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THE EXPECTED TIMING OF EMS REALIGNMENTS: 1979-83

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ABSTRACT

This paper develops and estimates a model of the time at which market participants expected the French franc to be devalued relative to the German deutschemark during the early years of the European Monetary System. The model assumes that the expected time of exchange rate realignment is determined by the time at which foreign exchange reserves in the Banque de France first fall below a critical threshold level, and that reserves are a Brownian motion process with a drift that depends on current economic conditions. Thus, the probability distribution for the time of the next realignment is an Inverse Gaussian distribution. The empirical analysis uses the term structure of forward exchange rate premia to form indicators of perceived probabilities of realignment over various time horizons. The model fits quite well, especially prior to the March 1983 realignment. The estimation suggests that the expected timing of realignments was quite sensitive to the level of reserves in France and to factors that affect the mean rate of change of reserves.

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I. Introduction

Anticipations of future events are widely viewed as important determinants of current economic behavior. In particular, a growing theoretical literature points to the critical impact of exchange rate expectations on activities ranging from resource allocation and international trade flows to portfolio management and capital flight. Considerably less work has focused on empirically analyzing determinants of exchange rate expectations.

The French frank, German deutschemark (FF/DM) exchange rate is especially interesting for such an analysis. France and Germany both belong to the European Monetary System (EMS). In this system, exchange rates are maintained within narrow bands around a central parity grid. During the early years of operation, there were a series of relatively large realignments of these central parities. In particular, the FF/DM central parity was realigned 3 times, by more than 25% in total between 1981 and 1983. (See Figure 1.) These exchange rate jumps were widely anticipated before they actually occurred. Observers speculated about when monetary authorities would decide to realign, and given a realignment, about the size of the adjustment. In fact, some at the time described the system as a crawling peg, in which periodic adjustment were to be the norm.

This paper empirically examines expectations about the FF/DM during 1981-83, focusing on **market perceptions of the timing** of realignments. It does not analyze determinants of the timing of actual realignments, because there have been so few of them. The paper develops an explicit model of the timing of realignment that provides a flexible, but tractable, specification for the probability that realignment will occur within particular future time horizons (within 1 month, 3 months, and 6 months). This formulation is potentially useful for modeling the actual

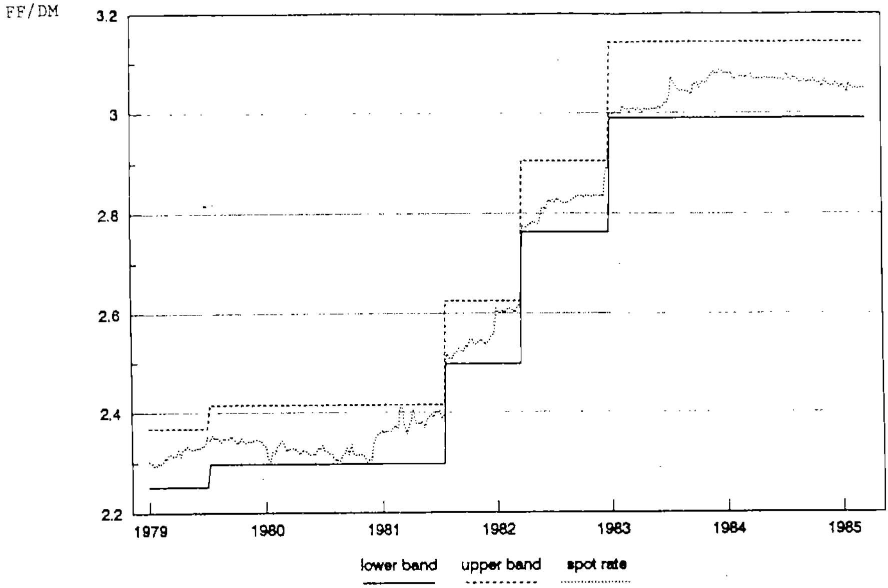

FIGURE 1

The Franc-Deutschemark Exchange Rate and Bands or expected duration of a variety of other regimes as well.

The empirical analysis uses the term structure of forward exchange rates to identify shifts in the expected timing of realignment. Weekly data on these forward rates provide considerable information about the shape of the perceived distribution of realignment dates. They suggest that there are often large shifts in the expected timing of the next realignment -- particularly in the weeks prior to an actual exchange rate adjustment. Although the possibility that the behavior of forward premia is due to time varying risk premia has not been ruled out, the risk premia interpretation seems extremely unlikely given the magnitude of the observed changes in forward premia, and the large body of not very satisfying empirical analyses of risk premia in foreign exchange markets. Reviews of this literature include Hodrick (1987) and Froot and Thaler (1990). Empirical investigations typically test how well the forward risk premia can be explained by what theory tells us should determine them, under the maintained assumption of no expected regime changes. This paper takes the opposite tack, and studies a model of expected regime change, under the maintained assumption of no time varying risk premia.

The model of the timing of realignments is quite different in spirit from most of the recent literature that interprets exchange rate bands in the EMS as target zones. Theoretical work on target zones includes Krugman (1991), as well as Bertola and Caballero (1989), and Froot and Obstfeld (1989). Much of the theoretical work explores the behavior of exchange rates, assuming the target zone is credible, and there is no perceived probability of realignment. Extensions have typically assumed that if a target zone collapses, the exchange rate goes to a free float (Flood and Garber (1989)) or, if there is a probability of a realignment to a new target zone, that this probability is exogenous (Svensson (1990)).

Attempts to empirically examine how well target zone models fit EMS data have proved mixed at best. Flood, Rose and Mathieson (1990) conclude that they have found little evidence of target zones. However, they do not incorporate probabilities of realignment. Rose and Svensson (1991) argue that allowing for a probability of realignment improves the empirical fit of target zone models to the EMS experience. However, their work essentially treats the expected devaluation as a residual (the difference between interest differentials and forecasts of exchange rate changes between realignments). Their approach also does not distinguish between the expected size of an exchange rate change and the probability. Nor does it distinguish between perceived probabilities of realignment at different future time horizons.

Instead of assuming that the probability of realignment is an exogenous stochastic process, the approach taken here is to assume that French monetary authorities will abandon the existing exchange rate band when foreign exchange reserves fall below a critical minimum level. Thus, the probability that a realignment occurs within any specified future time horizon is simply the probability that reserves first hit the critical level within that time interval. Under plausible assumptions, this first passage time distribution can be shown to have an Inverse Gaussian distribution. The paper discusses how well this approach can explain the observed shifts in the term structure of forward exchange rates.

In spirit, the approach is closer to an earlier literature on balance of payments crises. Much of this work postulated that the timing of collapse of a fixed exchange rate was determined by a country's foreign exchange reserves falling below a minimum level. There is a large body of work in this area. Theoretical contributions include Krugman (1979), Calvo (1985), Flood and Garber (1983, 1984) and Obstfeld (1986). Empirical applications include Blanco and

Garber's (1986) study of recurrent devaluations of the Mexican peso and Cumby and van Wijnbergen's (1989) analysis of the Argentinian crawling peg. While these papers estimate probabilities of a collapse, they do not attempt to estimate the expected timing of a regime change.

This paper is composed of six remaining sections. The next section provides a brief background on policy and performance in France during the early years of the EMS. Section III develops the theoretical model of realignments that is the basis for empirical analysis. Sections IV and V discuss econometric issues and data, respectively. Results are presented in Section VI and Section VII contains concluding remarks.

II. Background: France and the EMS, 1979-83

France has participated in the exchange rate mechanism (ERM) of the EMS since its inception in March 1979. At that time, French monetary authorities agreed to help maintain the FF/DM exchange rate (as well as other bilateral parities) within a narrow band of +/- 2.25% of a prespecified central parity.[1] Subject to agreement of the participants, these central parities could be realigned.[2] Thus, the exchange rate system uniquely combined elements of fixed exchange rates, that could be adjusted by authorities, and exchange rate flexibility -- within a narrow "target zone". This paper focuses on issues raised by the former.

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[1] Bilateral exchange rate bands involving the Italian lira were initially +/- 6% of their central parities. See Giavazzi and Giovannini (1990) and Ungerer et. al. (1986) for further description of the EMS experience.

[2] The theoretical section of this paper makes the simplifying assumption that the decision of when to realign is made by the monetary authorities of the country with the weak currency.

The establishment of this multiple peg exchange rate system appears not to have coincided with a commitment to policy convergence among members.[3] In particular, after an initial period during which both were restrictive, French and German macroeconomic policies began to diverge sharply in their responses to the 1979 oil price shock. In 1981, Germany remained committed to monetary and fiscal restraint. In France, however, the public had grown dissatisfied with rising unemployment and slow economic growth. Francois Mitterand was elected President in May 1981, pledging to restore growth through expansionary macroeconomic policies. He began to implement these policies in the second half of the year. 1982 saw a growing gap between the austerity in Germany and the expansion in France.

Given the climate, it is not surprising that the FF/DM was devalued sharply in October 1981, and again in June 1982 and in March 1983. These realignments are shown in Figure 1, which plots both the actual FF/DM spot rate and the upper and lower limits of the band.

The 1981-83 realignments of the franc were widely anticipated. Evidence of this comes from the behavior of forward exchange rates prior to realignments. As discussed further below, we treat k-period (eg. 3 month) forward exchange rates as indicators of the expected exchange rate k periods (3 months) in the future. Thus, the 3 month forward premium is an indicator of expected depreciation over the next three months. If the current exchange rate band were fully credible, this expected depreciation would be bounded by the deviation of the current spot rate from the upper and lower boundaries. The point is illustrated in Figure 2: the solid and dashed

[3] For further discussion of French policies in the early EMS years, see Sachs and Wyplosz (1986). Rogoff (1985) and Collins (1988) examine policy convergence among EMS members during its early years. Weber (1991) provides a more recent discussion of EMS membership and the credibility of macroeconomic policy, with extensive references.

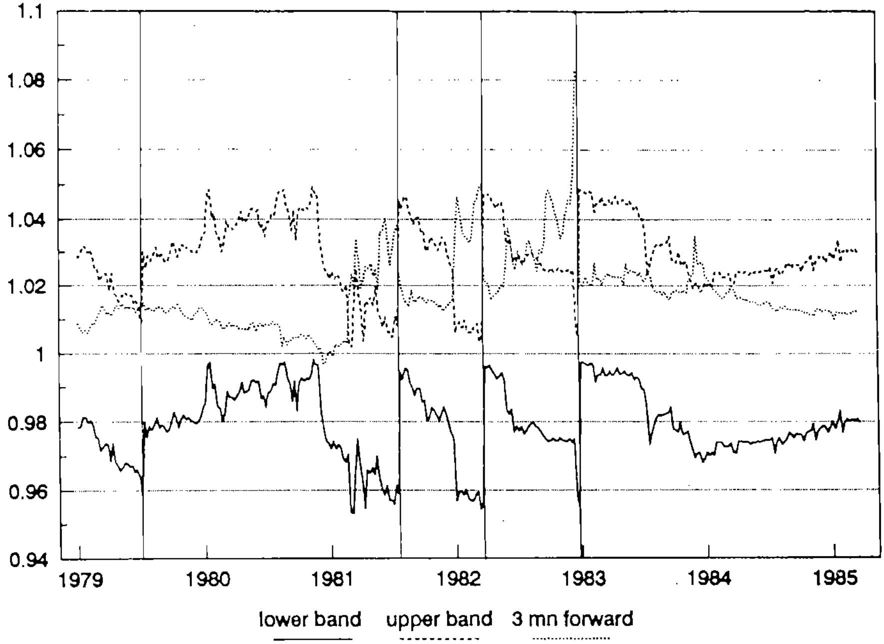

FIGURE 2

3 Month Forward Premia and Constraints from the FF/DM Exchange Rate Bands

lines plot the minimum and maximum exchange rate change consistent with the current band, and the dotted line plots the 3 month forward premium. Horizontal lines denote the dates at which the FF/DM central parity was changed. The figure shows that before each of these realignments, the FF/DM was expected to depreciate outside the current band over the next three months.

Before each realignment, the following pattern was evident. First, the longer term forward premium (eg. 6 month) rose above the upper bound, while the shorter term ones (eg. 1 and 3 month) remained below. This suggests that market participants perceived the probability of a realignment in the short run to be unlikely relative to the probability of one within a longer horizon. Then the three month premia move outside the boundary, and finally, the one month. Interestingly, in the weeks preceding a realignment, the one-month forward premium jumps above the per month three- and six-month forward premia[4], suggesting that the perceived probability of a realignment in the next month exceeds the perceived per month probability of a realignment over the next three or six months. In the body of the paper, these shifts in the term structure of forward exchange rates are used to provide information about shifts in the expected timing of realignment.

As shown in Figure 3, each of the 1981-83 realignments was preceded by an outflow of net foreign exchange reserves from the French Central Bank. (These data are discussed in Section V.) The pattern suggests that expectations of the timing of realignments may be well explained by the critical reserve level model developed in the next section.

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[4] The per month forward premia is defined as $[(F_{t,k}-S_t)/S_t]^{1/k}$.

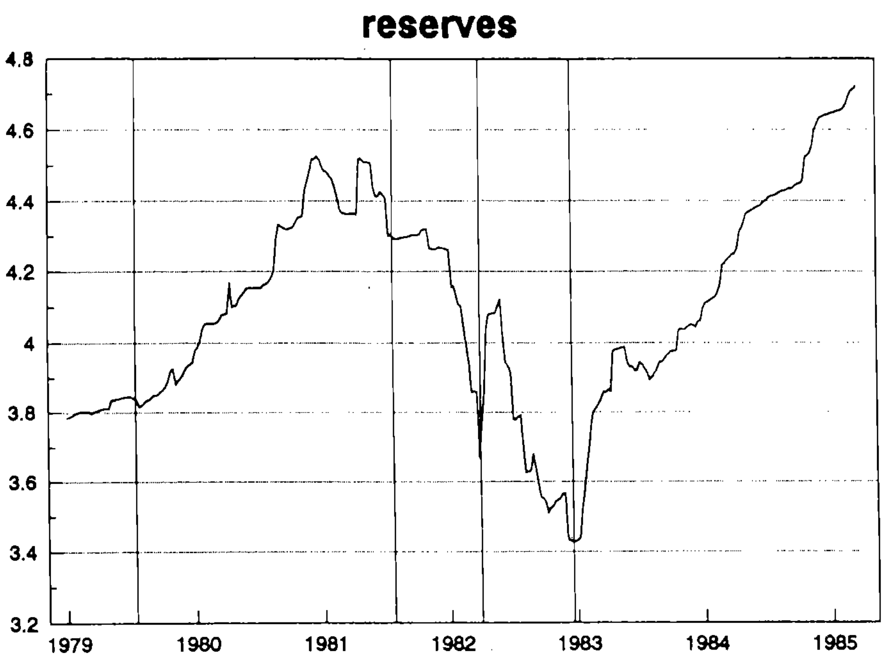

FIGURE 3

Net Foreign Exchange Reserves of the Banque de France

Unlike the two previous cases, the March 1983 realignment was accompanied by a switch to restrictive policies. The emphasis of federal policy shifted from maintaining employment to achieving profitability and enhancing competitiveness. Part of the explanation for this policy reversal appears to have been the results of French mid-term elections, held two weeks before the 1983 realignment. The poor showing of Mitterand's Democratic Socialist party appears to have been interpreted as a lack of public support for the policies implemented since 1981.

Macroeconomic policy and performance have converged considerably since 1983, both between France and Germany and among EMS members more generally. Since then, realignments have been relatively infrequent, and members are now taking steps toward further monetary integration.

III. A Critical Reserves Model of Realignment

This section develops the theoretical specification for the empirical analysis in Section V. Assume that at time t, there is a specified band for the FF/DM. Market participants believe that, at time t+k, either the FF/DM will be maintained inside the same exchange rate band, or inside a new exchange rate band that was established between t and t+k.[5]

As shown in equation (1), the unconditional expectation at time t of the exchange rate at time t+k, ${}_tS_{t+k}$, can be decomposed into three parts.

[5] There is assumed to be a zero probability of more than one realignment, or of a switch to a different exchange rate system -- such as a flexible rate. In fact, the longest time horizon considered in the empirical work is six months, and there was never more than one realignment of the FF/DM central parity in a six month period.

$$
\begin{aligned}
{}_tS_{t+k} &= {}_tS^N_{t+k} \cdot (1 - {}_tP_{t+k}) + {}_tS^R_{t+k} \cdot {}_tP_{t+k} \\
&= {}_tS^N_{t+k} + {}_tP_{t+k} \cdot ({}_tS^R_{t+k} - {}_tS^N_{t+k})
\end{aligned}
\tag{1}
$$

Two of these components are the exchange rate expected at time t+k conditional on no realignment, ${}_tS^N_{t+k}$, and the expected size of realignment -- ie. the expected increment to the level of the exchange rate if there is a realignment between t and t+k -- (${}_tS^R_{t+k}$ - ${}_tS^N_{t+k}$), where ${}_tS^R_{t+k}$ is the exchange rate expected at time t+k conditional on a realignment.

The third component is ${}_tP_{t+k}$, the perceived probability of a realignment between t and t+k, also conditional on information available at time t. As k varies, this traces out the perceived timing of a realignment. It is convenient here to think in terms of a probability density function at each time t that describes the perceived realignment probabilities at each future time t+k, k>0. The probability density may be skewed towards the present if the market perceives a realignment to be imminent, or skewed away from the present if the market expects the current exchange rate band to last for a long time. The determinants of the shape of the density of realignment probabilities is the focus of the empirical analysis.

The remainder of this section first specifies exchange rate expectations, conditional on whether or not realignment occurs, and then develops a model of the probability of realignment. Assumptions about these conditional exchange rate expectations are kept simple so as to focus attention on the expected timing.

III.1 Exchange Rate Expectations

To operationalize (1), the following assumptions are made:

$$f_{t,k} \equiv \frac{F_{t,k} - S_t}{S_t} = \frac{{}_tS_{t,k} - S_t}{S_t} + \alpha_k + \nu_{t,k} \tag{2}$$

where $F_{t,k}$ is the t+k FF/DM forward exchange rate as of time t.

$$ {}_tS^N_{t+k} = S_t \tag{3}$$

$$\frac{{}_tS^R_{t+k} - S_t}{S_t} = \theta \tag{4}$$

Equation (2) says that the k period ahead forward premium, $f_{t,k}$, differs from the expected depreciation between time t and time t+k by a constant term, α_k, and by a random error term that is assumed to be white noise. (In the empirical work, the errors are allowed to be contemporaneously correlated across time horizons.) This implies that if risk premia exist, they are either constant for each time horizon k, or are independent of information available at time t.[6]

Equation (3) says that the exchange rate expected, conditional on no realignment between time t and t+k is S_t for all time horizons. This is clearly a simplifying assumption. It rules out the possibility that exchange rates are expected to move toward central parities between realignments, and the possibility that the expected position of the exchange rate inside the band

[6] An interesting area for future work would be to extend this analysis to allow for time varying risk premia. However, this may prove very difficult to estimate.

is correlated with the perceived probability of realignment. The assumption is made to keep the equations to be estimated tractable.

Finally, equation (4) says that the expected size of a realignment is θ. This θ is assumed to be a constant during each exchange rate regime. In other words, during October 1981 to June 1982, there is one expected size of realignment, say θ_A. There is another, θ_B, during the next period, June 1982 to March 1983, which may be different. The equation also implies that the same θ is relevant for all horizons, k. As above, a simplified view of exchange rate behavior between realignments has been adopted here to keep the specification tractable. Further, in the actual estimations, the market is assumed to have known the size of each of these three realignment. Thus, θ is treated as data at each point in time.

Using assumptions (2), (3) and (4), equation (1) can be rewritten as:

$$f_{t,k} = \alpha_k + \theta \cdot {}_tP_{t+k} + \nu_{t,k} \tag{5}$$

Note that, (5) is a system of equations -- one for each time horizon, k. The next step is to specify the realignment probabilities.

III.2 Realignment Probabilities

French authorities will continue to defend the current exchange rate band as long as foreign exchange reserves exceed a critical level, R^c. (This critical level will be treated as a parameter, and estimated in the empirical analysis.) As soon as reserves fall below R^c, the FF/DM central parity will be realigned. Therefore, market perceptions of the probability of realignment during [t,t+k] are given by the perceived probability that reserves first hit the critical level during this interval -- the first passage time probability.

There are three steps to determining the perceived timing of realignment. First, the stochastic process for reserves will be specified. Second, the first passage time distribution for this process will be discussed. Third, the reserve drift will be specified as a function of economic conditions. These pieces will then be put together to specify the expected timing of realignment.

A. <u>A Stochastic Process for Reserves</u>

At each time t, the (log of the) reserve stock is believed to be a stochastic process, $R_t(k)$, $k \geq 0$. The process has an initial level, $R_t(k=0) \equiv R_t$, and a constant mean rate of change, δ_t. This drift may depend on current economic conditions, as discussed below.[7] Reserves deviate from trend as a result of frequent positive and negative shocks -- which could be interpreted as shocks to money supply and/or to money demand. Thus, the process for reserves has the following three properties:

1. ${}_t[R_t(k_2) - R_t(k_1)] = (k_2 - k_1) \cdot \delta_t, \;\; k_i \geq 0, \; i = 1,2.$

   The expected reserve inflow (outflow) in any future time interval is proportional to the length of the interval.

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[7] A more general formulation would allow the expectation at time t of the drift of reserves $\delta_t(s)$, $t < s < t+k$, to vary over the time interval [t, t+k] as a function of information available at time t. Future work will consider the distribution of first passage times for a Brownian motion process with a variable drift in this context. Note that one interpretation of the constant expected drift assumption is that market participants have static expectations about the future values of variables which influence δ_t.

2. If $[t+k_1, t+k_2]$ and $[t+k_3, t+k_4]$, $k_i \geq 0$, $i = 1,2,3,4$ are non-overlapping intervals, then $[R_t(k_2) - R_t(k_1)]$ and $[R_t(k_4) - R_t(k_3)]$ are statistically independent. This implies that, given R_t, forecasts of future reserve stocks can not be improved by information about reserves before time t.

3. $R_t(k_2) - R_t(k_1)$ is normally distributed with variance $\sigma^2(k_2-k_1)$ for any interval $0 \leq k_1 \leq k_2$. Its mean is given in 1.

These assumptions define $R_t(k)$ as a Brownian motion process with drift. Since $R_t(k)$ can not pass through R^c without a regime change (a realignment of the exchange rate bands), R^c can be thought of as an absorbing barrier.

Figure 4 illustrates two possible paths for reserves, beginning with an initial stock of $R_t > R^c$ at time t. In case A, $\delta_t < 0$. On average, reserves are being depleted and the reserve stock trends towards the critical level. One would expect to find this situation in the weeks prior to an anticipated realignment. In case B, $\delta_t > 0$. On average, reserves are being accumulated and the reserve stock is drifting away from R^c. One might expect this situation immediately following a devaluation, or during periods of currency undervaluation.

B. First Passage Times and Realignment Probabilities

The probability of realignment between time t and time t+k is the probability that reserves first hit R^c during [t, t+k], given $R_t > R^c$.

Define: τ_t as the remaining duration, as of time t, of the existing central parity. (Then $t + \tau_t$ is the time at which reserves first pass through R^c.) and

FIGURE 4

INTERNATIONAL RESERVES:
POSSIBLE PATHS

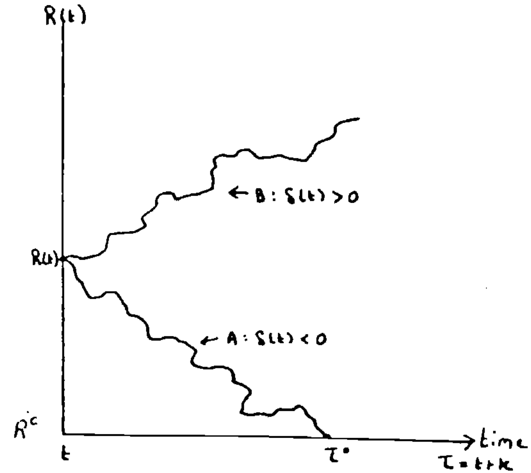
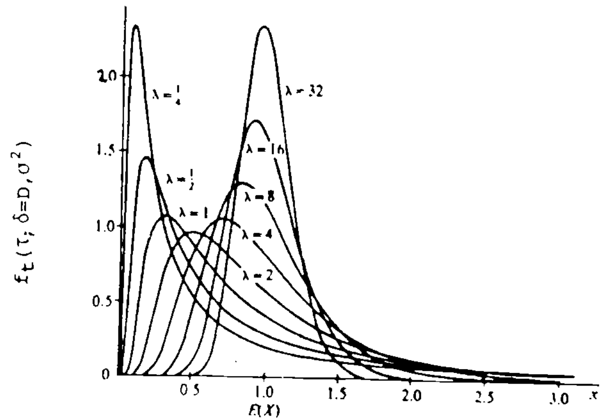


FIGURE 5

INVERSE GAUSSIAN DENSITY FUNCTIONS
$[E(x) = \mu = 1]$
$\lambda \equiv D\delta/\sigma^2$
Source: Johnson and Kotz (1970), p. 142.



$D_t \equiv R_t - R^c$ as the amount reserves must be depleted for the exchange rate to collapse, or the distance to the barrier.

Then at time t, the probability that reserves will have hit R^c by time t+k is:

$$G_t(k;D_t,\delta_t,\sigma) = Prob(\tau_t \leq k;D_t,\delta_t,\sigma) \tag{6}$$

This probability distribution function, $G_t(k;\cdot)$, depends on three factors: the distance between the starting level of reserves and the critical level and on the mean rate of change and the variance of the reserve process. (For the remainder of the discussion, R_t, D_t, τ_t and δ_t will be written as R, D, τ and δ, except where it is confusing to do so.)

It can be shown that this first passage time has an Inverse Gaussian distribution, given by equation (7).[8]

$$G(k;D,\delta,\sigma) = \Phi\left(\frac{-k\cdot\delta - D}{\sigma\sqrt{k}}\right) + \exp\left(\frac{-2\cdot\delta\cdot D}{\sigma^2}\right)\cdot\Phi\left(\frac{k\cdot\delta - D}{\sigma\sqrt{k}}\right) \tag{7}$$

where Φ is the cumulative distribution function for a standard normal variate.

The first term in equation (7) is the probability that the amount of reserve depletion between t and t+k is at least D. In other words, it is the probability that reserves are less than R^c at time

[8] See Cox and Miller (1965), Johnston and Kotz (1970) and Chhikara and Folks (1978) for discussions of properties and applications of Inverse Gaussian distributions. These distributions have been used in a variety of applications, but have appeared infrequently in the economics literature. Exceptions are Lancaster's (1972) study of strike durations, Whitmore's (1978) study of labor turnover, Hausman and Wise (1983) retirement study and Lo's (1985) analysis of asset pricing. All of the empirical applications of which I am aware use the distribution to fit data on completed spells.

t+k. However, this probability is less than the first passage probability because it does not include the possibility that reserves have crossed back and forth over the barrier R^c during that time period. The additional terms adjust for the fact that, with an absorbing barrier, the process for reserves is no longer normally distributed, but has a "sink" at R^c.

When reserves are drifting towards R^c (when $\delta < 0$), it can be shown that τ is finite with probability one. However, when reserves are drifting away from R^c, (when $\delta > 0$), the probability that reserves never hit R^c is:

$$Prob(\tau = \infty) = 1 - \exp\left(\frac{-2\cdot\delta\cdot D}{\sigma^2}\right) \quad ; \delta > 0 \tag{8}$$

The expectation and variance of the first passage time, given $\delta < 0$, are shown in (9). $E(\tau)$ can be interpreted as the expected remaining duration of the current exchange regime. (For $\delta > 0$, this expectation is infinite.)

$$E(\tau) = \frac{-D}{\delta} \quad , \quad Var(\tau) = \frac{-D\sigma^2}{\delta^3} \quad ; \delta < 0 \tag{9}$$

The probability density function for first passage times, $g(k;\cdot)$, corresponding to (7) is given in equation (10).

$$g(k;D,\delta,\sigma) = \frac{D}{\sigma\sqrt{2\pi k^3}} \cdot \exp\left(-\frac{(k\cdot\delta + D)^2}{2\sigma\sqrt{k}}\right) \tag{10}$$

The Inverse Gaussian distribution has attractive properties for duration studies. Its density is unimodal, and its shape depends on $x \equiv |\delta| D/\sigma^2$. To illustrate the various possible shapes, Figure 5 shows the standardized distribution ($|\delta| = D$) as x varies. Suppose $\sigma^2 = 1$. Then the figure shows that for large values of x (such as $x=34$; $\delta = D \approx 5.6$), the density resembles a normal density with a peak of about $D=-\delta=1$. In the present application, this would correspond to perceived probabilities of realignment concentrated in the medium term, with small probabilities of realignment in the near and very distant future. As x declines (the distance between R_t and R^c declines) the density becomes more skewed towards the near future. This reflects the fact that the importance of the random component of the reserve process (σ) increases relative to the importance of the relationship between the drift (δ) and the distance to the barrier (D). For $x < 1$, the density looks more like the density of an exponentially distributed variable.

More generally, given the variance of shocks, σ^2, and the distance to the absorbing barrier, D, an increase in the average rate of depletion (a larger negative δ) has two effects. First, it reduces the expected time to the exchange rate collapse, moving the mean closer to the present. Second, it increases x, concentrating the density function around this mean.

C. The Drift of Reserves

A key parameter in determining the expected timing of realignment is δ_t, the average per period change in reserves. The simplest specification for the drift is simply to assume that it is a constant. This possibility will be considered first in the empirical section. However, the actual behavior of reserves suggests that this is likely to be a poor assumption (see Figure 3).

A constant drift also provides little flexibility for capturing shifts in the density of first passage times discussed above.

In a managed exchange rate system, foreign exchange reserves are endogenous. The change in reserves is the counterpart to the gap between the change in money demand and domestic credit expansion. Given money demand, an increase in domestic credit will lead to a one-for-one outflow of reserves. However, money demand is unlikely to remain unchanged. Especially if market participants are worried about devaluation, a domestic credit expansion may contribute to a decline in money demand (rising domestic interest rates, and a decreased willingness to hold domestic currency). Thus, the offset coefficients can easily exceed one. The existence of capital controls may limit the outflow of reserves, but in practice, rarely eliminates capital flight.[9]

The above discussion suggests that relevant determinants of reserve drift are determinants of money demand (and supply[10]). This paper assumes that demand for domestic currency depends on two factors: domestic interest rates and the position of the exchange rate. (Changes in income are unlikely to matter much on a week to week basis.) First, as domestic interest rates increase, market participants should expect the rate of reserve depletion to accelerate. However, because of capital controls, on shore interest rates may overstate the true willingness of domestic residents to hold domestic currency. Thus, the percentage deviation of the exchange

[9] France maintained restrictions on private capital outflow in the early 1980s. Differentials between on and off-shore interest rates preceding realignments suggests that these restrictions were partially effective. However, it is clear from Figure 3 that they were unable to eliminate periods of very rapid reserve depletion.

[10] The empirical analysis considered indicators of (lagged) domestic credit expansion. However, these are extremely noisy, and proved to have little explanatory power.

rate from the current central parity is also included. A more depreciated exchange rate provides evidence of a decreased net demand for French francs, and should be associated with an increased expected reserve outflow.

Thus, the assumed specification for reserve drift, as of time t, is:

$$\delta_t = \delta_0 + \delta_1 i_t + \delta_2 z_t \tag{11}$$

where i_t is the French domestic (on shore) interest rate.
z_t is the % deviation of the spot rate its central parity.

Both δ_1 and δ_2 are expected to be negative. δ_t is expected to be negative shortly before realignments, but may be positive or negative at other times.

IV. Econometric Issues

Pulling together the pieces from Section III gives the following system of equations:

$$\begin{aligned} f_{t,k} &= \alpha_k + \theta_t \cdot \left[\Phi\left(\frac{-k\cdot\delta_t - D_t}{\sigma\sqrt{k}}\right) + \exp\left(\frac{-2\cdot\delta_t \cdot D_t}{\sigma^2}\right) \cdot \Phi\left(\frac{k\cdot\delta_t - D_t}{\sigma\sqrt{k}}\right)\right] + \nu_{t,k} \quad ; k=1,3,6 \\ \delta_t &= \delta_0 + \delta_1 i_t + \delta_2 z_t \\ D_t &= R_t - R^c \end{aligned} \tag{12}$$

This specification focuses on the expected timing of realignment. The empirical estimation focuses on the timing as well, by using data on three time horizons: 1, 3 and 6 months for each time t. The three equations are then estimated jointly using nonlinear least squares so as to constrain the parameters of the function that determines probabilities to be the same across equations.

Two additional changes were made to focus explicitly on timing. First, in (12), probabilities are multiplied by the expected realignment size. As discussed below, this is at most 11%. To scale up the importance of changes in probabilities in explaining the dependent variable, both sides were divided through by θ. Since the actual (and by assumption, the expected) magnitudes of realignment differed across sub-periods, this introduced heteroskedasticity to the new error terms. All of the estimates reported below correct for heteroskedasticity using the White procedure.

Second, (12) specifies the probabilities in terms of the distribution function, $G_t(k;\cdot)$, not in terms of the density function, $g_t(k;\cdot)$. However, the appeal of the Inverse Gaussian is precisely that it allows for such a wide range of shapes for the density. This variety implies much less pronounced variety in the shapes of the distribution function. Therefore, the estimation focuses on incremental exchange rate expectations: at one month, between one and three months and between three and 6 months).

$$
\begin{aligned}
y_{t,1} &\equiv \frac{f_{t,1}}{\theta_t} = \frac{\beta_1}{\theta_t} + {}_tP_{t+1} + \xi_{t,1} \\
y_{t,3} &\equiv \frac{(f_{t,3}-f_{t,1})}{\theta_t} = \frac{\beta_3}{\theta_t} + ({}_tP_{t+3} - {}_tP_{t+1}) + \xi_{t,3} \qquad (13) \\
y_{t,6} &\equiv \frac{(f_{t,6}-f_{t,3})}{\theta_t} = \frac{\beta_6}{\theta_t} + ({}_tP_{t+6} - {}_tP_{t+3}) + \xi_{t,6}
\end{aligned}
$$

Defining ${}_tP_{t+k}$ as above, these changes result in the three equation system (13). For a given value of σ, this system converged quite easily. Thus, a grid search was carried out over values of σ so as to find good starting values for the full estimation.

There are eight parameters to be estimated. Each of the three equations has a separate constant term. The critical reserve level R^c is treated as a parameter and estimated. In addition, there are up to four parameters from the (perceived) behavior of reserves: parameters that determine the drift as of time t, and the variance of random shocks.

V. Data

Equation (13) is estimated using weekly data from April 1981 to March 1983. Weekly data are used because key series, such as reserves, are unavailable at higher frequencies. However, monthly data are too infrequent to capture the large changes in exchange rate expectations that occur just before realignment.

This is the most interesting time period to study expected realignments of the FF/DM. The previous two EMS realignments did not change the FF/DM central parity, so that the relevant θ is zero from November 1979 to March 1981. Similarly, the next realignment, in June 1985, did not involve the FF/DM.[11] There was also a realignment on February 22, 1982 that did not adjust the FF/DM central parity. The period October 5, 1981 to February 22, 1982 is therefore excluded from the sample. Also excluded are the two weeks following each realignment. Thus, there are a total of 81 weeks in the sample period. Given three time horizons, there are a total of 243 observations.

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[11] On November 30, 1979, the Danish krone was devalued vis a vis other ERM participants. On March 23, 1981 and again on July 22, 1985, the Italian lira was devalued.

The values of θ are the actual changes in the FF/DM central parities in the next realignment: 8.74% before the October 1981 realignment, 10.62% before the June 1982 realignment and 8.19% before the March 1983 realignment.[12]

Data on net foreign exchange reserves were constructed from weekly data on money stocks published by the French central bank. The series is meant to measure the value of net foreign assets realistically available for defense of the franc. Thus, it excludes gold holdings, but includes the country's net position in the European Monetary Cooperation Fund (EMCF) that provides a short term borrowing facility for EMS members to maintain their currencies within the requisite bands.[13]

Weekly data (Thursdays) on spot and forward exchange rates are used to construct $y_{t,k}$ and z_t.[14] Domestic interest rates, i_t are one month deposit rates. Since both z_t and i_t are potentially endogenous, lagged values are used in the estimation. Table 1 shows the means, standard deviations and ranges of key variables.

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[12] These figures are the actual percentage adjustment of the FF/DM central parities. More typically quoted has been the percentage changes of bilateral central rates against the group of currencies whose bilateral parities remained unchanged. For example, using this definition, the FF was devalued by 5.75% in March 1983, while the DM was revalued by 4.25%.

[13] Net foreign exchange reserves of the Banque de France were constructed from data in Banque de France, Bulletin Trimestriel, Table 38, "Situation Hebdomadaire de la Banque de France" various issues.

The series was constructed as follows: Foreign assets (line 1) - Gold (1.25* line 1.1) + net position in the EMCF (line 4 - [liabilities] line 5). Lines 1, 1.1 and 4 come from the asset portion of the central bank balance sheet, and line 5 from the liabilities side. Note that Foreign assets (line 1) include gold, ECUs, foreign currency and other reserves. ECUs are held on a 3 month swap basis, and are updated to represent 20% of gold and foreign currency holdings. Thus, the gold component of ECUs is subtracted off to construct net reserves.

[14] Spot and forward exchange rate data are the average of bid and offer rates, quoted at 8:30 AM in New York on Thursdays.

Table 1

Description of Variables

	Mean	Standard Deviation	Minimum	Maximum
R_t	4.02	0.37	3.42	4.52
$f_{t,1}$	1.19	1.09	-0.13	7.24
$f_{t,3}$	3.04	1.49	-0.08	8.28
$f_{t,6}$	5.47	2.26	0.21	11.82
i_t	21.23	9.39	11.13	84.00
z_t	0.39	1.13	-2.15	2.25

(See text for definitions of variables and sources of data.)

VI. Empirical Results

Table 2 reports estimation results. The first column shows the results when the drift of reserves is assumed to be constant $\delta_t = \delta_0$. This specification fits surprisingly well. (The value of the log likelihood and of the adjusted R^2 for each equation are reported at the bottom of the table.) The estimates suggest that the critical minimum level of reserves is only slightly above the level that reserves fell to in March 1983 (see Figure 3). The drift is estimated to be positive (about 1% per month) but is not estimated very precisely. The standard deviation of reserve changes, σ, is nearly nine times this mean rate of change.

What about the implied probabilities of realignment? Although the probabilities do increase slightly over time, these estimates with constant drift imply essentially zero perceived probability of realignment (even over a six month horizon) before the October 1981 adjustment. In the second period, perceived probabilities are tiny until the week before the June 22 1982 realignment, at which time the 3 month and the 6 month probabilities rise to 3% and 11% respectively. In Period 3 (before the March 1983 realignment) perceived probabilities are also tiny initially. They rise to about 2%, 20% and 30% for 1, 3 and 6 month horizons in November 1982, and jump to about 34%, 55% and 65% for 1, 3 and 6 month horizons in the five weeks before realignment. These jumps correspond to a sharp drop in the level of reserves.

There are two reasons why these estimates might suggest that market participants did not anticipate the 1981 and 1982 realignments. First, constraining the drift to be constant means that only changes in the level of reserves can influence perceived probabilities. (See equation (7)). To remedy this, the drift is allowed to change, following equation (11). Second, parameters are assumed to be the same across sample periods. In particular, the market participants are

Table 2

Estimation Results

	1	2	3	4
R^c	3.340	3.328	-16.801	1.393
	(0.048)	(0.053)	(11.890)	(0.484)
δ_0	0.010	0.087	-2.621	1.589
	(0.008)	(0.022)	(1.411)	(0.424)
δ_1	-	-0.004	-0.051	-0.065
		(0.001)	(0.032)	(0.010)
δ_2	-	0.039	-0.108	-0.382
		(0.005)	(0.108)	(0.084)
σ	0.097	0.102	4.962	--*
	(0.017)	(0.021)	(2.986)	
β_1	0.966	0.888	1.038	-0.328
	(0.062)	(0.070)	(0.101)	(0.389)
β_3	1.486	1.449	-0.270	0.840
	(0.091)	(0.089)	(0.120)	(0.249)
β_6	2.133	2.058	-2.645	2.490
	(0.135)	(0.138)	(0.447)	(0.240)
$\ln(\mathcal{L})$	-846.664	-836.096	-379.031	-347.883
adj. R^2:				
eq. 1	0.438	0.628	0.031	0.632
eq. 3	0.341	0.333	0.715	0.487
eq. 6	0.526	0.520	0.668	0.513
# weeks	81	81	44	37
# obs.	243	243	132	111

Notes:
Standard errors (in parentheses) are adjusted for heteroskedasticity (White).
The first two columns show estimates using the entire sample:

Period 1 -- April 1981 to October 1981.
Period 2 -- March 1982 to June 1982.
Period 3 -- July 1982 to March 1983.

The third column uses only Periods 1 and 2, while fourth uses only Period 3.

* In column 4, σ is fixed at 2.0. (see text)

assumed to have had the same beliefs about the critical reserve level and about the behavior of reserves in Period 3 as in Periods 1 and 2. However, in Period 3, the issues of exchange rate management, and realignment were considerably more acute, and the subject of active public debate.

Estimates with a varying drift for the entire sample are reported in the second column of Table 2. The new parameter estimates are statistically significant. The fit of equation 1 (explaining one month forward premia) improved markedly, while the fits for longer horizons become marginally poorer. However, the actual estimates change surprisingly little. The estimates for R^c and σ are virtually unchanged. The mean of $\delta_t = \delta_0 + \delta_1 i_t + \delta_2 z_t$ is 0.02 over the entire sample. It ranges from -0.18 to 0.10. As expected, increased domestic interest rates increase the rate of anticipated reserve depletion. However, depreciation within the exchange rate band seems to be associated with increased anticipated reserve accumulation. These estimates still imply very small perceived probabilities of realignment for Periods 1 and 2. In fact, the maximum 6 month probability in Period 2 is now just 2%. But perceived realignment probabilities in Period 3 are greater than before. They rise to 87% for 1 month, and to just under 100% for 3 and 6 month horizons in mid March 1983.

The remaining columns in Table 2 report estimates for separate sub-samples. Column 3 shows estimates for Periods 1 and 2 combined. (Period 2 is too short to estimate separately.) The results are strikingly different from those in column 2. However, many of the key parameters are estimated imprecisely and the fit for equation 1 (one month horizon) is extremely poor. These results suggest that the critical reserve level was perceived to be far below actual reserve levels.[15] None of the estimates of parameters that determine drift are statistically different from zero, and the estimated standard deviation of reserves is very large.

The estimates in column 3 paint a very different picture of perceived realignment probabilities for Periods 1 and 2 than did the estimates in columns 1 and 2. Here, perceived probabilities of realignment are consistently tiny (less than .1%) over a one month horizon, but range from 12 to 25% over a three month horizon and from 50 to 80% over a six month horizon.

Finally, estimates for Period 3 (June 1982 to March 1983) are reported in the fourth column. Here, it was not possible to estimate the full model. In the grid search over σ, the value of the likelihood function initially increased substantially for small values of σ. It then leveled off, but did not peak, for larger and larger values of σ. The function had become virtually flat for σ=2.0. The estimates, fixing σ at 2.0, are the ones reported.

As shown, the fit is quite good for all three equations. The estimates suggest a critical reserve level of 1.4. The parameters that determine the drift are also quite sensible. In particular, both higher domestic interest rates and depreciation of the exchange rate in the current band are associated with a perceived increase in the mean rate of reserve depletion. The implied reserve drift is quite large, ranging from -4.55 to 1.41. Its mean is 0.47, also large but only one quarter the size of the (assumed) standard deviation of reserves.

The implied 1, 3 and 6 month realignment probabilities are plotted in Figure 6. The plot shows that the perceived likelihood of realignment was small in the first weeks of the new parity

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[15] It is not implausible for the critical reserve level to be negative. Countries can easily have negative net reserve stocks when they borrow abroad.

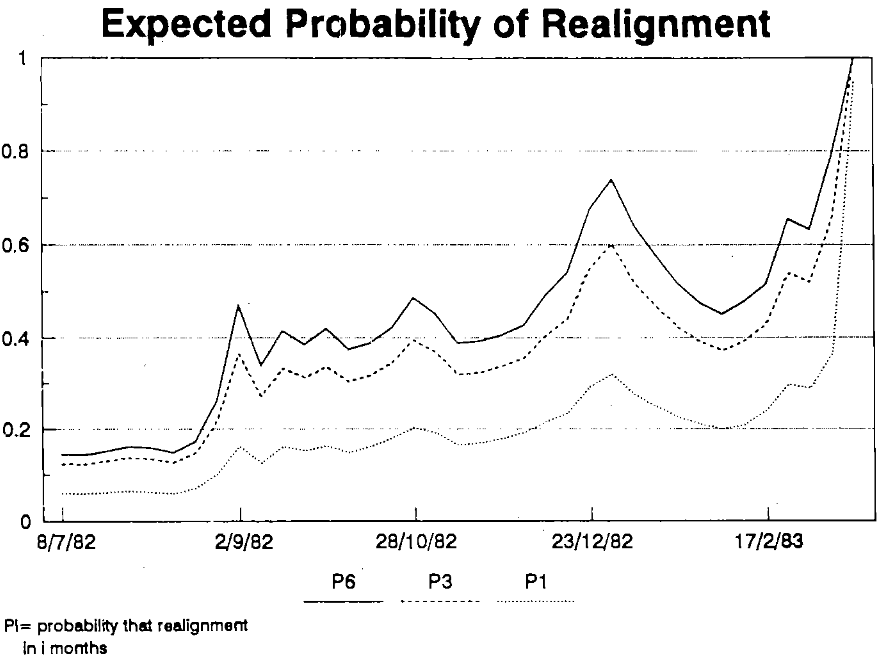
Expected Probability of Realignment
1
0.8
0.6
0.4
0.2
0
8/7/82
2/9/82
28/10/82
23/12/82
17/2/83
P6
P3
P1
PI= probability that realignment
in i months

FIGURE 6

bands. Initially, the perceived likelihood of a realignment is just 6% within 1 month and 15% within 6 months. (In fact, the realignment occurred in about 9 months.) By the week before the realignment, even the one month probability had risen to 95%.

VII. Concluding Remarks

This paper has made three main points. First, the term structure of forward premia provide information about the expected timing of exchange rate adjustments. Shifts in this term structure over time can be used to study the sensitivity of exchange rate expectations to changing economic (and other) conditions. In fact, there were dramatic shifts in the term structure of forward premia on French francs relative to German deutschemarks prior to EMS realignments that adjusted the central parity between these two currencies.

Second, the expected timing of realignments can be modeled as the expected timing of the first passage of central bank foreign exchange reserves through a critical minimum level of reserves. The approach builds on theoretical and empirical work on balance of payments crises. It is less closely tied to more recent work on exchange rate target zones, both because it makes very simplistic assumptions about the behavior of exchange rates between realignments (essentially, they are treated as fixed) and because that work typically does not model the decision, by monetary authorities, to adjust exchange rates.

The first passage time approach implies that the distribution of realignment probabilities is Inverse Gaussian. This distribution is appealing because of its extreme flexibility and its tractability. It allows for shifts in the mass of the distribution consistent a shift from an expected realignment in the distant future, to an expected realignment in the very near future. The distribution has been used infrequently in econometric applications.

Third, this critical reserves model fits data on realignments of the franc relative to the deutschemark during 1981-83 very well. Empirical estimates suggest that the expected timing of realignments has been highly sensitive to the level of foreign exchange reserves, and to factors likely to influence the mean rate of change of those reserves, such as domestic interest rates and the position of the exchange rate in the current band.

There are a number of possible extensions of this work. Two are mentioned in closing. First, it would be interesting to consider other types of economic, social or political conditions than might influence expected devaluations. In principle, it is straightforward to allow the drift of reserves to depend on additional factors, measured by continuous variables. However, it is less straightforward to adequately incorporate non-economic information, such as the timing and outcome of elections. Another difficulty is that it is not obvious how to increase the number of observation in the current application.

Second, the current framework makes very simplistic assumptions about the behavior of exchange rates within bands. It would be interesting to explore these issues empirically, thereby linking this work more closely with the empirical target zone literature.

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