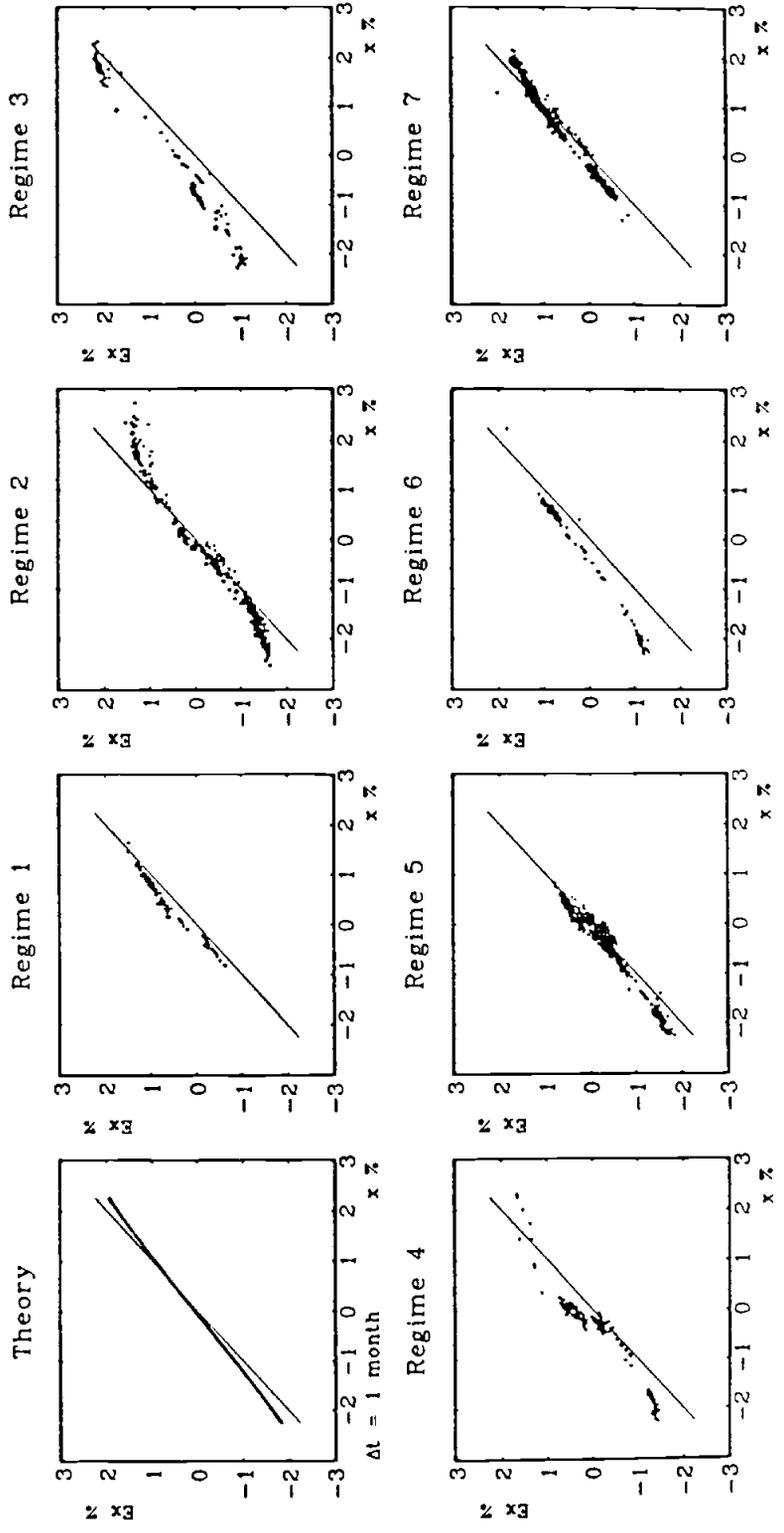


Figure 5. Expected rates of depreciation and interest rate differentials

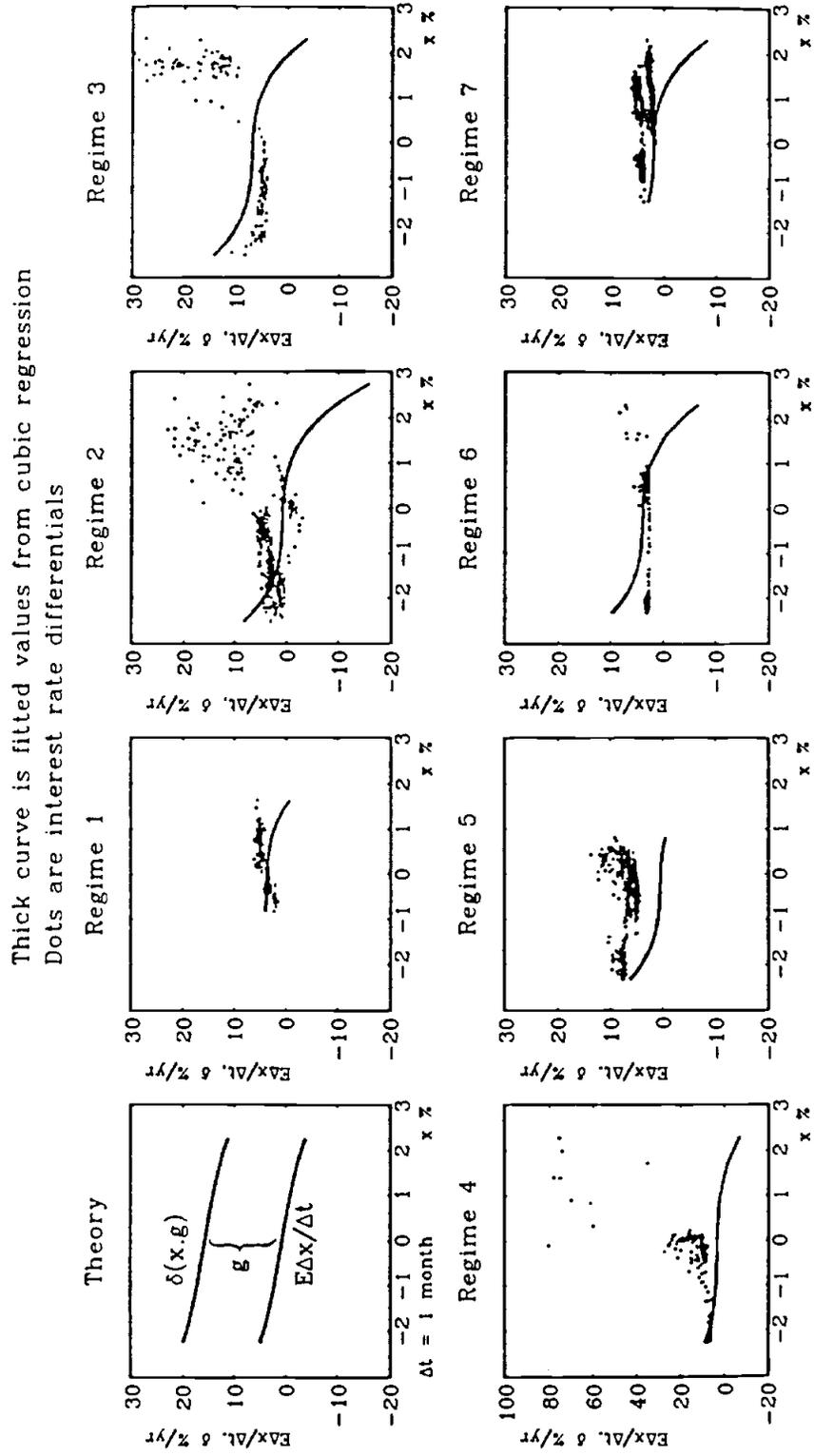


Figure 6a. Expected rate of depreciation
cubic regression

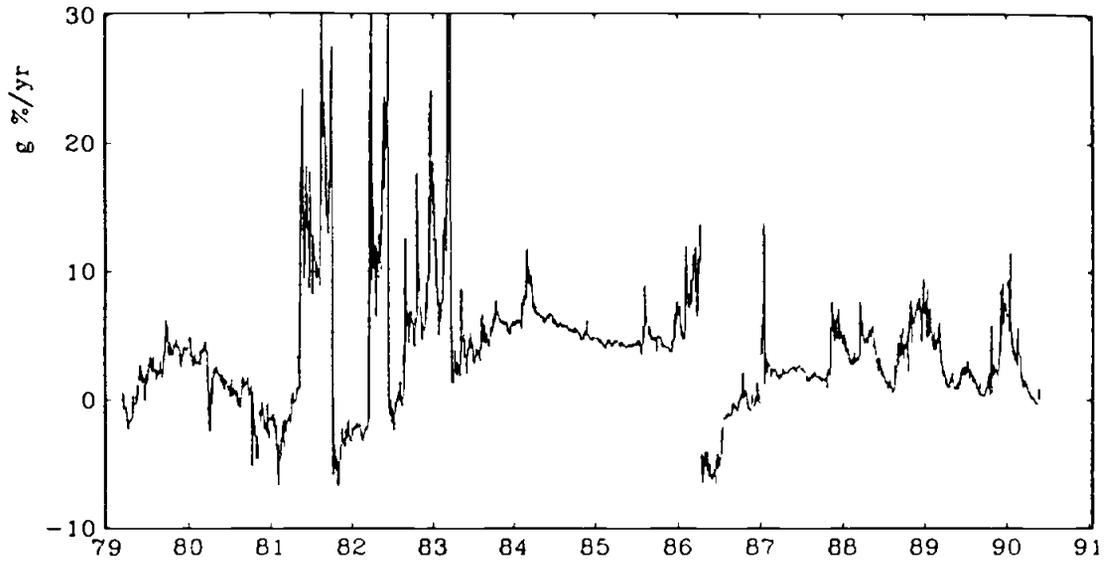


Figure 6b. Expected rate of depreciation
linear regression

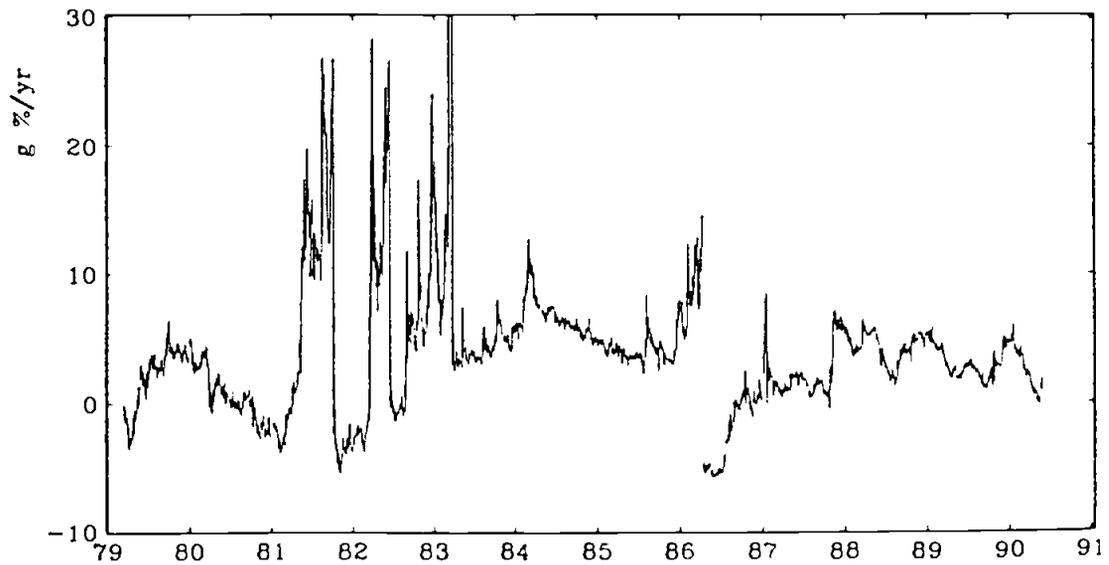


Figure 7a. The exchange rate function

$\alpha = 1$

Thick curve is x plotted against h

Dots are x plotted against $f-c$

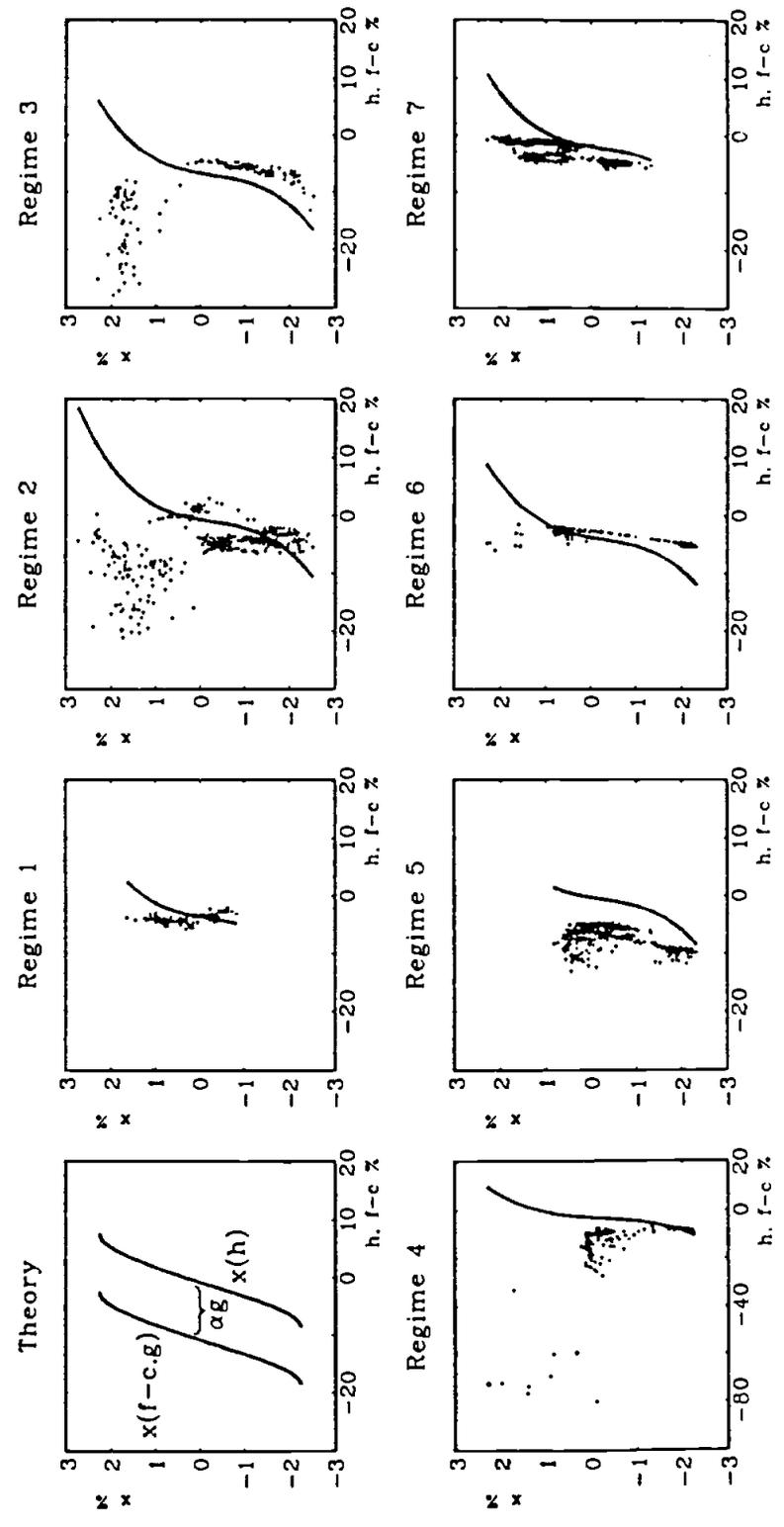


Figure 7b. The exchange rate function

$\alpha = 0.1$

Thick curve is x plotted against h

Dots are x plotted against $f-c$

