DEVALUATION EXPECTATIONS: THE SWEDISH KRONA 1982-1991

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ABSTRACT

Devaluation expectations for the Swedish krona are estimated

for the period 1982-1991 with several methods. First the

"simplest test" is applied under either only the minimal

assumption of "no positive minimum profit" or the additional

assumption of uncovered interest parity. Then a more precise

method suggested by Bertola and Svensson is used, in which

expected rates of depreciation within the exchange rate band,

estimated in several ways, are subtracted from interest rate

differentials. In addition the probability density of the time

of devaluations is estimated. Finally, estimated devaluation

expectations are to some extent explained by a few macrovariables

and parliament elections.

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I. Introduction

This paper provides a comprehensive study of devaluation expectations for the Swedish krona during the period January 1982-February 1991. During this period Sveriges Riksbank (the central bank of Sweden) unilaterally defended a fixed exchange rate regime, in which the krona was allowed to fluctuate in a narrow band around a central parity defined in terms of a basket of foreign currencies. On one occasion during the period, on October 8, 1982, the krona was devalued. On this occasion, and on several other occasions during the period, devaluation rumors circulated, interest rate differentials between krona and foreign-currency denominated assets rose, and capital outflows occurred. In this paper devaluation expectations are estimated for the period in a systematic way with several methods, with increasing sophistication and precision.[1]

A "naive" estimate of devaluation expectations is the interest rate differential between interest rates on krona denominated and foreign-currency denominated deposits and bonds. This estimate is naive and potentially misleading because interest rate differentials are also affected by expected exchange rate movements inside the band. The paper employs several alternatives to the naive estimate. First, the "simplest test" of target zone credibility, described in Svensson (1991b), is undertaken, with only the minimal assumption of "no positive minimum profit." By adding assumption of uncovered interest parity, we can calculate the maximum and minimum expected rate of devaluation. Then a more precise method to estimated expected rates of devaluation, suggested by Bertola and Svensson (1990), is employed. The estimated expected rates of devaluation are constructed by subtracting estimates of expected rates of exchange rate depreciation within the band from the interest rate differentials. The expected rates of

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

depreciation within the band are estimated with a variety of methods and specifications.[2]

The Bertola-Svensson method is extended to include an estimation of the probability density of the timing of a devaluation, by using interest rate differentials and estimated expected rates of depreciation within the band for several different maturities.

The paper also examines whether the estimated devaluation expectations can be explained by macro variables like the current account, the real exchange rate and the rate of unemployment.

Section II presents some details on the Swedish exchange rate regime and the data used. Section III explains the methods used, section IV presents the results of the simplest test, and section V presents the results of the more precise estimation of devaluation expectations. Section VI examines whether the estimated devaluation expectations can be explained by macro variables, and section VII concludes. An appendix includes some technical details on stochastic processes that model realignments.

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[2] The Bertola-Svensson method has been empirically implemented by Rose and Svensson (1991) on French franc/Deutsche mark exchange rates during the EMS, and by Frankel and Phillips (1991) and Svensson (1991a) on all EMS exchange rates. Frankel and Phillips use survey data on exchange rate expectations rather than interest rate differentials and uncovered interest parity.

II. The Swedish Exchange Rate Band

In August 1977 Sweden devalued and withdrew from the then existing system of European exchange rate collaboration (known as the snake). Instead, a unilateral target zone was established. An exchange rate index was defined as the exchange rate between the krona and an announced trade-weighted currency basket consisting of the currencies of Sweden's fifteen largest trade partners with convertible currencies. The central parity of the basket exchange rate was initially set to 100. At the devaluation on September 14, 1981, the central parity was changed to 111 and at the latest devaluation on October 8, 1982, to 132. The exchange rate band was officially declared to be ±1.5 percent in June 26, 1985. For the earlier period, Sveriges Riksbank claims to have been defending an unofficial band of ±2.25 percent. The system with the currency index was abandoned on May 17, 1991, when Sveriges Riksbank unilaterally pegged the krona to the theoretical ecu. This measure was not accompanied by any realignment of the krona and the width of the band was kept unchanged at ±1.5%.

The data used in this study are daily and cover the period January 1, 1982-February 17, 1991. Interest rates on Euro-currency deposits and spot exchange rates were obtained from the Bank for International Settlements (BIS). The interest rates on deposits denominated in basket currency were constructed from the Euro-rates according to the currencies' effective weights in the currency basket. The Swedish currency index was obtained from Sveriges Riksbank. Lindberg and Söderlind (1991b) provide a detailed description of the data and some basic statistics.

Diagram 2.1 shows the Swedish currency index. The exchange rate band is marked with dotted lines in the diagram. *Diagram 2.2a-d* show the interest rate differentials (expressed as annualized rates of return) between Swedish krona Euro-deposits and basket-currency Euro-deposits carrying a fixed maturity of 1, 3, 6, and 12 months, respectively. The dates of the latest devaluation (October 8, 1982) and the narrowing of

the exchange rate band (June 27, 1985) are marked with vertical dotted lines in the diagram. The interest rate differentials have fluctuated substantially, but usually above the zero level. At certain instances, as in 1985 and 1990, they have reached a level of about 8 percent. Such large levels of interest rate differentials surely suggest the presence of devaluation expectations, but we will be able to measure devaluation expectations with much better precision below.

III. Extracting Devaluation Expectations

A. The simplest test of target zone credibility

We begin by outlining "the simplest test" of target zone credibility described in Svensson (1991b). Let S_t denote the (spot) exchange rate at time t, measured in units of domestic currency per unit of foreign currency (or in index units), and let $\underline{S}_t$ and $\bar{S}_t$ denote the lower and upper edge of the exchange rate band at time,

$$(3.1) \qquad\qquad \underline{S}_t \leq S_t \leq \bar{S}_t$$

The simplest test under the minimal assumption of no positive minimum profit

Let F_t^T denote the forward exchange rate at time t for maturity τ (expressed in years).[3] The net profit at maturity time $t+\tau$ from a forward sale of one unit foreign currency is $F_t^T - S_{t+\tau}$.

Suppose that with certainty at time t no realignment or change in the bandwidth is expected up to and including the maturity time $t+\tau$. Then, the spot exchange rate at time $t+\tau$ is expected with certainty to remain within the exchange rate band, $\underline{S}_t \leq S_{t+\tau} \leq \bar{S}_t$. It follows that the net profit from a forward sale of one unit foreign currency is bounded according to

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[3] The forward exchange rate is the price measured in units of domestic currency per unit of foreign currency (or in index units) and contracted at time t to be paid at time $t+\tau$ for receiving one unit of foreign currency (or one unit of the currency basket) at time $t+\tau$.

(3.2)
$$F_t^T - \bar{S}_t \leq F_t^T - S_{t+\tau} \leq F_t^T - \underline{S}_t.$$

We see from (3.2) that if the forward exchange rate is above the exchange rate band $(F_t^T > \bar{S}_t)$, the *minimum* profit from a forward sale of foreign currency is *positive*. Thus, although the precise level of profit is uncertain, it is certain that it will be positive and above a certain minimum level. This arbitrage possibility would give incentives for investors to sell increasing amounts of foreign currency forward until the profit opportunity is eliminated. If the forward exchange rate remains above the exchange rate band, it must be the case that the exchange rate target zone is not completely credible, in the following sense: The upper edge of the exchange rate band at time $t+\tau$ must with positive probability be expected to increase to a level above the forward exchange rate, either because of an upward realignment of the central parity at constant bandwidth (a devaluation), or an increase in the bandwidth (including a regime shift to a free float), or both.

Similarly, we also see from (3.2) that if the forward exchange rate is *below* the exchange rate band $(F_t^T < \underline{S}_t)$, the minimum profit from a forward *purchase* of foreign currency is positive. In this case investors that believed in the fixity of the target zone would buy foreign currency forward. If the forward rate is not (instantaneously) moved back inside the band the exchange rate target zone cannot be completely credible, and the *lower* edge of the exchange rate band at time $t+\tau$ must with positive probability be expected to *decrease* to a level below the forward exchange rate.

Let us formally state the *assumption of no positive minimum profit: the minimum profit (from a forward transaction) cannot be positive.* Then we can summarize the simplest test of target zone credibility under the minimal assumption of no positive minimum profit:

(i) *If the forward exchange rate falls outside the exchange rate band, the exchange rate target zone is not credible, in the precise sense that the exchange rate band is with positive probability expected to shift to include the forward exchange rate, either by a realignment or*

an increase in the bandwidth, or both.

(ii) If the forward exchange rate is inside the exchange rate band, the test is inconclusive and the exchange rate target zone may or may not be credible.

Covered interest parity

In the test just mentioned market forward exchange rates can be used. Alternatively, under the assumption of covered interest parity, forward and spot exchange rates are related to the spot exchange rate and domestic and foreign currency interest rates, and forward exchange rates can easily be computed from the latter. This is what we will do in practice below.[4] [5]

B. A maximal bound for the expected rate of realignment

It will be practical to introduce the logarithms of the exchange rate and its band. Therefore, let s_t, $\underline{s}_t$ and $\bar{s}_t$ be the natural logarithms of S_t, $\underline{S}_t$ and $\bar{S}_t$, so the exchange rate

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[4] More precisely, introduce a home currency interest rate i_t^T and a foreign currency interest rate (or a currency basket interest rate) i_t^{*T}, both for discount deposits/bills/bonds of the same default-risk and the same maturity $\tau > 0$. (The interest rates are expressed as annualized rates of return, to allow comparison across maturities.) Under the assumption of *covered interest parity*, the forward exchange rates fulfills $F_t^T = S_t[(1+i_t^T)/(1+i_t^{*T})]^T$. For example, if the 1-month domestic and foreign currency interest rates are 18 and 6 percent year expressed as annualized rates of return, the 1-month forward exchange rate is $S_t[(1 + .18)/(1 + .06)]^{1/12}$.

If interest rates are expressed not as annualized rates of return (i_t^T) but as simple annualized rates $(\bar{i}_t^T)$ (which is normally the case for maturities below one year), covered interest parity can be written on the form $F_t^T = S_t(1+\bar{i}_t^T\tau)/(1+\bar{i}_t^{*T}\tau)$ (where τ is expressed in years). [The annualized rates of return and the simple annualized rates are related by $(1 + i_t^T)^T \equiv 1 + \bar{i}_t^T\tau$.]

[5] Empirical work has confirmed that covered interest parity is a realistic assumption. For Sweden it holds very well (see Lindberg (1991)).

band can be expressed as

(3.3) $$\underline{s}_t \leq s_t \leq \bar{s}_t.$$

Furthermore, introduce (the natural logarithm of) the *central parity*,

(3.4) $$c_t \equiv (\underline{s}_t + \bar{s}_t)/2.$$

A *realignment* is a jump in the central parity. Between realignments the central parity is constant.

Next, let us introduce

(3.5) $$x_t \equiv s_t - c_t,$$

the exchange rate's (log) deviation from the central parity. We shall informally refer to x_t as the *exchange rate within the band.* Finally, let $\bar{x} \equiv (\bar{s}_t - \underline{s}_t)/2$, so the exchange rate band (in logs) is $\pm\bar{x}$ around the central parity, with the bandwidth $2\bar{x}$. It follows that the exchange rate within the band will fulfill

(3.6) $$-\bar{x} \leq x_t \leq \bar{x}.$$

Let us from now on *assume that the bandwidth is not subject to change.* The only possible change in the exchange rate regime is therefore a change in central parity, a realignment.

It will be practical, in particular for comparison across different maturities, to consider *rates* of realignment rather than the absolute sizes of realignments. Let us therefore rewrite the central parity as $c_t \equiv s_t - x_t$, and let us write the (average) *rate of realignment* from time t to time $t+\tau$ as $\Delta c_{t+\tau}/\tau \equiv \Delta s_{t+\tau}/\tau - \Delta x_{t+\tau}/\tau$, where $\Delta c_{t+\tau}$ is a simplified notation for $\Delta_\tau c_{t+\tau} \equiv c_{t+\tau} - c_t$, the backward τ-length difference of $c_{t+\tau}$. It follows that

(3.7) $$E_t \Delta c_{t+\tau}/\tau \equiv E_t \Delta s_{t+\tau}/\tau - E_t \Delta x_{t+\tau}/\tau,$$

where E_t denotes expectations conditional upon information available at time t. That is, *the expected rate of realignment equals the expected (total) rate of depreciation minus the expected rate of depreciation within the band.*

Interpretation of the expected rate of realignment

Let us extend on how the expected rate of realignment can be interpreted. At a realignment central parity jumps to a new level and remains constant there until the next realignment. Market expectations of realignments will be modeled in the following way.

First, let us assume that at most one realignment is expected to occur within the maturities we shall consider (up to 12 months). Although this assumption is certainly innocuous for short maturities, it may not be realistic for maturities around 12 month in all circumstances. There were for instance three realignments of the Belgian franc/Deutsche mark exchange rate between September 1981 and September 1982 (see Ungerer, Hauvonen, Lopez-Claros and Mayer (1990)). But we argue that the assumption is realistic for the Swedish krona during the sample period, 1982-1991. The economic debate during this period made it clear that what was at stake was whether there would be zero or one (fairly sizeable) devaluation, and the possibility of having several (smaller) devaluations during a 12 month period can certainly be disregarded. We shall also see below that the expected rate of devaluation dropped down to zero for some time after the devaluation of the krona 1982.[6] (For the case when more than one realignment can occur within the mauturities considered, see the Appendix.)

Let p_t^T be the *probability at time t of a realignment* during the period from time t up to and including time $t+\tau$. During the time interval τ central parity c_t remains constant with probability $1 - p_t^T$, whereas it takes a jump of independent random size z_t with probability p_t^T. It follows that the expected change in central parity, the *expected realignment*, can be written

(3.8)
$$E_t[\Delta c_{t+\tau}] = (1-p_t^T)\cdot 0 + p_t^T \cdot E_t[\Delta c_{t+\tau}|\text{realignment}]$$
$$= p_t^T \cdot E_t[\Delta c_{t+\tau}|\text{realignment}],$$

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[6] The assumption of at most one expected realignment within a 12 month horizon is also supported by the empirical results in Rose and Svensson (1991) for the FF/DM exchange rate, and in Svensson (1991a) for other EMS DM exchange rates, in that the expected rate of devaluation usually drops to around zero for some time after a realignment.

where $E_t[\Delta c_{t+\tau}|\text{realignment}]$ denotes the *expected conditional realignment size* (conditional upon a realignment). (The expected conditional realignment size is positive if a devaluation is expected, negative if a revaluation is expected.) That is, *the expected realignment is the product of the probability of a realignment during the time to maturity and the expected conditional realignment size.*

Define the (expected average) *frequency of realignment* during the time to maturity as $\nu_t^T \equiv p_t^T/\tau.$[7] It follows that the expected *rate* of realignment in (3.7) can be written as

(3.9)
$$E_t[\Delta c_{t+\tau}]/\tau = \nu_t^T \cdot E_t[\Delta c_{t+\tau}|\text{realignment}].$$

The expected rate of realignment is the product of the frequency of realignment and the expected conditional realignment size.

Uncovered interest parity

Let $\delta_t^T \equiv i_t^T - i_t^{*T}$ denote the home country's *interest rate differential* at time t for maturity τ. Then *uncovered interest parity* can be expressed as

(3.10)
$$\delta_t^T = E_t[\Delta s_{t+\tau}]/\tau.$$

That is, the interest rate differential equals the expected rate of depreciation to maturity. Uncovered interest parity is a good approximation if the *foreign exchange risk premium* is small. Svensson (1990) argues that the foreign exchange risk premium is likely to be small in exchange rate target zones, even when there is devaluation risk.[8]

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[7] For short maturities the frequency of realignment is approximately equal to the "intensity" of realignment, the instantaneous average rate at which realignments occur. These concepts are further discussed below and in the Appendix.

[8] Svensson (1990) shows that the foreign exchange risk premium for an imperfectly credible exchange rate band with devaluation risk 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 undoubtedly 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 then the first, but still of moderate size: Even with a coefficient of relative risk aversion of 8 and an expected conditional devaluation size of 10 percent, the foreign exchange risk premium is no more than 1/5 of the total interest rate differential. Hence at least 4/5 of the interest rate differential

It is well known that uncovered interest parity has been rejected in a large number of empirical tests (see Hodrick (1987) and Froot and Thaler (1990)). The standard test of whether the forward exchange rate is an unbiased predictor of the future exchange rate is misleading for exchange rates within exchange rate bands with realignment risk. This is so since the realignment risk is just one example of the well-known Peso problem, which undermines the standard unbiasedness test. Put differently, with realignment risk there is the problem that the sample distribution may not be representative of the underlying distribution of the error term, unless the sample includes a large number of realignments.[9] Interestingly, for the French franc/DM exchange rate, which has experienced a few realignments, there is actually empirical support for uncovered interest parity, as noted by Rose and Svensson (1991).

For the rest of this paper we shall assume uncovered interest parity. From uncovered interest parity it follows that (3.7) can be written

$$(3.11) \qquad E_t \Delta c_{t+\tau}/\tau = \delta_t^T - E_t \Delta z_{t+\tau}/\tau .$$

The expected rate of realignment is equal to the interest rate differential minus the expected rate of depreciation within the band. As observed by Bertola and Svensson (1990), equation (3.11) has empirical implications: In order to find an estimate of the expected rate of realignment, $E_t \Delta c_{t+\tau}/\tau$, it is sufficient to find an estimate of $E_t \Delta z_{t+\tau}/\tau$, the expected rate of depreciation within the band, and simply subtract that estimate from the interest rate differential.

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remains to be explained by something other than the foreign exchange risk premium.

Frankel and Phillips (1991) rely on exchange rate surveys rather than uncovered interest parity and interest rate differentials. They report similar results as Rose and Svensson (1991), which to some extent supports the assumption of uncovered interest parity.

[9] The possibility of occasional jumps in floating exchange rates casts doubts about unbiasedness tests of floating exchange rates, too.

A maximal bound for the expected rate of realignment

At this stage we can define maximal bounds for the expected rate of realignment. Later we shall present more precise estimates of the expected rate of realignment. From (3.6) it follows the rate of depreciation within the band is bounded according to

$$(3.12) \qquad (-\bar{x} - x_l)/\tau \le \Delta x_{l+\tau}/\tau \le (\bar{x} - x_l)/\tau.$$

It follows that the *expected* rate of depreciation within the band must also be bounded in the same way. Substitution of these bounds into (3.11) results in bounds for the expected rate of realignment,[10]

$$(3.13) \qquad \delta_l^T - (\bar{x} - x_l)/\tau \le E_l \Delta c_{l+\tau}/\tau \le \delta_l^T - (-\bar{x} - x_l)/\tau.$$

Empirical estimation of the the expected rate of depreciation in (3.11) allows a more precise estimate of the expected rate of realignment than provided by the bounds in (3.13). This will be the subject below. Before that, we shall mention three possible alternative *simple assumptions* about the expected rate of depreciation within the band. These assumptions allow a more precise, but not necessarily more correct, estimate of the expected rate of realignment.

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[10] From (3.13) follows a second test of target zone credibility: (*i*) *If* $\delta_l^T - (\bar{x} - x_l)/\tau > 0$, *we must have* $E_l \Delta c_{l+\tau}/\tau > 0$, *that is, a positive expected rate of realignment (an expected devaluation).* (*ii*) *If* $\delta_l^T - (-\bar{x} - x_l)/\tau < 0$, *we must have* $E_l \Delta c_{l+\tau}/\tau < 0$, *that is, a negative expected rate of realignment (an expected revaluation).* (*iii*) Otherwise, *the test is inconclusive and the expected rate of devaluation may be positive, negative or zero.*

It may appear that this second test uses uncovered interest parity, since we have indeed referred to uncovered interest parity in deriving it. However, the test only needs covered interest parity and the assumption of unchanged bandwidth, in which case it is identical to the the previous test mentioned.

More precisely, using the approximation $\ln(1+i_l^T) \approx i_l^T$, covered interest parity can be written in the convenient loglinear form, $(f_l^T - s_l)/\tau = \delta_l^T$, where f_l^T is the natural logarithm of F_l^T. That is, *the forward premium per unit maturity equals the interest rate differential.* Substitution of this into (3.13) leads to $(f_l^T - \bar{s}_l)/\tau \le E_l \Delta c_{l+\tau}/\tau \le (f_l^T - \underline{s}_l)/\tau$, which is under the assumption of unchanged bandwidth equivalent to the first test.

C. Possible assumptions about the expected rate of depreciation within the band

The *first* simple assumption is that the exchange rate within the band is a *martingale*, that is, $E_t x_{t+\tau} \equiv x_t$, which implies a zero expected rate of depreciation within the band, $E_t \Delta x_{t+\tau}/\tau \equiv 0$. Then the expected rate of depreciation in (3.11) is simply equal to the interest rate differential,

$$(3.14) \qquad \qquad E_t \Delta c_{t+\tau}/\tau = \delta_t^\tau,$$

and the interest rate differential can be used as a direct quantitative estimate of the expected rate of realignment. Empirically, exchange rates are normally found to behave like a random walk, a special case of a martingale. Exchange rates within bands cannot literally be random walks – just because of the boundaries. It is comforting that the hypothesis that the exchange rate within the band follows a random walk is empirically rejected below.[11]

A *second* simple assumption, clearly unrealistic, is that market agents have *perfect foresight* about exchange rate movements within the band, that is $E_t x_{t+\tau} \equiv x_{t+\tau}$, which implies $E_t \Delta x_{t+\tau}/\tau \equiv (x_{t+\tau} - x_t)/\tau$. Then the expected rate of realignment fulfills

$$(3.15) \qquad \qquad E_t \Delta c_{t+\tau}/\tau = \delta_t^\tau - (x_{t+\tau} - x_t)/\tau,$$

and the interest rate differential adjusted for the actual *ex post* rate of depreciation for the band can be used as a quantitative estimate of the expected rate of realignment.

A *third* simple assumption is that the exchange rate within the band *reverts to the middle of the band*, that is, $E_t x_{t+\tau} \equiv 0$, which implies $E_t \Delta x_{t+\tau}/\tau \equiv -x_t/\tau$. Then the expected rate of realignment fulfills

$$(3.16) \qquad \qquad E_t \Delta c_{t+\tau}/\tau = \delta_t^\tau - x_t/\tau,$$

and the interest rate differential adjusted for this mean reversion of the exchange rate within the band is a quantitative estimate of the expected rate of realignment. Below we

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[11] The hypothesis of a random walk (a unit root) for the exchange rate within the band has been rejected by Lindberg and Söderlind (1991b) for the Swedish currency index, by Rose and Svensson (1991) for the FF/DM exchange rate, and by Svensson (1991a) for the other EMS DM exchange rates (except the lira/DM rate).

shall see that this assumption will to some extent be confirmed for longer maturities.

Now we shall go on to discuss the empirical estimation of the expected rate of depreciation within the band.

D. Empirical estimation of the expected rate of depreciation within the band

The most precise estimation of the expected rate of realignment is by empirically estimating the expected rate of depreciation within the band, and then adjusting the interest rate differentials by subtracting the latter estimate, according to (3.11). If the exchange rate within the band were a martingale, the adjustment would be meaningless and the interest rate differentials would be the best estimate of the expected rate of realignment. However, we will be able to reject the closely related hypothesis that the exchange rate within the band is a random walk, and we will show that the exchange rate within the band actually displays strong mean reversion. Therefore, the estimation of the expected rate of depreciation within the band will indeed be essential for a precise estimation of the expected rate of realignment.

The estimation of the expected rate of depreciation within the band is made a bit complicated by the fact that the exchange rate within the band may take a jump at a realignment (recall that a realignment is defined as a jump in central parity). For instance, at EMS realignments usually the exchange rate for a "weak" currency (that is, a currency that is devalued) jumps from a position near the "weak" edge of the old exchange rate band to a position near or at the "strong" edge of the new exchange rate band. Therefore, the jump in the exchange rate is usually less than the jump in the central parity. Sometimes when the realignment is small and the new band overlaps with the old, there is no jump at all in the exchange rate.

It is complicated to estimate the expected rate of depreciation within the band inclusive of possible jumps inside the band at realignments, since there may be relatively few realignments and the sample distribution of realignments may not be representative.

Then expectations of realignments and jumps inside the band may introduce a Peso problem in the estimation of the expected rate of depreciation within the band. For these reasons it seems safer to estimate the expected rate of depreciation within the band *conditional upon no realignment.*[12] This practice, however, has consequences for the estimation of the expected rate of realignment that need to be clarified.

Hence, let us expand the expected change of the exchange rate within the band in two components,

$$(3.17) \qquad E_t[\Delta x_{t+\tau}] \equiv (1-p_t^\tau)E_t[\Delta x_{t+\tau} \,|\, \text{no realignment}] + p_t^\tau E_t[\Delta x_{t+\tau} \,|\, \text{realignment}]$$
$$\equiv E_t[\Delta x_{t+\tau} \,|\, \text{no realignment}]$$
$$- p_t^\tau \{ E_t[x_{t+\tau} \,|\, \text{no realignment}] - E_t[x_{t+\tau} \,|\, \text{realignment}] \},$$

where we recall that p_t^τ is the probability of a realignment from date t up to and including date $t+\tau$ (and "realignment" means that a realignment occurs sometime during the period from date t to $t+\tau$). It follows from (3.17) that (3.11) can be written as

$$(3.18) \qquad E_t[\Delta c_{t+\tau}]/\tau + p_t^\tau \{ E_t[x_{t+\tau} \,|\, \text{realignment}] - E_t[x_{t+\tau} \,|\, \text{no realignment}] \}/\tau$$
$$= \delta_t^\tau - E_t[\Delta x_{t+\tau} \,|\, \text{no realignment}]/\tau.$$

We shall use the left-hand side of (3.18) as our operational definition of the *expected rate of devaluation* and denote it by g_t^τ (if it is positive a devaluation is expected, if it is negative a revaluation is expected). Hence, by (3.18) *the expected rate of devaluation equals the difference between the interest rate differential and the expected rate of depreciation within the band conditional upon no realignment.*

The expected rate of devaluation as we have defined it differs from the expected rate of realignment by the second term on the left-hand side in (3.18). In order to understand this term better, let us rewrite the expected rate of devaluation as

$$(3.19a) \qquad\qquad\qquad g_t^\tau \equiv \nu_t^\tau \tilde{z}_t^\tau,$$

where

(3.19b) $\qquad \bar{z}_t^T \equiv E_t[\Delta c_{t+\tau}|\text{realignment}]$

$\qquad\qquad\qquad + E_t[x_{t+\tau}|\text{realignment}] - E_t[x_{t+\tau}|\text{no realignment}]$

is the *expected conditional devaluation size* (conditional upon a realignment between date t and date $t+\tau$), and where we recall that $\nu_t^T \equiv p_t^T/\tau$ is the frequency of realignment. Hence, the expected rate of devaluation is the product of the frequency of realignment and the excpected conditional devaluation size. The expected conditional devaluation size is the sum of the expected conditional realignment size and the difference between the expected exchange rate at maturity conditional upon a realignment and the expected exchange rate at maturity conditional upon no realignment. Consider the latter difference. If the maturity τ approaches zero, the difference approaches the jump in the exchange rate within the band at a realignment. Then the expected conditional devaluation size is the expected actual jump in the (total) exchange rate at a realignment, which differs from the jump in central parity by the jump in the exchange rate within the band. If the maturity τ becomes large, the difference becomes small. Then the expected conditional devaluation size is close to the expected conditional realignment size.

E. The Expected Timing of a Realignment

With a more specific model of the realignments/devaluation process, it is possible to infer the expected timing of a realignment from estimated expected rates of devaluation for different maturities (see the Appendix for details). Let us for given t consider the time period $[t,t+\tau]$ ($0 \le \tau$). As before, we assume that there is a finite $\bar{\tau} > 0$, such that the possibility of more than one realignment during $[t,t+\bar{\tau}]$ can be disregarded ($\bar{\tau}$ will equal one year).[13]

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[13] Such a stochastic process differs from a standard marked (or compound) Poisson process in that it has time-varying intensity and, more fundamentally, that it has memory. Previous realizations of the process affect future realizations, in contrast to the fundamental property of Poisson processes that increments are independent. The present process is an example of a "self-exciting" stochastic process (see Snyder (1975) and the Appendix).

Let us the specify that at time t a first realignment is expected to occur during the period $[t, t+\tau]$ $(\tau \geq 0)$ according to the *intensity function* $\lambda_t(\tau) \geq 0$ $(\tau \geq 0)$ and that the possibility of a second realignment during $[t, t+\bar{\tau}]$ can be disregarded. The intensity function has the interpretation that, conditional upon a realignment *not* occurring during $[t, t+\tau]$, the probability of a realignment occurring during the small interval $[t+\tau, t+\tau+\Delta\tau]$ $(\Delta\tau > 0)$ is $\lambda_t(\tau)\Delta\tau + o(\Delta\tau)$.[14] Let the associated *parameter function* $\Lambda_t(\tau)$ be the integral of the intensity function, $\Lambda_t(\tau) = \int_0^\tau \lambda_t(u)du$. Clearly the parameter function will be non-decreasing and fulfill $\Lambda_t(0) = 0$. The probability of a realignment during $[t, t+\tau]$, p_t^T, is given by

$$(3.20) \qquad p_t^T = 1 - \exp[-\Lambda_t(\tau)].$$

The (unconditional) probability of a realignment occurring during the small interval $[t+\tau, t+\tau+\Delta\tau]$ is $\varphi_t(\tau)\Delta\tau$, where $\varphi_t(\tau)$ denotes the probability density function of the time to realignment, given by

$$(3.21) \qquad \varphi_t(\tau) = \lambda_t(\tau)\exp[-\Lambda_t(\tau)].$$

The expected time to a realignment, T_t, is then given by[15]

$$(3.22) \qquad T_t = \int_0^\infty \tau\varphi_t(\tau)d\tau.$$

Let the expected conditional devaluation size, $\bar{z}_t^T$, be independent of the maturity and denoted by $\bar{z}_t$. The expected devaluation during $[t, t+\tau]$, $g_t^T\tau$, fulfills $g_t^T\tau = p_t^T\bar{z}_t$ according to (3.18). Conditional upon a given $\bar{z}_t$ an estimate of the probability of a devaluation follows from the estimated expected rate of devaluation for a particular maturity,

$$(3.23) \qquad \hat{p}_t^T \equiv \hat{g}_t^T\tau/\bar{z}_t.$$

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[14] The notation $o(\Delta\tau)$ means $\lim_{\Delta\tau \to 0} o(\Delta\tau)/\Delta\tau = 0$.

[15] For a constant intensity across maturities, $\lambda_t(\tau) \equiv \lambda$, we have the familiar results from the standard Poisson process: $p_t^T = 1 - \exp[-\lambda\tau]$, $\varphi_t(\tau) = \lambda\exp[-\lambda\tau]$ (the exponential distribution), and $T_t = 1/\lambda$ (except that p_t^T should then be interpreted as the probability of one or more realignments between date t and date $t+\tau$).

From this we can extract the intensity function. First, it follows that we get associated estimates, or observations, of the parameter function,

$$(3.24) \qquad \hat{\Lambda}_t(\tau) \equiv -\ln(1 - \hat{p}_t^\tau),$$

for the maturities for which we have data. Second, we can the fit a function $\hat{\Lambda}_t(\tau)$ $(0 \leq \tau \leq \bar{\tau})$ to these observations (and also use that $\hat{\Lambda}_t(0) = 0$), restricting the function to be at least piece-wise differentiable. Third, we can then construct an estimate of the intensity function by

$$(3.25) \qquad \hat{\lambda}_t(\tau) \equiv \partial \hat{\Lambda}_t(\tau)/\partial \tau,$$

for τ for which the estimated parameter function is differentiable. The simplest way, which we shall use, is to make the parameter function piece-wise linear by connecting the observations with straight lines, and then let the estimates of the intensity function be given by the slopes of these lines.[16]

From the estimates of the intensity and parameter functions we can then compute an estimate of the probability density function for the time to a realignment,

$$(3.26) \qquad \hat{\varphi}_t(\tau) \equiv \hat{\lambda}_t(\tau)\exp[-\hat{\Lambda}_t(\tau)].$$

Finally, an estimate of the expected time to a realignment, $\hat{T}_t$, can be computed by numeric integration of $\int_0^\infty \tau\hat{\varphi}_t(\tau)d\tau$ according to (3.22) (given an assumption about how the estimated density function is extrapolated beyond the maturitites for which data exist).

Let us also relate the (expected average) frequency of realignment, $\nu_t^\tau = p_t^\tau/\tau$, to the intensity function. We exploit that $\Lambda_t(\tau) \equiv -\ln(1 - \nu_t^\tau \tau)$ and $\lambda_t(\tau) \equiv \partial \Lambda_t(\tau)/\partial \tau$. It follows that

$$(3.27) \qquad \lambda_t(\tau) \equiv [\nu_t^\tau + \tau \partial \nu_t^\tau/\partial \tau]/(1 - \nu_t^\tau \tau).$$

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[16] This procedure does not ensure that the parameter function is non-decreasing, so some intensities may become negative. A more sophisticated estimation of the parameter function is of course to select a set of feasible parameter functions (non-decreasing, going through $(0,0)$, and appropriately smooth) and then fit a feasible function to the points $(\tau, -\ln(1-\hat{p}_t^\tau))$ according to a suitable loss function.

For short maturities the intensity and the frequency are approximately equal. In general the intensity is the marginal rate of realignment, conditional upon no previous realignment, whereas the frequency of realignment is the unconditional average frequency of realignment.

IV. The Simplest Test of Target Zone Credibility for the Swedish Krona

We follow the methodology outlined in section IIIA and make the assumption of no positive minimum profit: the minimum profit from a transaction in the forward currency market cannot be positive.

Diagram 4.1 shows the 1, 3, 6 and 12 month forward exchange rate (expressed in percentage deviation from central parity). The position of the exchange rate band is marked with dotted horizontal lines. As before, the two dotted vertical lines represent the latest devaluation (October 8, 1982) and the date when the bandwidth was reduced and made public (June 27, 1985). A few things are worth noting. The 1-month forward exchange rate is always inside the band. The simplest test is thus inconclusive for the whole period on a 1-month horizon, that is, the exchange rate band may or may not have been credible. If we look at the longer terms this has not always been the case. The 6 and 12-month forward rates were above the upper edge of the band at the time before the devaluation of 1982. This indicates that the devaluation 1982 was expected. The 3, 6 and 12-month forward rate were also above the upper edge during the spring of 1985. In a way it is rather surprising that the target zone was not credible at that time, since the Swedish economy then seemed rather healthy. However, there were rumors about a devaluation in conjunction with the general election in September 1985 (the devaluation in 1982 occurred after a general election). Furthermore, the exchange rate band was not public at the time. The market may have expected the target zone to be wider than the actual ±2.25%. During the following years the 12-month forward rate was frequently well

above the upper edge of the target zone. The 3 and 6-month forward rates cross the upper edge of the band on two occasions: in February 1990 and at the end of 1990.

Thus, from the 3, 6 and 12-month forward rates we can conclude that the Swedish exchange rate band has lacked credibility quite often during 1982-1991, in the sense that the central parity or the bandwidth, or both, have been expected to increase with positive probability.

Now, let us assume that the bandwidth has not been expected to increase. Then, it must be the case that a realignment, that is, an upward shift of the central parity, is expected when the forward rate is above the upper edge of the band. Moreover, if we assume uncovered interest parity we can interpret the forward exchange rates as expected future exchange rates. Then, it is possible to compute the maximal bound of the expected rate of realignment from (3.13).

Diagram 4.2a-d shows the maximal bounds for the expected rate of realignment for the maturities 1, 3, 6, and 12 months (note that the vertical scale in Diagram 4.2a differs from that in Diagram 4.2b-d). The maximal bounds, or what we might call "100 percent confidence intervals," provide us with all possible information that earlier was obtained from Diagram 3.1: the minimum and maximum expected rate of realignment have the same (opposite) sign when the forward rate is outside (inside) the band. In addition, the diagrams tells us that the confidence interval is wider for shorter maturities. For instance, the maximal bound for the 1-month expected rate of realignment in Diagram 4.2a is ±18 percent per year, while the maximal bound for the 12-month in Diagram 4.2d is ±1.5 percent per year. This stems from the fact that the maximum bound for the expected *rate* of depreciation within the band is wider for shorter maturities. This reveals why the simplest test of target zone credibility tends to be inconclusive for shorter maturities. It also suggests that the precision could be improved, especially on short horizons, by obtaining a point estimate (with proper confidence intervals) of the expected rate of depreciation within the band.

V. A More Precise Estimation of Devaluation Expectations

A. Estimation of Expected Depreciation within the Band

In order to estimate the expected rate of devaluation, we shall consequently estimate the conditional expectation of the future rate of depreciation within the band, conditional upon no realignment, $E_t[\Delta x_{t+\tau}|\text{no realignment}]/\tau \equiv E_t[x_{t+\tau} - x_t|\text{no realignment}]/\tau$. This is equivalent to estimating the conditional expectation of the future exchange rate within the band, $E_t[x_{t+\tau}|\text{no realignment}]$. We find it illuminating to discuss the estimation in terms of the expected future exchange rate.

Expected future exchange rates

Let us first consider what the theory predicts about the expected future exchange rate within the band. In the Bertola-Svensson (1990) model the only determinant of the expected future exchange rate within the band is the current exchange rate within the band, x_t. The expected future exchange rate within the band, considered a function of the current exchange rate and the time interval, can be computed as the solution to a partial differential equation, the Kolmogorov backward equation, with appropriate initial and boundary conditions. This is done in Svensson (1991c) for the target zone model with only marginal interventions, and in Lindberg and Söderlind (1991a) for a target zone model with intra-marginal interventions as well. Although the computations are a bit complicated, the main result is simple and intuitive.

Diagram 5.1, taken from Lindberg and Söderlind (1991a), shows the theoretical expected future exchange rate (conditional upon no realignment), plotted against the current exchange rate, for the maturities 1, 3, 6 and 12 months. The exchange rate within the band displays mean reversion. The mean reversion is stronger for longer maturities. For an infinite maturity the expected future exchange rate within the band would be constant and equal to its unconditional mean. However, already for 6 and 12 months

maturity the expected future exchange rate is fairly flat. Furthermore, for finite maturities the relationship between the expected future exchange rate within the band and the current exchange rate within the band is non-linear and S-shaped, although for typical parameters the relationship is close to linear. The non-linearity is hardly visible in Diagram 5.1.[17]

The theory hence suggests that the linear approximation,

$$(5.1) \qquad\qquad E_t x_{t+\tau} = \beta_0 + \beta_1 x_t,$$

may be adequate. The parameters β_0 and β_1 can then be estimated by regression of the future exchange rate on the current exchange rate according to the equation

$$(5.2) \qquad\qquad x_{t+\tau} = \beta_0 + \beta_1 x_t + \epsilon_{t+\tau},$$

where by rational expectations $E_t \epsilon_{t+\tau} = 0$ and $E_t x_t \epsilon_{t+\tau} = 0$.

Near-linearity may only arise for some parameters and some model variants. Therefore, we shall include as a test of possible non-linearity the square and the cube of the current exchange rate among the explanatory variables as well as estimating a logistic transformation of (5.2). We shall also use locally weighted regression as a nonparametric method to capture any nonlinearity.

Since our estimation need not presuppose either the Bertola-Svensson model or any other specific target zone model, we shall also allow variants of (5.2) with additional explanatory variables besides the current exchange rate within the band, namely lags of exchange rates within the band, a seasonal variable, and the interest rate differential.

The expected future exchange rate is estimated on our daily data for the maturities $\tau = 1, 3, 6$ and 12 months ($\tau = 1/12, 1/4, 1/2$ and 1 years). The total sample period from January 1, 1982, to February 17, 1991 is divided into two subsamples, "regimes," before

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[17] Diagram 5.1 is computed with the aggregate fundamental being a reflected Ornstein-Uhlenbeck process with a drift function with zero intercept and slope equal to -2, a rate of variance of the aggregate fundamental equal to 1 percent/year (corresponding to an instantaneous standard deviation of 10 percent/$\sqrt{\text{year}}$), and a semi-elasticity of money demand (α) equal to 3 years.

and after June 27, 1985, which is the date when the exchange rate band was reduced from ±2.25 percent to ±1.5 percent and publicly announced. Hence regime I runs from January 1, 1982, to June 26, 1985, and regime II from June 27, 1985, to February 17, 1991. Since we wish to estimate the expected future exchange rate conditional upon no realignment, the observations within the time interval τ before the realignment on October 8, 1982, are excluded from regime I (which excludes the jump in the exchange rate within the band at the realignment). In addition the month after the realignment (one month corresponds to about 22 daily observations) is also excluded.[18]

The expected future exchange rate within the band is estimated separately for each regime and maturity. The estimation of equation (5.2) is complicated by several factors. First, the "overlapping observations" problem (the sampling interval is shorter than the forecasting horizon) results in serially correlated error terms (see Hansen and Hodrick (1980)). Second, since the expected future exchange rate within the band cannot be outside the band, the error terms must be realizations from a distribution with a finite support. Third, a wide class of exchange rate band models suggests that the error terms are likely to be heteroskedastic with a non-normal shape of the conditional distribution (also within the band), mainly due to the stabilizing effect of the boundaries.

Equation (5.2) and its variants have been estimated with several different methods. First, we have used OLS with Newey-West (1987) standard errors which allows for heteroskedastic and serially correlated error terms. We have chosen the number of off-diagonal bands in the error covariance matrix equal to the number of observations corresponding to τ, since our observations are overlapping by τ. This method has also been implemented as recursive least squares (RLS) with a moving window of fixed length,

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[18] The latter exclusion is made on a purely judgmental basis. Immediately after the realignment the exchange rate within the band was positioned close to the lower edge of the exchange rate band. During the month following the realignment the exchange rate within the band increased steadily until the middle of the band was reached. This process was by all likelihood geared by Riksbank interventions and seems to be a unique event. Since we believe that this episode was atypical, we prefer to exclude it from the regressions.

which allows for parameters changing gradually over time.[19]   Second, we have used GARCH as in Bollerslev (1986) to allow for conditional heteroskedasticity of error terms, with and without the moving average adjustment of Baillie and Bollerslev (1990).[20] Third, we have used a nonparametric method, locally weighted regression (LWR), as described in Cleveland, Devlin and Grosse (1990) and Diebold and Nason (1990), which allows for arbitrary (smooth) nonlinearity. Fourth, we have used an autoregressive method in order to handle the serial correlation of the residuals.

The different estimation methods and the different variants of (5.2) result in a large number of estimates of the expected future exchange rate within the band. In the choice between these estimates, in addition to relying on standard statistical criteria, we exclude estimates that are "unreasonable." We consider an estimate unreasonable if either of two conditions are fulfilled: (1) the estimate of the expected future exchange rate within the band is outside the band, and (2) the estimate of the coefficient β_1 for the current exchange rate in (5.2) is significantly negative. Condition (1) is obvious. Condition (2) is motivated by the theoretical result in Diagram 5.1, and in particular it excludes the fairly bizarre situations when the expected future exchange rate is closer to the strong edge of the band the closer the current exchange rate is to the weak edge of the band.

The estimation method and equation variant that consistently seem to give the most sensible estimates are OLS and (5.2) without any additional explanatory variables. The result of that estimation is reported in *Table 5.1* and illustrated in *Diagrams 5.2 and 5.3*.[21]

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[19] RLS on (5.2) are done in the following way. Consider a window of fixed integer size w. Construct the estimates $\hat{\beta}_{0t}$ and $\hat{\beta}_{1t}$ by OLS regression of the w observations of future exchange rates $x_{t-w+\Delta t},\ x_{t-w+\Delta t+1},\dots,\ x_{t+\Delta t}$ on the w observations of current exchange rates $x_{t-w},\ x_{t-w+1},\dots,x_t$. Then form the estimate of the expected future exchange rate at time t, $\hat{E}_t x_{t+\Delta t} \equiv \hat{\beta}_{0t} + \hat{\beta}_{1t}x_t$. Repeat this for $t+1$, $t+2$, etc. (See also Hendry (1989).)

[20] The moving average adjustment of Baillie and Bollerslev (1990) is designed precisely for handling the overlapping observations problem.

[21] In accordance with the theoretical predictions, the residuals from our regressions are

In Table 5.1 we see that for regime II the slope of (5.2) is estimated to be less than unity for all maturities and (more or less) decreasing in maturity: .78 for 1 month maturity, .22 for 3 months maturity, -0.08 for 6 months maturity and 0.06 for 12 months maturity. The latter three are not significantly different from zero. We see that the "t-values" for the slopes being less than unity are less than -3, hence the standard Dickey-Fuller test rejects a unit root on a 5% significance level, and confirms mean reversion, for all maturities.[22] For regime I, the slopes are also less than unity and decreasing in maturity. The slope for 6 months maturity is not significantly different from zero, whereas the slope for 12 months maturity is significantly negative. The t-value for the slope for 1 month maturity being less than unity is -2.5, hence the unit root hypothesis is not rejected even at the 10 percent significance level for that maturity.

The estimation results from Table 5.1 are illustrated in Diagram 5.2. Diagram 5.2 plots, for each maturity and each regime, the point estimate of the future exchange rate within the band together with a 95 percent confidence interval, against the current exchange rate within the band. That is, for each maturity the fitted values of equation (5.2) and a 95 percent confidence interval are shown, for both regimes. The dashed lines correspond to regime I, the solid lines to regime II. The boxes corresponding to bandwidths ±2.25 percent (regime I) and ±1.5 percent (regime II) are also shown. The empirical graphs in Digram 5.2 are to be compared with the theoretical graph in Diagram 5.1. The similarity with the theory is remarkable, except that the line for 12-month maturity during regime I is negatively sloped. We also see that the estimated expected future exchange rate within the band in that case falls below the (±2.25 percent) exchange rate band for current exchange rates within the band above .75 percent from the central parity. Hence, the 12-month maturity during regime I is unreasonable according to our

strongly serially correlated (in all cases), conditionally heteroskedastic (in most cases) and non-normally distributed (in most cases).

[22] The critical values for the 5 and 10 percent significance levels are -2.87 and -2.57, for a sample size of 500 (Fuller (1976, Table 8.5.2)).

discussion above. In this context it is worth noting that Swedish banks were forbidden to hedge long-term forward positions freely until March 24, 1986. This resulted in a thinner and less efficient forward exchange markets for maturities longer than 6 months. Since the Euro-deposit and forward market are closely related, the Euro-deposit market in kronor was affected in the same way. This gives additional support to our decision not to report any further estimates for 12 months maturity during regime I.[23]

As mentioned we have considered a number of additional explanatory variables. The square and cube of the current exchange rates were included in order to capture possible non-linearities. The square and the cube were not significant, though, except that the square was significant for the 6-month maturity during regime I. The estimates of the expected future exchange rates with the square and the cube included were not much different from those when they were excluded.[24] Similar results were achieved by estimating a logistic transformation of (5.2). (The logistic transformation makes sure that the expected future exchange rate within the band cannot fall outside the band.) A seasonal variable was included in order to capture a possible year cycle and end-of-the-year effect. It was significant for 3, 6 and 12-month maturity during regime II but had little effect on the estimates. Various lags were included and some lags were significant for the 6-month maturity during regime I and 1 and 12-month maturity during regime II.

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[23] The confidence intervals are computed under the assumption that the estimated coefficients in Table 5.1 are asymptotically normal. Then the estimated expected future exchange rates within the band are also asymptotically normally distributed. However, we know that the estimated expected future exchange rate within the band cannot fall outside the exchange rate band and that the conditional distribution is likely to have a non-normal shape within the band. Hovewer, the non-normal distribution may to some extent be taken into account by the heteroskedasticity-consistent estimate of the covariance matrix. Therefore it is likely that the confidence intervals could be narrowed by explicitly using a truncated distribution. However, since in most cases the confidence intervals are well inside the exchange rate band, any such modification is likely to have a small effect on the confidence interval. Consequently no such modification has been undertaken.

[24] For the FF/DM exchange rate Rose and Svensson (1991) find that the square and cube of the current exchange rate are marginally significant. The coefficients have the signs predicted by the theory and have some effect on the estimates.

The estimated 1-month future exchange rate during regime II was more variable and jagged than without the lags. The other cases of significant lags gave rise to unreasonable estimates that fell outside the band for parts of the regimes. The interest rate differential was included, but it was only marginally significant for 1-month maturity during regime II and had little effect on the estimated expected future exchange rate.

These specification tests hence confirm that the simple specification (5.2) generates the most sensible results.

Several different estimation methods besides OLS were also used. Although OLS is a consistent estimator, it is not necessarily the most efficient estimator. GARCH may be desirable since conditional heteroskedasticity has been documented for the krona by Lindberg and Söderlind (1991b). GARCH with the moving-average extension of Baillie and Bollerslev (1990) lead to rather strange results, with constant expected future exchange rates for as short maturity as 1 month. This holds also for the autoregressive method. GARCH without the MA-extension gave results similar to OLS. That error terms are truncated and definitely non-normal make us skeptic about the use of GARCH, though. That error terms are highly serially correlated because of overlapping observations invalidates the assumptions for GARCH without the MA extension. Locally weighted regression (LWR) gave results similar to OLS except for 6-month maturity during regime I, for which case expected future exchange rates are constant for exchange rates in the lower half of the band. This lack of non-linearities in a prediction equation for the Swedish krona is very much in line with the findings of Lindberg and Söderlind (1991b). RLS gave very volatile estimates for short windows of 1 year or less; a 2-year window gave unreasonable negative slopes for 6 and 12-month maturity.

These results from alternative estimation methods confirms OLS with Newey-West covariance matrix as the estimator that most consistently generates sensible results.

Expected rates of depreciation within the band

The estimated expected rates of depreciation within the band, conditional upon no realignment, are easily calculated as

(5.3) $\qquad \bar{E}_t[\Delta x_{t+\tau}| \text{no realignment}]/\tau = [\hat{\beta}_0 + (\hat{\beta}_1-1)x_t]/\tau,$

where a hat ($\hat{}$) denotes estimates of the parameters β_0 and β_1 in (5.1) (displayed in Table 5.1). These estimated expected rates of depreciation are plotted against time in *Diagram 5.3a-d*. In accordance with the discussion earlier, the results for 12 months maturity in regime I are not shown.

Diagram 5.3a-d hence shows the amount of adjustment in interest rate differentials of Diagram 2.2 that is warranted. We see that the adjustment often is of the same magnitude as the interest rate differential, which is suggestive of the importance of going further than just observing interest rate differentials when discussing devaluation expectations. The results for 1, 3 and 6 months look quite similar. This is explained by the fact that, according to Table 5.1, both $\hat{\beta}_0$ and $\hat{\beta}_1$ decrease approximately proportionally to τ. But, since the degree of mean reversion is very strong, the expected exchange rate after 6 and 12 months are virtually the same and constant (see Diagram 5.2c and d). Hence, the expected *rate* of change of the exchange rate for 12 months is about half of that for 6 months.

B. Estimation of Devaluation Expectations

The estimates of the expected rate of devaluation are hence constructed according to (3.18) by subtracting the estimated expected rates of depreciation in Diagram 5.3 from the interest rate differentials in Diagram 2.1. That is, the expected rate of devaluation is given by

(5.4) $\qquad \hat{g}_t^\tau \equiv (\hat{\nu}_t^\tau \hat{z}_t^\tau) \equiv \delta_t^\tau - [\hat{\beta}_0 + (\hat{\beta}_1-1)x_t]/\tau,$

The resulting point estimates are displayed in *Diagram 5.4*, while *Diagram 5.5* shows the 95 percent confidence intervals. As expected, the estimated expected rates of devaluation are fluctuating over time and often of considerable magnitude. Moreover, the results are

qualitatively similar to the results from the Simplest Test shown in Diagram 4.1. But, the results in Diagram 5.4 are much more precise. It is interesting to compare the previous Diagram 4.2 with Diagram 5.5. Diagram 4.2 shows the maximal bounds for the expected rates of realignment, what we might call 100 percent confidence intervals. The much narrower 95 percent confidence intervals in Diagram 5.5 demonstrate the gain in precision obtained by estimating the expected rate of depreciation within the band. (Note that the vertical scales differ between Diagrams 4.2 and 5.5, making the difference between the two sets of confidence interval even larger than they at first appear.) The maximal bound for the expected rate of realignment in regime II in Diagram 4.2 are ±18%, ±6%, ±3 and ±1.5% percent per year for 1,3,6 and 12 months, respectively. The typical 95% confidence interval for the rate of devaluation in Diagram 5.5 are ±2%, ±2%, ±1% and ±0.5% percent per year, respectively. Hence, the gain in precision by estimating the expected depreciation within the band is substantial, especially for short maturities. The practical consequence of this can be exemplified by the estimates of the devaluation expectations for 1 month maturity during the weeks preceding the devaluation on October 8, 1982. According to the Simplest Test in Diagram 4.1, the result is inconclusive since the forward rate is inside the band, but in Diagram 5.4a and 5.5a we see a markedly significant positive estimate of the expected rate of devaluation.

Edin and Vredin (1991) have estimated expected rates of devaluation for the Nordic countries with monthly data for the sample period January 1979-May 1989. They use a method very different from ours. They follow Baxter (1990) and treat actual central parities as censored variables that are adjusted to a shadow exchange rate only when the difference between the shadow exchange rate and the central parity exceeds a threshold. They estimate devaluation probabilities and devaluation sizes in a censored regression of actual devaluations on selected macrovariables as explanatory variables.[25] For the year

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[25] The selected macrovariables are nominal money stocks, foreign interest rates, industrial productions, real exchange rates, foreign price levels and foreign exchange reserves.

1982 (which includes the one Swedish devaluation in the sample), their estimates of expected rates of devaluation for Sweden are fairly similar to ours. Throughout the period January 1983-May 1989, however, their estimated expected rates of devaluation are zero, whereas our estimated expected rates of devaluation fluctuate between -3 and +10 percent per year (the peak occurs during the unrest of June 1985). Their sample does not extend beyond May 1989, so we do not know whether their method would indicate positive expected rates of devaluation during the unrest in the Winter 1989/90 and in the Fall of 1990.

There are several reasons why Edin and Vredin's and our estimates are not directly comparable. First, they estimate *objective* probabilities and sizes of devaluation conditional only upon selected macrovariables, whereas we in a very direct way estimate the market's *subjective* expected rates of devaluation, which may depend on a variety of information. (In practice interest rate differentials and the exchange rates within the band seem to be sufficient statistics for that information. Edin and Vredin's selected macrovariables exclude the domestic interest rate and the current exchange rate, probably because they are considered endogenous.[26]) Second, Edin and Vredin estimate probabilities and sizes of devaluation during each month conditional upon values of the macrovariables during the previous month. Since the macrovariables are published with a lag, information about them actually becomes available during the month for which devaluation probabilities and sizes are estimated. Therefore, in practice Edin and Vredin estimate probabilities and sizes of *current* devaluations conditional upon current information, whereas we estimate expected rates of *future* devaluations conditional upon

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[26] Edin and Vredin's estimates of devaluation probabilities and sizes are *objective* in the sense that they are derived from the data on the macrovariables regardless of what the market's devaluation expectations actually were. (Perhaps one could say that they are trying to find Nordic governments' central banks' decision rule for devaluations.) Our estimates of expected rates of devaluation are *subjective* in the sense that they extract the market's devaluation expectations regardless of whether or not those expectations were warranted by the the state of the economy (or by the behavior of governments and central banks).

current information. Nevertheless, even though Edin and Vredin's and our estimates are not directly comparable, it is clear that they give very different results, and further research is probably necessary to clarify why.

The expected time to a devaluation

In general, the expected rates of devaluation do not vary much across maturities. This could, for instance, be consistent with devaluation expectations characterized by general uncertainty about the exact timing of the devaluation. This pattern could be modeled as a jump process for devaluations with a random walk frequency of realignment, as in Bertola and Svensson (1990). But, at certain instances there is a clear profile across maturities of the expected rates of devaluation. These include the short period before the devaluation in October 1982, the prolonged period around the general election 1985, the very short period during the government crisis in February 1990 and also the late fall the same year. Under the assumption that the expected conditional devaluation size $\bar{z}_t^\tau$ is constant across maturities, this can be used for a more precise estimation of the expected timing of the devaluation. This assumption will be exploited below. To be more precise, we will assume that the expected conditional devaluation size $\bar{z}_t^\tau$ was 10 percent. This number is fairly reasonable, given the Swedish experience, and the results would not change much if we instead assumed, say, 7 or 13 percent. Given this assumption, it is straightforward to calculate the estimated probability density for the time to realignment $\hat{\varphi}_t(\tau)$ according to (3.26). But unfortunately, we are not able to give good estimates of the expected time to realignment T_t, given by (3.22). In order to do so we would need estimates of the probability densities for maturities longer than one year ($\tau > 1$). For the sake of illustration, let us assume that the intensity $\lambda_t(\tau)$ for maturities longer than one year ($\tau > 1$) equals the intensity for one year $\lambda_t(1)$. Then the expected time to a realignment can be calculated and used as a summary indicator of the perceived timing of devaluations.

We shall look at four episodes with especially high devaluation expectations. *Diagram 5.6a* shows the estimated probability density for the time to realignment, $\varphi_t(\tau)$, given $\bar{z}_t = 10$ percent, for the period September-October 1982. The date t along the horizontal axis is measured in weeks, and the numbering follows the Swedish convention of numbering the weeks of a year from 1 to 53. The day of the devaluation, October 8, 1982, is marked by a dotted vertical line. The curves show the estimated density functions $\varphi_t(\tau)$ plotted against t for $\tau = 1$, 3, 6 and 12 months. According to Diagram 5.6a, the timing of the devaluation of October 8, 1982, seems to have been anticipated to a large extent. The probability densities were high for all maturities during the month preceding the devaluation. Furthermore, the density for the 1 month maturity took an upward jump about one week before the devaluation. Two dates in weeks 41 and 42 (September 6 and 11), marked by arrows in Diagram 5.6a, are further analyzed in *Diagram 5.6b*. In Diagram 5.6b, the probability density is plotted against maturity for the two dates. Hence, this diagram is indeed our estimate of the density function for the time to realignment, for maturities up to and including one year. On October 6, two days before the devaluation, the probability density was very high for the 1 month maturity and, more or less, successively smaller for longer maturities. Our estimate for October 6 of the expected time to realignment $\hat{T}_t$ equals 13 months.[27] Six days and one devaluation later, on September 11, 1982, the densities were zero or negative. The negative densities are of course an anomaly and reflects either an error in assuming a constant expected positive conditional devaluation size $\bar{z}_t$ also after the devaluation or, more generally, that the expected rates of devaluation immediately after the devaluation were not significantly different from zero, as can be seen in Diagram 5.4a-d.

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[27] Obviously, $\hat{T}_t$ is sensitive to assumptions about the intensity $\hat{\lambda}_t(\tau)$ for $\tau > 1$. For instance, if we instead assumed that $\hat{\lambda}_t(\tau) = \hat{\lambda}_t(1)/2$ for $\tau > 1$, then our estimates of the expected time to realignment would typically be about 30 percent longer at dates with high devaluation expectations.

During Spring 1985, the densities increased dramatically for the 1, 3 and 6 months maturities, as seen in *Diagram 5.6c*. One often stated explanation to this episode is the fear of a devaluation in conjunction with a new government taking office after the general election in September 1985 (as had happened in 1982). This is reasonable but probably not the whole story, since it cannot explain the high densities in May 1985 for short maturities. The uncertainty about the width of the exchange rate band (which was not official) could possibly be the missing part of the explanation. On June 27, 1985, Sveriges Riksbank narrowed the exchange rate band to ±1.5% (from ±2.25%) and made it official. This seems to have brought down the density for 6 months maturity during the course of a few weeks. The densities for the shorter maturities were affected much less or not at all. After that, the densities were more or less constant until two weeks after the general election in week 37. Thereafter they fell steadily. *Diagram 5.6d* shows the density against maturity for three dates in week 26 and 48 (June 26, June 28 and November 29) marked by arrows in Diagram 5.6c. The densities for short maturities were very high both immediately before and after June 27. The expected time to a realignment was about 8 months. On November 29, 1985 the densities for shorter maturities have fallen substantially and the density plot is virtually flat. The expected time to realignment was then above 2.5 years.

Diagram 5.7a shows the period January to March 1990 when the weak Swedish economy and government crisis made the densities soar, especially for shorter maturities. Hence, the market expected a devaluation soon. The turbulence settled very quickly, though. This is further illustrated in *Diagram 5.7b* which plots the density function for three dates in weeks 8 and 12 (February 19, February 23 and March 19). Here it is evident that it was only the short maturities that were affected. The expected time to realignment was 14, 20 and 21 months at the three dates.

The episode of high devaluation expectations in late 1990 was longer than in February 1990, as shown in *Diagram 5.7c-d*, but a similar pattern across maturities is displayed.

This implies that the market did not exclude the possibility of a devaluation *before* the general election in September 1991, perhaps in conjunction with the tying of the krona to the ecu. The expected time to realignment at the two dates (October 8 and October 18) was 19 and 14 months, respectively.

VI. Explaining Devaluation Expectations

In the previous section we estimated the markets devaluation expectations, regardless of the cause of these devaluation expectations. In this section, in contrast, we will try to shed some light on the cause of devaluation expectations. More specifically, we examine whether the expected rates of devaluation that we have estimated above can be explained by a set of macro variables. We do this by regressing estimated expected rates of devaluation on a selected set of macrovariables. Numerous specifications and hypothesis can be considered. This section is not an exhaustive examination, but should only be seen as containing the results for a few fairly obvious specifications.

Since the selected macrovariables are available only as monthly data, we have used monthly averages of the estimated expected rates of devaluation as regressand. The estimation method used is OLS with Newey-West (1987) standard errors, with 12 off-diagonal bands in the error covariance matrix. This allows for heteroskedastic and serially correlated error terms.

The explanatory variables that we use appear in *Table 6.1*. The selection of explanatory variables was primarily based on theoretical considerations, but has also been influenced by our experiences from the Swedish money and exchange rate market. We started with a relatively large set of explanatory variables. The level of the real exchange rate, the trade account, the inflation rate, the rate of nominal industrial wage growth and the rate of industrial production growth were later excluded from the equations. In most cases their coefficients were insignificant. In the remaining cases the excluded variables

were strongly correlated with some of the remaining. The excluded variables had a limited explanatory power as the exclusion only resulted in a minor drop of the R-square values.[28]

In the regression equation the explanatory variables reflect only the most recent information available during month t. The idea was to include the most important variables in the current information set that agents might use in forming devaluation expectations. The explanatory variables were consequently appropriately lagged or, in the cases where a particular statistic is revealed sometime during the month, constructed as averages of lagged values.[29]

The estimation results for the 3-month maturity are reported in Table 6.1. The results for the other maturities were similar, except where noted below. The equation has relatively high explanatory power. The current account has a negative effect on the expected rate of devaluation, at a 1 percent significance level. The rate of real exchange

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[28] For the regression equations in this section to be meaningful, it must not be the case that the explanatory variables tried here are omitted variables and have explanatory power in forecasting the future exchange rate within the band.

[29] For instance, the current account is published with a six week lag. Therefore, as an explanatory variable we use the average of the seasonally adjusted observation for month t-3 and month t-2. The monthly unemployment observation becomes available with a two week lag and enters the equation as an average of the seasonally adjusted observation for month t-2 and month t-1. The central government borrowing requirement (seasonally adjusted) and the change in foreign exchange reserves (due to private transactions) is announced weekly. Thus both variables enter the equation as an average of their monthly figures for month t-1 and month t. The money supply, i.e. seasonally adjusted M3, is available with a time lag somewhere in the range of two and five weeks. Thus, the money growth rate enters the equation as the average yearly growth rate during month t-2 and month t-1. The real exchange rate, expressed in units of domestic goods per unit of foreign goods, can be calculated with a two week lag, when the consumer price statistics become available. For the rate of real exchange rate depreciation, several lags were significant with similar coefficients, indicating that what effects the expected rate of devaluation is the average rate of real exchange rate depreciation over a longer period than 2-3 months. Therefore we use the average of the two 12-month rates of real exchange depreciation that end in month t-2 and t-1. The election dummy is equal to one if the months September or October of an election year (1982, 1985 and 1988) occur within the maturity, otherwise it is equal to zero.

Using an average of lagged variables implies an implicit restriction that the coefficients of each lagged variable are the same. We have run regressions with the lagged variables entering separately, and we have found that the hypothesis that the the restrictions are fulfilled cannot be rejected.

rate depreciation also has a negative effect, which is marginally significant. That is, an increase in the rate of real exchange rate depreciation (an increase in the rate of appreciation of Swedish competitiveness) reduces the expected rate of devaluation. (The effect of the rate of real exchange rate depreciation is not significant for the other maturities, though.) The parliament elections have a positive effect, at a 1 percent significance level. Finally, the coefficient for the change in foreign exchange reserves is positive and significant at a 1 percent level (the coefficient is not significant for the 6 and 12-month maturity). The coefficients of the unemployment rate, the money growth rate and the government borrowing requirement are not significantly different from zero.[30]

The significant coefficients have the expected signs except the coefficient for the change in foreign exchange reserves. Surprisingly, an increase in the capital inflow increases the expected rate of devaluation. This result is due to the events after October 1990, when the Riksbank after initial capital outflow and increases in interest rate differentials orchestrated a dramatic increase in overnight and treasury bills interest rates. This lead to a large capital inflow and an increase in foreign exchange reserves. A possible interpretation is that the Riksbank increased reserves so as to better withstand possible future devaluation speculation. If the observations from October 1990 on are excluded, the coefficient for capital flows is no longer significantly different from zero.[31] [32]

Some experience from the foreign exchange market suggest that market participants

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[30] The money growth rate has a positive effect, on a 5 percent significance level, for the 6-month maturity. The rate of unemployment has a positive effect, on a 1 percent significance level, for the 12-month maturity.

[31] During the dramatic increase of interest rate differentials in the Fall of 1990, overnight and treasury bill interest rates "overshot" covered interest parity, and covered interest parity was hence temporarily violated (during about a week for the 3-month maturity, see Lindberg (1991)). Interestingly, Euro interest rates did not overshoot but maintained covered interest parity. Therefore, the Euro interest rates (which we consistently use) may have been more reliable data for the estimation of devaluation expectations.

[32] Koen (1991) regress short and long run interest rate differentials (relative to the DM) of pooled ERM countries and Austria on selected macrovariables. Inflation differentials relative to Germany and hard currency dummies have significant effects of the expected sign.

follow fads in the sense that they focus for a while on a particular variable in forming devaluation expectations, then switch to focus on another variable for a while, etc. In order to allow for this possibility, we have used rolling regressions (with a window of 36 months) to check the stability of the coefficients reported in Table 6.1.

We choose to report only the most interesting results for the 3-month maturity. *Diagram 6.1a* to *6.1d* show the development of a 95 percent confidence interval for the coefficients of the current account, the unemployment rate, the money growth rate and the election dummy. The coefficients are plotted for the center of the windows. The first window covers the period April 1982-March 1985 and the last covers the period February 1988-January 1991.

The coefficient of the current account is the most stable one. It has a significant negative sign almost always, except during two periods in 1983 and 1988. The coefficient of the unemployment rate shows a different pattern. In the beginning it is significantly negative. Then, when the unemployment reaches a higher level at the end of the 1980's, it gets a significantly positive sign. In the regressions on the whole sample period the coefficient of the money growth rate was not significantly different from zero. However, in the rolling regressions, money growth has a significant positive impact on the expected rate of devaluation for most of the sample period. Finally, the development of the coefficient of the election dummy indicates that the effect of the election 1985 on the expected rate of devaluation was considerable large. The effects of the elections 1982 and 1988 were on the contrary quite modest.

The results from the rolling regressions confirm that several coefficients were unstable over the sample period, which is consistent with the idea of the market's focus shifting between different macrovariables.[33]

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[33] It may appear that an alternative to regression on lagged variables in the information set is regression on *leaded* variables. The idea would be that market agents may have a variety of information on which we lack data. This information is used by market agents to form consistent expectations of future devaluations and future macrovariables. By rational expectations the forecast errors on the realized values of these future

VII. Conclusions

We have applied several methods to estimate devaluation expectations for the Swedish krona during 1982-1991. First we used the simplest test, with the minimal assumption of no positive minimum profit. We found expectations of a devaluation, and hence a lack of credibility for the exchange rate band, within a 12-month horizon for a good part of the sample, in particular towards the end. Within shorter horizons, we also found a lack of credibility on some occasions, but the test is mostly inconclusive for shorter horizons and cannot tell whether the exchange rate band is credible or not.

Under the assumption of uncovered interest parity, we were able to estimate devaluation expectations with greater precision, and also to compute confidence intervals and conduct statistical hypothesis tests. The method consists of adjusting the interest rate differentials by subtracting expected rates of exchange rate depreciation within the band. This way we have estimated expected rates of devaluation, with appropriate confidence intervals, for the horizons 1, 3, 6 and 12 months. We have found that the expected rates of devaluation are usually significantly positive for most of the sample period, not only for the 12-month horizon but also for shorter horizons down to 1 month. The expected rates of devaluation were never significantly negative, except briefly in the Spring of 1984.

The main conclusion is that the exchange rate band for the krona has almost always lacked credibility during the sample period. The unilateral exchange rate target zone has thus not provided full credibility. It remains to be seen whether the recent unilateral peg to the ecu, the declaration that Sweden intends to apply for status as an associated

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macrovariables should be uncorrelated with everything in the current information set. The leaded macrovariables should therefore be potential explanatory variables in regressions on the expected rates of devaluation. As far as we can see, such regressions would be misleading, since a Peso problem would enter. In practice we would end up taking realized values conditional upon no realignment having occurred, which would be biased relative to the unconditional expectation of the variables.

member of EMS as soon as this option becomes available, the Swedish application for membership in the EC, and the recently appointed government commission on the status of the central bank will be associated with reduced devaluation expectations.

The adjustment of interest rate differentials require the estimation of expected rates of depreciation within the exchange rate band. We have employed a variety of estimation methods and specifications. A simple linear specification, OLS estimation of coefficients, and Newey-West estimation of the covariance matrix consistently deliver sensible results. Exchange rates within bands are not martingales but display strong mean reversion; estimated expected rates of depreciation within the band are often of the same magnitude as interest rate differentials, in particular for short maturities. This makes the adjustment of interest rate differentials essential to the precise measurement of devaluation expectations. For maturities longer than 12 months, though, estimated expected rates of depreciation within the band are fairly small and the adjustment of interest rate differentials does not matter much.

We have devised a method to estimate probability densities for the time to a devaluation. Normally the probability density does not change much, but around a few critical dates there seem to be considerable shifts in the expected timing of a devaluation.

We have examined how devaluation expectations can be explained by regressing estimated expected rates of devaluation on selected macrovariables. The results indicate that the current account surplus has a significant negative effect on devaluation expectations, and that an election dummy has a significant positive effect. The rate of real exchange rate depreciation has a marginally significant negative effect for the 3-month maturity. Several coefficients are unstable over time, consistent with the idea that market agents in forming devaluation expectations focus on a particular macrovariable for a while, and then shift to another. For instance, the rate of unemployment has a positive effect on devaluation expectations towards the end of the sample period.

If the assumption of uncovered interest parity is not accepted, anyone with a specific idea of the size and sign of the foreign exchange risk premium can easily adjust the estimated expected rates of devaluation accordingly. More generally, a confidence interval for the foreign exchange risk premium is easily added to the confidence intervals already estimated. Even with as large an interval for the foreign exchange risk premium as ±1 percent per year most of our conclusions are not affected.

Appendix

1. Several Independent Realignments Possible during $[t,t+\tau]$ (a Marked Poisson Process)[34]

We fix the date t, and consider the time interval $[t,t+\tau]$, $\tau \geq 0$. We let $N_t(\tau) = 0, 1,$ 2, ..., denote the number of realignments during $[t,t+\tau]$. Suppose the occurrence of realignments is described by a Poisson point process. Let the Poisson process be "doubly stochastic." That is, the rate at which realignments occur is itself a stochastic process. Let $\bar{\lambda}_t(\tau) \geq 0$ $(\tau \geq 0)$ denote the stochastic rate at which realignments occur at time $t+\tau$, the *stochastic intensity*. Then the probability of a realignment occurring during the small time interval $[t+\tau,t+\tau+\Delta\tau]$ $(\Delta\tau > 0)$ is $\bar{\lambda}_t(\tau)\Delta\tau + o(\Delta\tau)$.

Now, introduce the *(expected)* *intensity function* $\lambda_t(\tau) \geq 0$ $(\tau \geq 0)$, defined as $\lambda_t(\tau) \equiv E_t[\bar{\lambda}_t(\tau)]$, the expected rate at which realignments occur at time $t+\tau$, conditional upon information available at time t. The intensity function has the interpretation that the probability of a realignment occurring during the small time interval $[t+\tau,t+\tau+\Delta\tau]$ $(\Delta\tau > 0$), conditional upon informationa available at time t, is $\lambda_t(\tau)\Delta\tau + o(\Delta\tau)$. The treatment of doubly stochastic processes is much simplified by the fact that the stochastic intensity can be replaced by the conditionally expected intensity (see Snyder (1975, Chapt. 6). In the rest of the appendix, all intensities, expectations, probabilities and distributions are conditional upon information avialable at time t, unless explicitly stated otherwise.

The crucial property of a Poisson process is that future evolution of the process is not affected by past realizations. More precisly, it has independent increments; for $\tau_1 < \tau_2 < \tau_3 < \tau_4$, $N_t(\tau_2)-N_t(\tau_1)$ and $N_t(\tau_4)-N_t(\tau_3)$ are independent. This means that the above probability of a realignment during a small time interval does not depend on whether or not any realignment has just occurred before the time interval. We find this property of the Poisson process completely unrealistic as a description of actual realignments, and

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[34] See Snyder (1975) for details on and terminology of random point processes.

therefore we have chosen a modified, "self-exciting," process below. A self-exciting process is a process where the future evolution is affected by past realizations. In order to describe the self-exciting process, it is illuminating to first describe the Poisson process.

The *parameter function* $\Lambda_t(\tau)$ is the integral of the intensity function, $\Lambda_t(\tau) \equiv \int_0^\tau \lambda_t(u)du$. The parameter function will be non-decreasing and fulfill $\Lambda_t(0) = 0$. For a Poisson process the number of realignments during $[t,t+\tau]$ is Poisson distributed with parameter $\Lambda_t(\tau)$,

(A1.1) $$\text{Prob}\{N_t(t) = n\} = [\Lambda_t(\tau)^n/(n!)] \exp[-\Lambda_t(\tau)], \quad n = 0, 1,...,$$

and the expected number of realignments during $[t,t+\tau]$ is

(A1.2) $$E_t[N_t(\tau)] = \Lambda_t(\tau).$$

Let the Poisson process be a "marked" point process. That is, with each realignment, "point," there is associated a random variable, "mark," in our case the size of a devaluation. Let the expected conditional size of a devaluation at time $t+\tau$, $\bar{z}_t^\tau$, be independent of the maturity and denoted by $\bar{z}_t$. The expected devaluation (size) during $[t,t+\tau]$, $g_t^\tau\tau$, then fulfills

(A1.3) $$g_t^\tau\tau = E_t[N_t(\tau)]\,\bar{z}_t = \Lambda_t(\tau)\,\bar{z}_t.$$

It follows that, conditional upon a given $\bar{z}_t$, an estimate of intensity function can be computed by

(A1.4) $$\hat{\Lambda}_t(\tau) = \hat{g}_t^\tau\tau/\bar{z}_t.$$

2. At Most One Devaluation During $[t,t+\bar{\tau}]$ ($\bar{\tau} > 0$) (a Self-Exciting Point Process)

With the marked Poisson process above, one or several realignments can occur during $[t,t+\tau]$. Also, the probability of each new realignment is independent of whether any have just occurred. We find this unsuitable for describing actual realignments and prefer to modify the process so that there is a finite $\bar{\tau} > 0$, such that the possibility of more than one realignment during $[t,t+\bar{\tau}]$ can be disregarded. This means that the process is self-exciting, since the occurrence of a first realignment affects the occurrence of a second,

at least for some time. Conditional upon a realignment *not* occurring during $[t, t+\tau]$, the probability of a realignment occurring during the small interval $[t+\tau, t+\tau+\Delta\tau]$ $(\Delta t > 0)$ is $\lambda_t(\tau)\Delta\tau + o(\Delta t)$. Conditional upon a realignment *occurring* during $[t, t+\tau]$, $(0 \leq \tau \leq \bar{\tau})$, the probability of a realignment occurring during the small interval $[t+\tau, t+\tau+\Delta\tau]$ is zero.

In order to derive the probability of a realignment during $[t, t+\tau]$, p_t^τ, introduce $q_t(\tau) \equiv 1 - p_t^\tau$, the probability of no realignment during $[t, t+\tau]$. We have

$$(A2.1) \qquad q_t(\tau+\Delta\tau) \equiv \text{Prob}\{\text{no realignment during } [t, t+\tau+\Delta t]\}$$

$$\equiv \text{Prob}\{\text{no realignment during } [t, t+\tau]\} \cdot \text{Prob}\{\text{no realignment during } [\tau, \tau+\Delta t]\}$$

$$\equiv q_t(\tau) \cdot [1 - \lambda_t(\tau)\Delta\tau + o(\Delta t)].$$

We can rewrite this to get

$$(A2.2) \qquad [q_t(\tau+\Delta\tau) - q_t(\tau)]/\Delta\tau \equiv [-\lambda_t(\tau) + o(\Delta t)/\Delta\tau]q_t(\tau).$$

Taking the limit when $\Delta\tau \to 0$ gives the differential function

$$(A2.3) \qquad \partial q_t(\tau)/\partial\tau = -\lambda_t(\tau)q_t(\tau),$$

which has the solution $q_t(\tau) = A \exp[-\Lambda_t(\tau)]$ for some constant A. Since $q_t(0) = 1$, $A = 1$. Hence,

$$(A2.4) \qquad q_t(\tau) = \exp[-\Lambda_t(\tau)] \quad \text{and}$$

$$(A2.5) \qquad p_t^\tau = 1 - \exp[-\Lambda_t(\tau)].$$

In order to identify the probability density function, $\varphi_t(\tau)$, of the time to a realignment, we observe that

$$(A2.6) \qquad \varphi_t(\tau)\Delta t = \text{Prob}\{\text{realignment during } [\tau, \tau+\Delta\tau]\}$$

$$= \text{Prob}\{\text{realignment during } [\tau, \tau+\Delta\tau] \mid \text{no realignment during } [t, t+\tau]\} \cdot$$

$$\text{Prob}\{\text{no realignment during } [t, t+\tau]$$

$$= \lambda_t(\tau)\Delta\tau \cdot \exp[-\Lambda_t(\tau)],$$

where we for simplicity disregard the terms of order $o(\Delta t)$.

Let the expected conditional devaluation size, $\bar{z}_t^\tau$, be independent of the maturity and denoted by $\bar{z}_t$. The expected devaluation during $[t, t+\tau]$, $g_t^\tau\tau$, fulfills

$$(A2.7) \qquad g_t^\tau\tau = p_t^\tau\bar{z}_t$$

It follows from (A2.7) and (A2.5) that an estimate of the intensity function, conditional upon a given $\bar{z}_t$, can be computed by identifying

$$(A2.8) \qquad\qquad 1 - \exp[-\hat{\Lambda}_t(\tau)] = \hat{g}_t^\tau \tau / \bar{z}_t.$$

We notice the difference between (A1.4) and (A2.8). According to (A1.4), for a marked Poisson process the ratio between the expected devaluation and the conditional devaluation size equals the expected number of devaluations, which equals the value of the parameter function. According to (A2.8), for the self-exciting marked process described above, the same ratio equals the probability of a realignment, which equals one minus the exponential of the negative of the value of the parameter function.

We also note that

$$(A2.9) \quad 1 - \exp[-\Lambda_t(\tau)] = 1 - \Sigma_{n=0}^\infty [-\Lambda_t(\tau)]^n/(n!) = \Lambda_t(\tau) + \Sigma_{n=1}^\infty [-\Lambda_t(\tau)]^n/(n!).$$

For short maturities and small values of the intensity function, the parameter function is small and the right-hand side is approximately equal to $\Lambda_t(\tau)$, in which case the the two realignment models give similar estimates of the parameter function. However, since in our case the ratio between the expected devaluation and the expected conditional devaluation size is sometimes not far from unity, the two models give rather different estimates.

Table 5.1. OLS estimation of expected future exchange rates, (5.2)

	Maturity			
	1 month	3 months	6 months	12 months
Regime I				
(82:01:01 – 85:06:26)				
Intercept	-.00 (.06)	-.05 (.17)	-.56 (.32)	-1.32 (.19)
Slope	.85 (.06)	.60 (.16)	-.15 (.52)	-1.27 (.37)
Diagnostics				
N	776	698	580	386
R-squared	.66	.24	.01	.35
σ	.45	.70	.84	.73
Regime 2				
(85:06:27 – 91:02:17)				
Intercept	-.13 (.06)	-.46 (.18)	-.64 (.19)	-.51 (.18)
Slope	.78 (.06)	.22 (.19)	-.08 (.19)	.06 (.18)
Diagnostics				
N	1337	1299	1235	1123
R-squared	.60	.04	.005	.004
σ	.34	.53	.54	.56

OLS on (5.2) with Newey-West standard errors within parentheses (lags equal to each maturity). Exchange rates within the band are measured in percent log deviation from central parity. The number of observations decrease with maturity since observations corresponding within one maturity are excluded at the end of each regime, and before the realignment during regime I.

Table 6.1. Regression of estimated expected rate of devaluation
on selected macro variables (3 months maturity)

Intercept	-1.93 (2.15)
Current account (SEK billion per month)	-1.03** (.23)
Rate of unemployment (percent)	1.47 (1.04)
Central government borrowing requirement (SEK billion per month)	.02 (.06)
Rate of money growth (percent per year)	.01 (.005)
Rate of real exchange rate depreciation (percent per year)	-.19* (.08)
Election dummy	2.75** (.98)
Change in foreign exchange reserves (SEK billion per month)	.13** (.05)

Diagnostics

N	106
R-squared	.56
σ	1.67

Newey-West standard errors within parentheses (12 lags). The sample period is April
1982-January 1991. A * denotes significance on a 5 percent level, ** on a 1 percent level.
Data were obtained from Sveriges Riksbank, IFS and Monthly Digest of Swedish
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Diagram 2.1 Exchange rate (currency index)

Diagram 2.2a Interest rate differential: 1 month

Diagram 2.2c Interest rate differential: 6 months

Diagram 2.2b Interest rate differential: 3 months

Diagram 2.2d Interest rate differential: 12 months
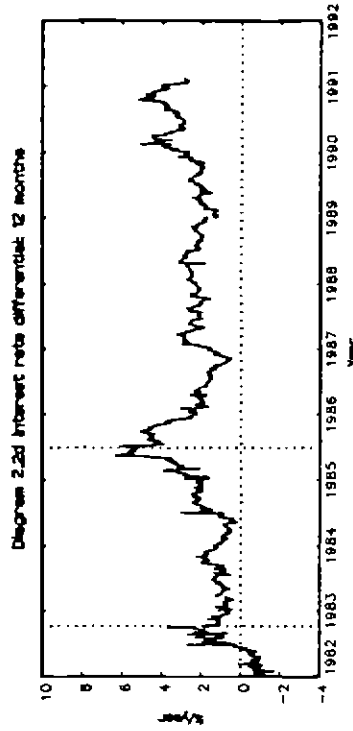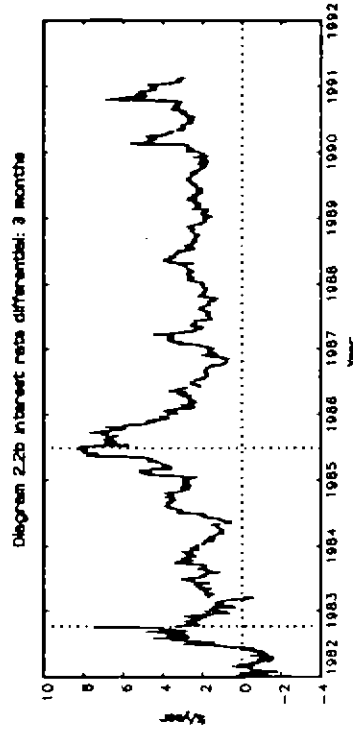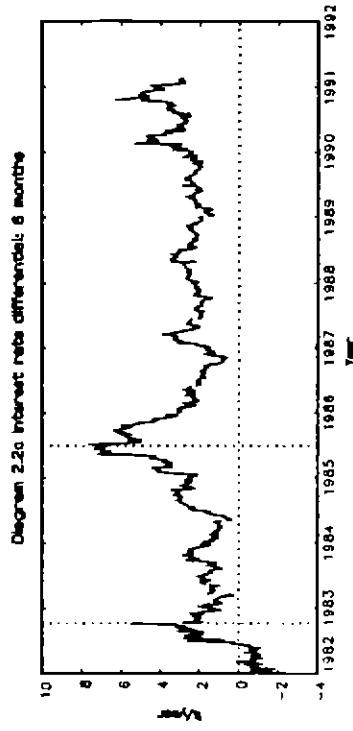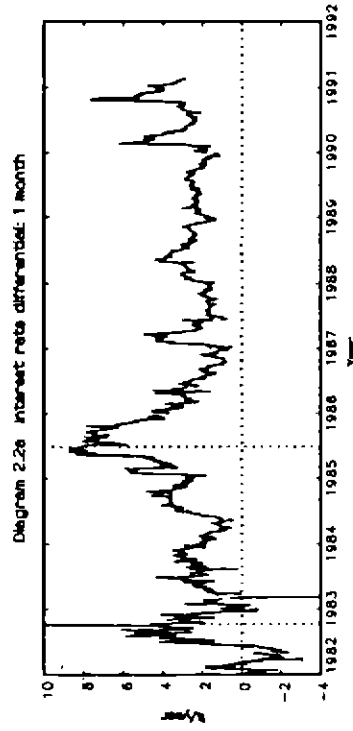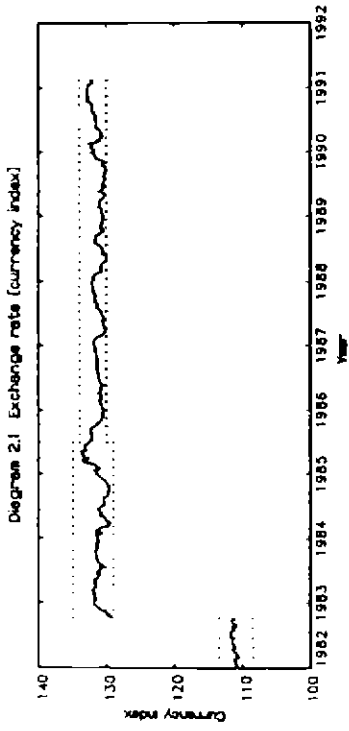
Diagram 4.1 Forward exchange rate
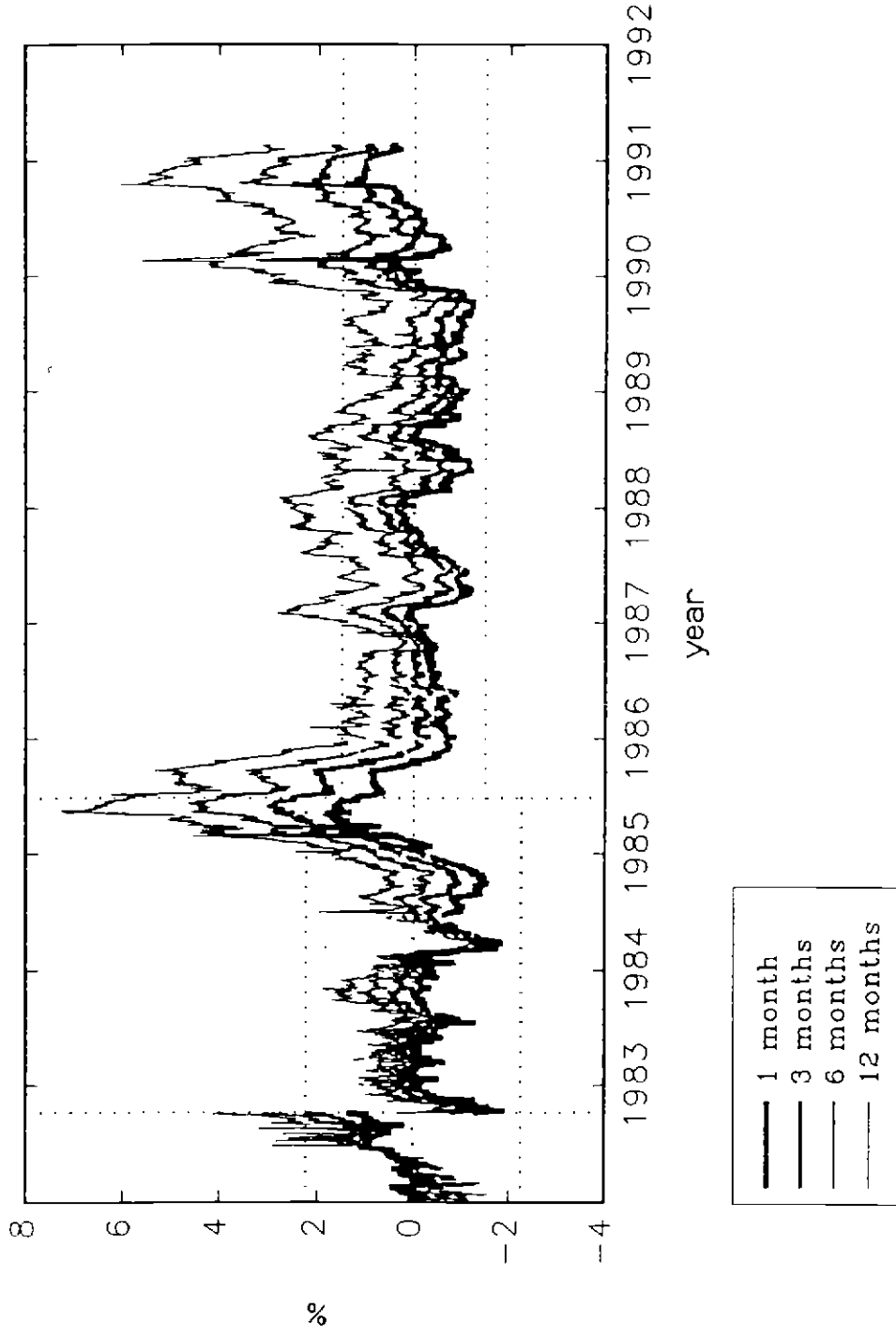
Diagram 4.2a: Expected rate of realignment: 1 month:
min and max
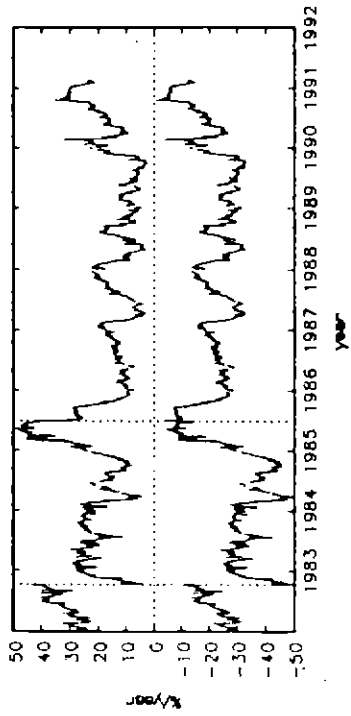
Diagram 4.2b: Expected rate of realignment: 3 months:
min and max
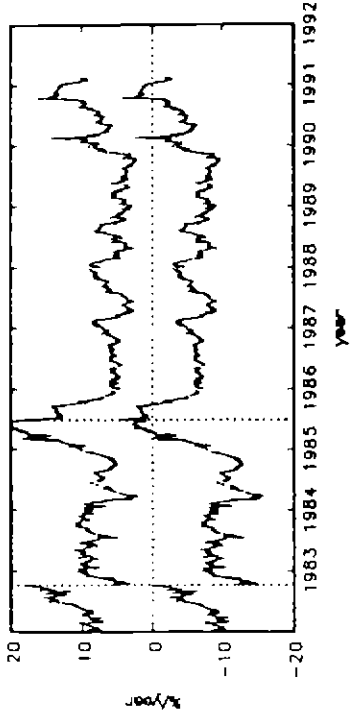
Diagram 4.2c: Expected rate of realignment: 6 months:
min and max
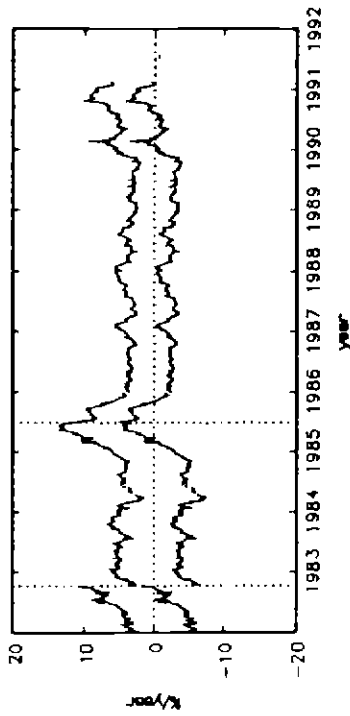
Diagram 4.2d: Expected rate of realignment: 12 months:
min and max
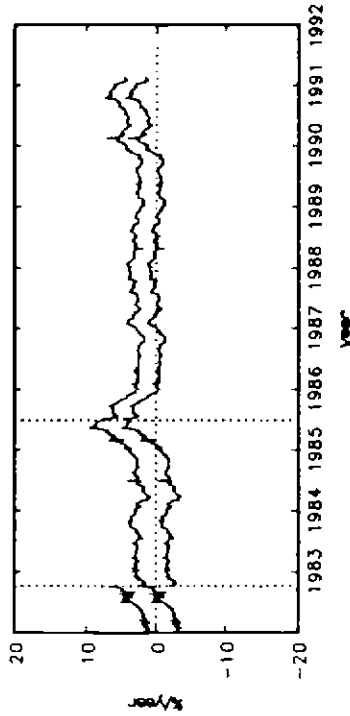
Diagram 5.1 Expected exchange rate

Exchange rate, %

%

after 1 month
after 3 months
after 6 months
after 12 months
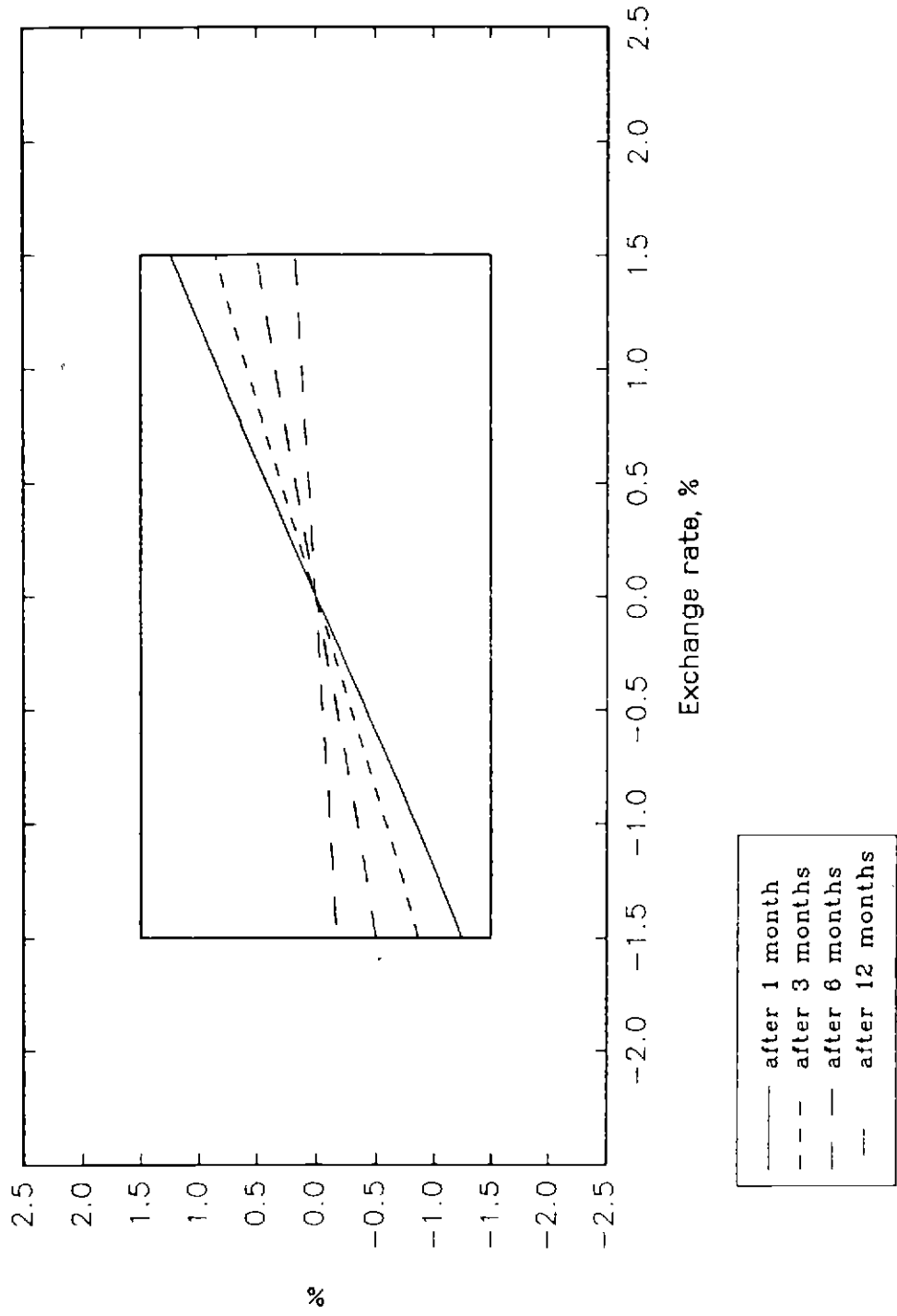
Diagram 5.2a Expected exchange rate: 1 month point estimate and 95% confidence band
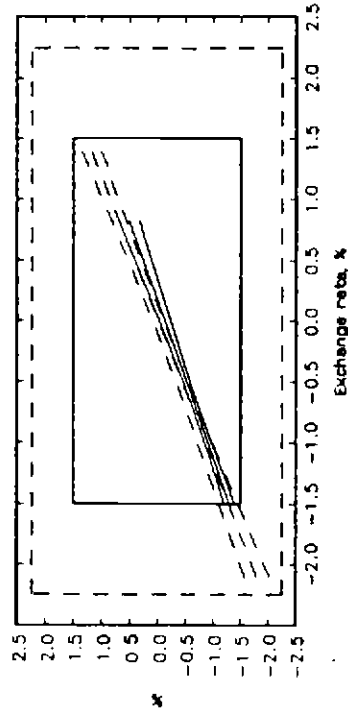
Diagram 5.2b Expected exchange rate: 3 months point estimate and 95% confidence band
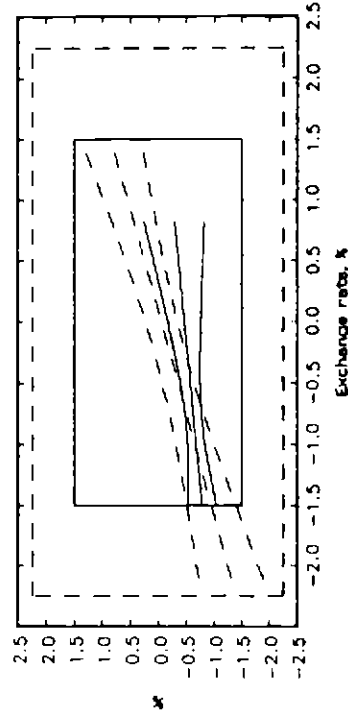
Diagram 5.2c Expected exchange rate: 6 months point estimate and 95% confidence band
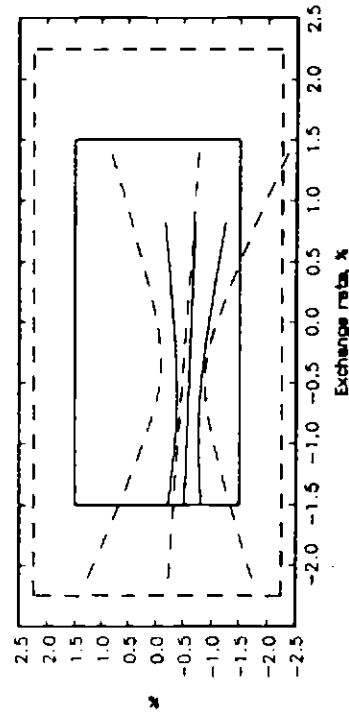
Diagram 5.2d Expected exchange rate: 12 months point estimate and 95% confidence band

Exchange rate, %
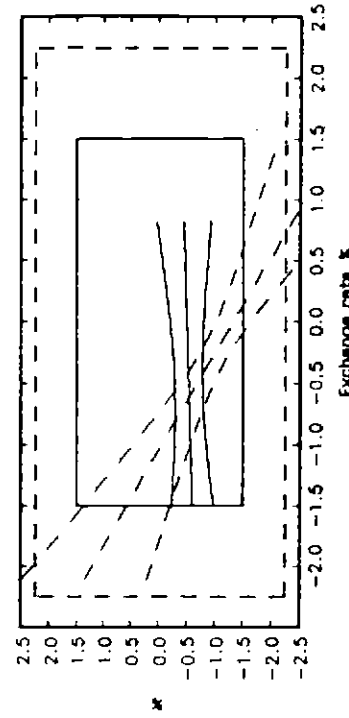
Diagram 5.3a: Expected rate of depreciation within the band: 1 month
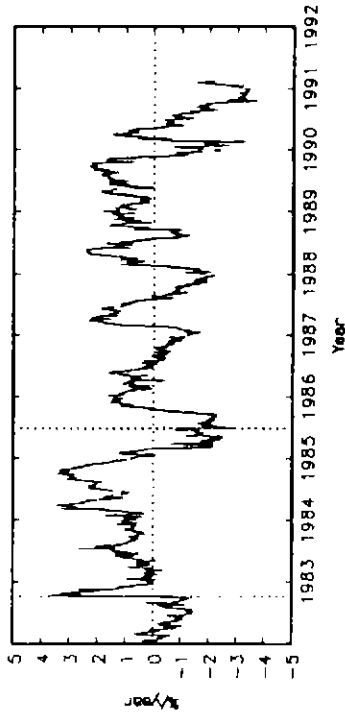
Diagram 5.3b: Expected rate of depreciation within the band: 3 months
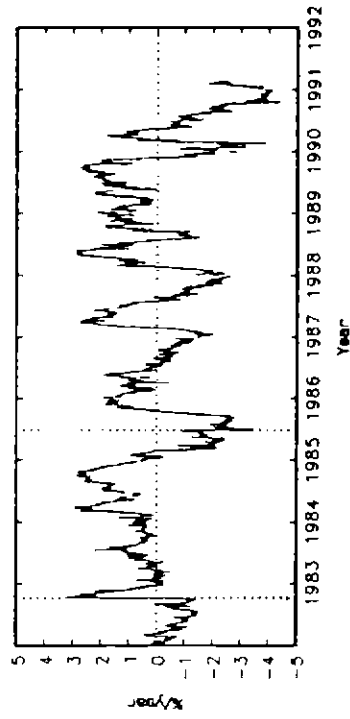
Diagram 5.3c: Expected rate of depreciation within the band: 6 months
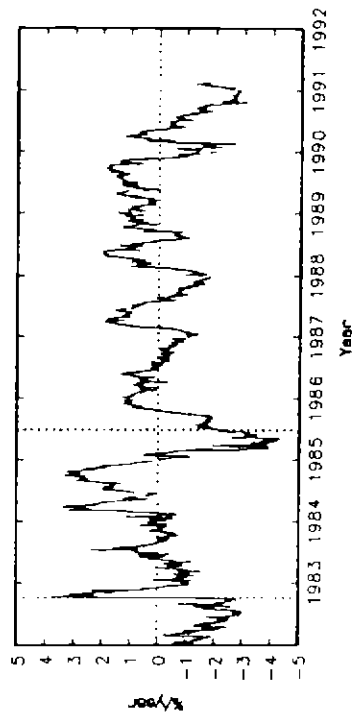
Diagram 5.3d: Expected rate of depreciation within the band: 12 months
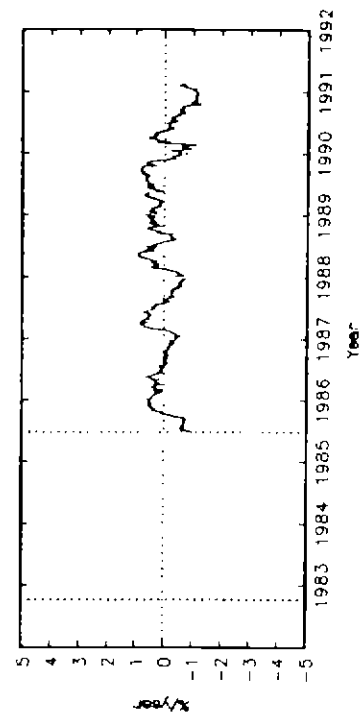
Diagram 5.4a Expected rate of devaluation: 1 month
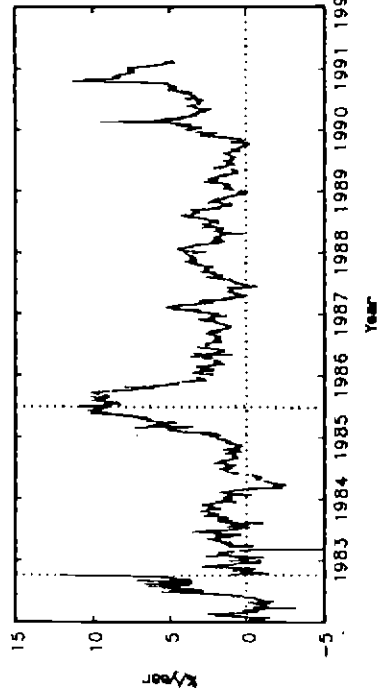
Diagram 5.4b Expected rate of devaluation: 3 months
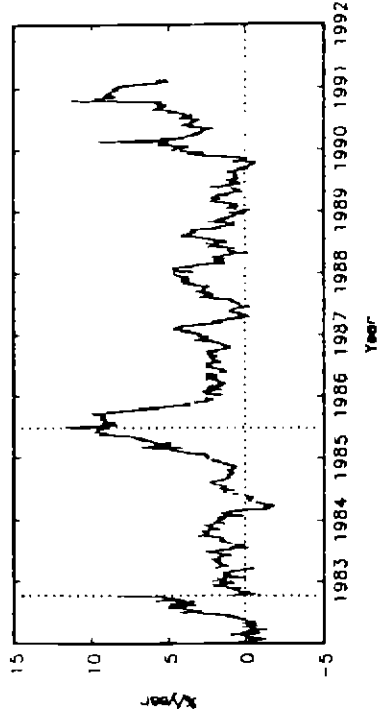
Diagram 5.4c Expected rate of devaluation: 6 months
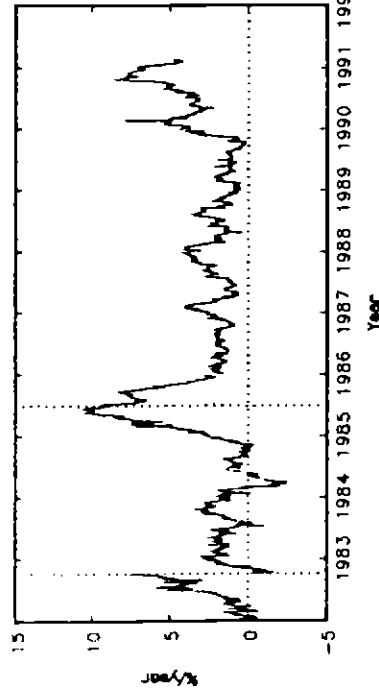
Diagram 5.4d Expected rate of devaluation: 12 months
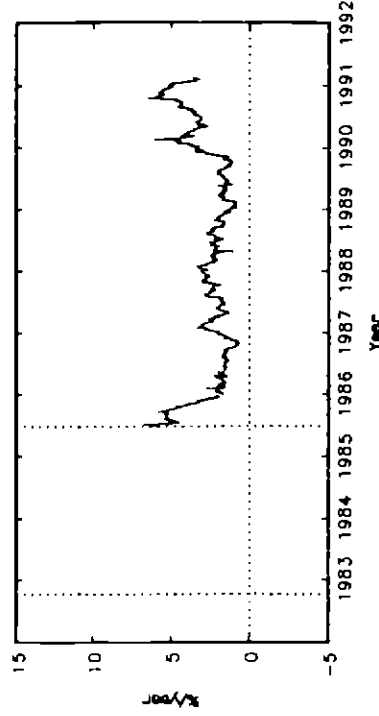
Diagram 5.5a Expected rate of devaluation: 1 month
95% confidence interval
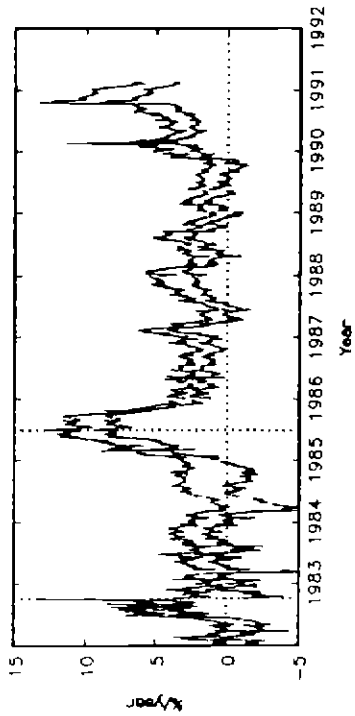
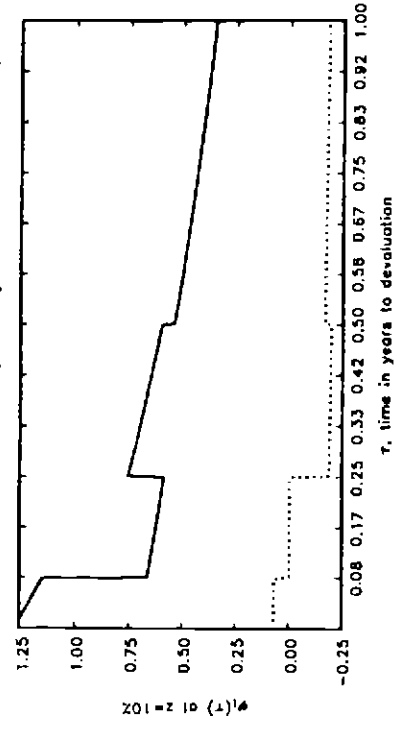Diagram 5.5b Expected rate of devaluation: 3 months
95% confidence interval
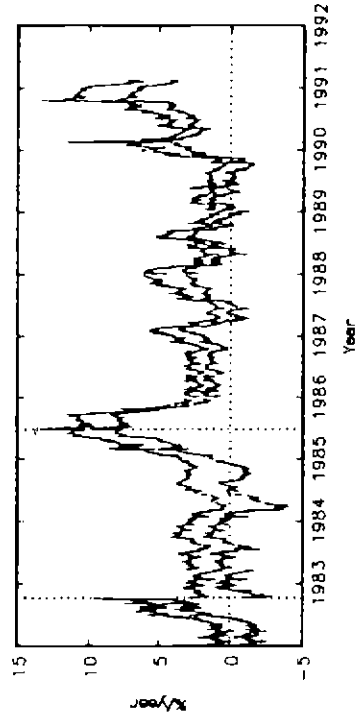
Diagram 5.5c Expected rate of devaluation: 6 months
95% confidence interval
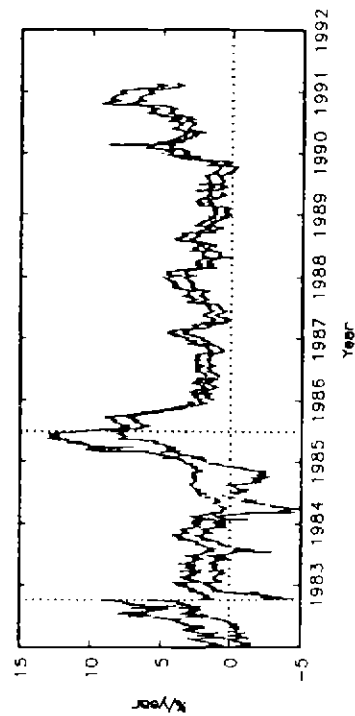
Diagram 5.5d Expected rate of devaluation: 12 months
95% confidence interval

%/year

Year

15 10 5 0 -5

1983 1984 1985 1986 1987 1988 1989 1990 1991 1992

Diagram 5.6b Probability density for time to devaluation

τ, time in years to devaluation

$\phi_t(\tau)$ at z=10%

t = October 8, 1982
t = October 11, 1982
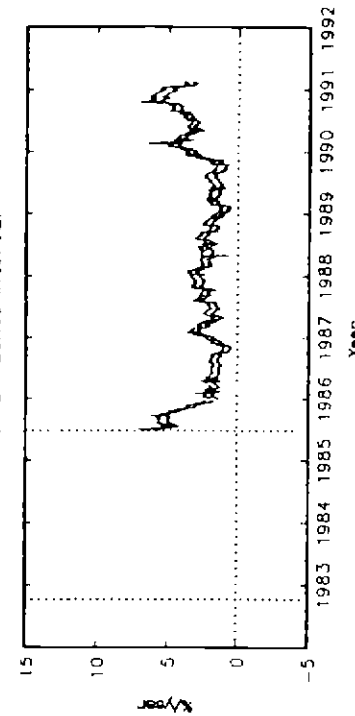
Diagram 5.6a Probability density for time to devaluation

t, week No. in 1982 (September - October)

$\phi_t(\tau)$ at z=10%

τ = 1 month
τ = 3 months
τ = 6 months
τ = 12 months
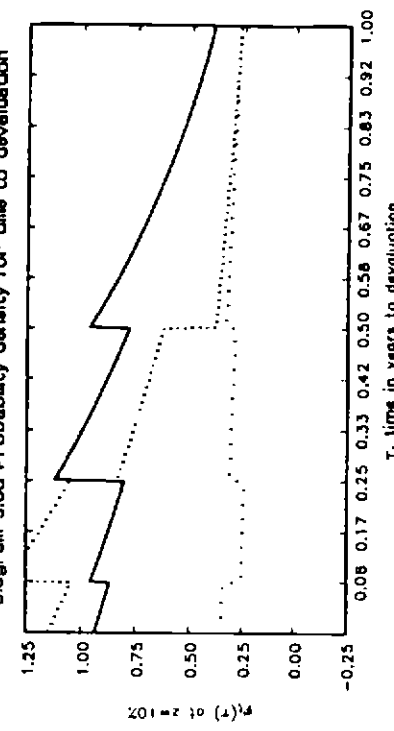
Diagram 5.6d Probability density for time to devaluation

τ, time in years to devaluation

$\phi_t(\tau)$ at z=10%

t = June 24, 1985
t = June 25, 1985
t = November 29, 1985

Diagram 5.6c Probability density for time to devaluation

t, week No. in 1985 (April - November)

$\phi_t(\tau)$ at z=10%

τ = 1 month
τ = 3 months
τ = 6 months
τ = 12 months

Diagram 5.7b Probability density for time to devaluation

$\varphi_t(\tau)$ at $z=10\%$

τ, time in years to devaluation

t = February 19, 1990
t = February 23, 1990
t = March 19, 1990

Diagram 5.7d Probability density for time to devaluation

$\varphi_t(\tau)$ at $z=10\%$

τ, time in years to devaluation

t = October 8, 1990
t = October 18, 1990

Diagram 5.7a Probability density for time to devaluation

$\varphi_t(\tau)$ at $z=10\%$

t, week No. in 1990 (January – March)

τ = 1 month
τ = 3 months
τ = 6 months
τ = 12 months

Diagram 5.7c Probability density for time to devaluation

$\varphi_t(\tau)$ at $z=10\%$

t, week No. in 1990 (October – December)

τ = 1 month
τ = 3 months
τ = 6 months
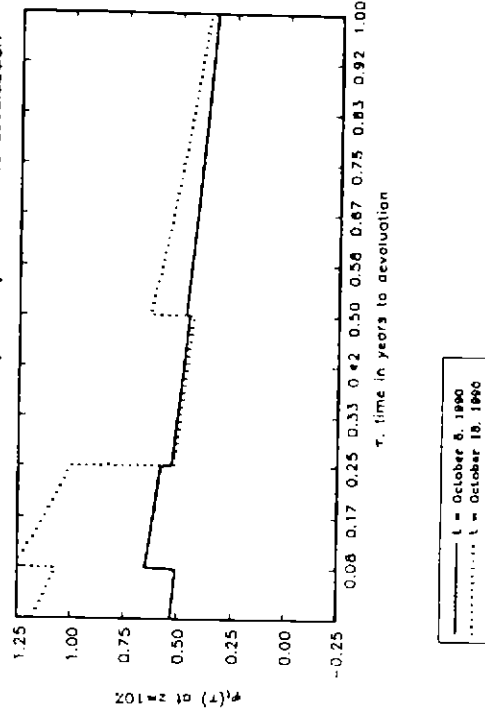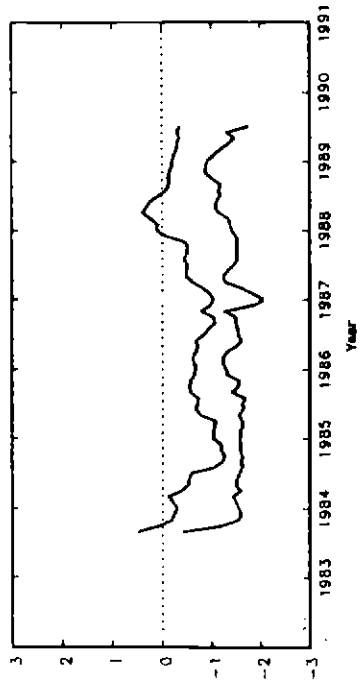τ = 12 months

Diagram 6.1a   Current account coefficient: 3 months
95% confidence interval

Year

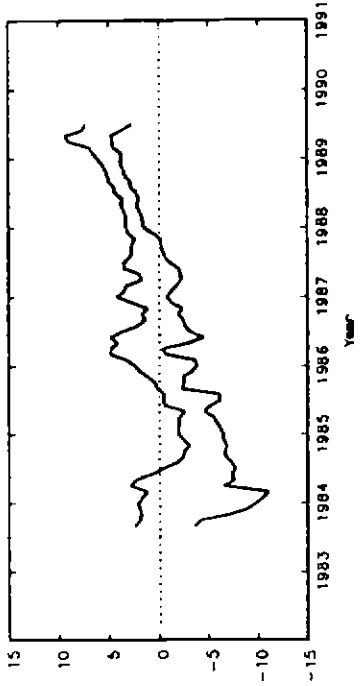Diagram 6.1c   Money growth coefficient: 3 months
95% confidence interval

Year

Diagram 6.1b   Unemployment coefficient: 3 months
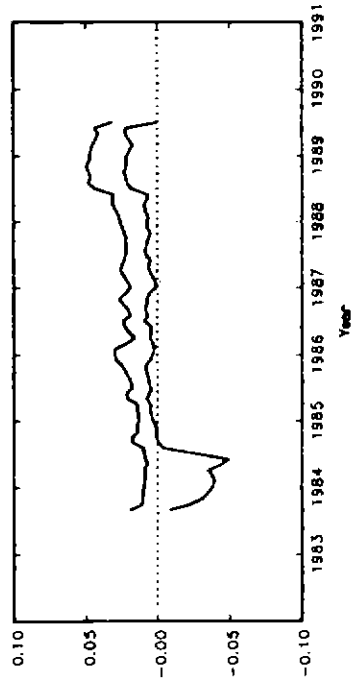95% confidence interval

Year

Diagram 6.1d   Election dummy coefficient: 3 months
95% confidence interval

Year