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TARGET ZONES BIG AND SMALL

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ABSTRACT

Under different assumptions about the underlying monetary shocks, we study target zones of various widths and the effect they have on variables like the interest differential.

The stochastic disturbances assumed are successively a non-zero mean random walk and a mean reverting process. The latter is used to incorporate the "leaning against the wind" policy (intramarginal intervention) which is prevalent in the EMS.

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This paper is an extension of earlier work. In Delgado and Dumas (1990) a general solution technique is used to analyze different contracting arrangements between two central banks who agree to intervene in the foreign exchange market to maintain their currencies within certain limits. In this study we would like to address a different issue, namely the effects on macro variables of the widening and narrowing of the target zone, with special emphasis on changes in the interest rate differential. The experiment of progressivly narrowing the target zone is of interest as a representation of the transition between a target zone arrangement and a unique currency, assuming that a fully credible fixed exchange rate is identical to a unique currency.

Svensson (1989) has already studied this question. He restricted himself to the study of a stochastic process without drift. We extend his work and Delgado and Dumas (1990) by incorporating successively a non-zero drift and a mean-reverting process. As Svensson suggested, it is necessary to study a process that is not characterized by a constant mean. A mean reverting process has this property. This type of process will be used to model the fact that in the functioning of the EMS about 85% of the intervention is done intramarginally.

The paper is organized as follows: Section I lays out the basic framework for both the non-zero mean linear Brownian motion and the mean-reverting process. The necessary assumptions will be made in this section. Section II presents the various solutions for the exchange rate process in the Brownian motion case. Section III studies the limiting properties of the zone when the target zone is either very wide or very narrow; this includes the behavior of the interest rate differential. Section IV describes the various interpretations of the mean reverting process and presents the various solutions for the exchange rate function. Section V establishes the limiting properties of the mean reverting case. We conclude in Section VI.

I. THE MODEL: DIFFERENTIAL EQUATION FOR THE EXCHANGE RATE

The basic equation on which most of the target zone literature is based is:

$$S = m - m^{*} + v + \gamma E(dS \mid \Phi(t))/dt \qquad (1)$$

where S is the exchange rate between two currencies (the domestic currency value of foreign exchange), $m = \ell n(R + D)$ and $m^{*} = \ell n(R^{*} + D^{*})$ are domestic and foreign measures of <u>controllable</u> money supply and v is an <u>exogenous</u> monetary shock. In this study m and m^{*} are deemed controllable because foreign exchange intervention by Central Banks modifies reserves R and R^{*}; D and D^{*} stand for domestic credit. γ is a coefficient interpreted as an interest semi-elasticity of money demand and $E(dS \mid \Phi(t))/dt$ is the conditionally expected instantaneous change in the exchange rate; $\Phi(t)$ is the information set of economic agents acting in the foreign exchange market.

The following assumptions are made:

A1) Intervention in the foreign exchange market which occurs at the boundaries of the target zone (marginal intervention) is instantaneous and infinitesimal. Intervention which occurs within the band (intramarginal intervention) is proportional in intensity to the deviation from some target, so that we can model it by means of a mean reverting process. This reflects a policy of "leaning against the wind".[1]

[1]Lewis (1990) models "leaning against the wind" in a different manner.

A2) There is full cooperation between central banks to render the target zone completely credible. The burden of intervention is shared. If the country whose currency is weak has run out of reserves, the other central bank intervenes by printing money. The assumption is made in order to avoid the problem of running out of reserves which has been examined elsewhere [Delgado and Dumas (1990); see, by way of contrast, their Assumption 2].

A3) Commodity prices are flexible, purchasing power parity and uncovered interest rate parity hold. There is full capital mobility and interventions are not sterilized.

A4) Both countries share the same money demand function with identical parameters.

Svensson (1989) has examined limiting properties of some solutions of (1) under the assumption that the shock v follows a zero-drift arithmetic Brownian motion. Here we extend the analysis to Brownian motions with a non zero constant trend and to mean-reverting processes. The constant-trend formulation is:

$$dv = \mu dt + \sigma dW; \qquad \mu,\ \sigma \text{ constant and } > 0 \qquad (2)$$
$$v_0 > 0 \text{ given.}$$

In (2), μ and σ are constants and dW is the increment of a standard Wiener process. For $\mu > 0$ -- which, for the sake of definiteness, will be assumed -- we will say that the domestic currency is inherently weak because the trend in fundamentals works against it. Without intervention the domestic currency is expected to depreciate.

We also extend the analysis to the case of mean-reverting shocks which produces a variable drift:

$$dv = -\rho(v - a_0)dt + \sigma dz; \qquad \rho,\ \sigma \text{ constant and } > 0 \quad v_0 > 0 \text{ given,} \tag{3}$$

where a_o is the long-run level of v and ρ is the speed with which the process tends towards this value. In this specification a positive shock to v is detrimental to the domestic currency in the short run but also induces a drift which in the long run is favorable to the domestic currency. Appendix A reminds the reader [see also Svensson (1989), Froot and Obstfeld (1989b, footnote 2)] that it is conceivable to interpret v either as a supply or a demand shock. As long as v follows a constant drift process, the distinction is immaterial. When v is mean reverting, however, more care must be exercised; we return to the issue in section IV.

Equation (1) is the basic equation which Krugman (1990) used to study exchange rate target zones. Define the "fundamentals" X as: $m - m^* + v$. Note that X includes controllable (reserves) and uncontrollable (domestic credit) terms. Equation (1) can be rewritten as:

$$S = X + \gamma E\{dS \mid \Phi(t)\}/dt. \tag{4}$$

II. SOLUTIONS OF THE MODEL: *THE CONSTANT-MEAN CASE*

We are now ready to solve the model for the two basic assumptions about the stochastic process followed by the "fundamentals". In the next two sections we analyze the non-zero constant mean case and in the following ones the mean reverting case.

We interpret the constant-trend case [equation (2)] as one in which intervention occurs at the margins only and is of the instantaneous variety. The stochastic differential equation for the fundamentals can be written as the non-regulated fundamentals plus two terms that take into account the intervention of the central banks, dU and dL:

$$dX = \mu dt + \sigma dW - dU + dL, \tag{5}$$

with initial condition $X(0) = X_0 = m_0 + m^*_0 + v_0$, $U(0) = 0$, $L(0) = 0$, U and L being two non negative non decreasing processes, and U increases only when $S = \bar{S}$ while L increases only when $S = \underline{S}$. U and L stand for the cumulative amounts of intervention done by the two countries. Because of Assumption A2 we do not have to specify who performs the intervention. Equation (5) indicates that the same fixed trend drives v and the fundamentals X.

Assume that the value of the exchange rate is a twice continuously differentiable function of X and apply Itô's lemma to calculate $E\{dS \mid \Phi(t)\}/dt$ explicitly. Substitution of the resulting expression into (4) yields the basic differential equation which must be satisfied by the exchange rate function, irrespective of the particular government policy regarding exchange rates:

$$S = X + \gamma[\mu S'(X) + 0.5\sigma^2 S''(X)]. \tag{6}$$

This equation applies over the domain of X where no intervention takes place.

The <u>general solution</u> of (6) is:

$$S(X) = X + \gamma\mu + Ae^{\alpha X} + Be^{-\beta X} \tag{7}$$

where A and B are constants of integration which must be solved for, using the boundary conditions implied by the exchange rate policy. α and $-\beta$ are the positive and negative roots of the characteristic equation: $1 = \gamma\mu q + 0.5\gamma\sigma^2 q^2$. One property of the roots will prove useful later: $1/\alpha - 1/\beta = \gamma\mu$.

<u>The free-float particular solution</u>: Resorting to a no-bubble argument and considering the fact that X under free float has support in $(-\infty,\infty)$ both exponential terms are eliminated on the grounds that they would generate explosive paths. This implies $A = B = 0$. Therefore, the equation for the exchange rate is:

$$S = X + \gamma\mu. \tag{8}$$

The free-float solution, shown in Figure 1 and other figures, is a 45^{o} line with intercept at $S = \gamma\mu$

<u>A fixed-rate regime</u> is, in theory, an exchange rate system in which the government is committed to doing whatever is necessary to maintain the exchange rate fixed. Because of the full credibility assumption, we can identify in this study a fixed-rate regime and a one currency world.[2]

If we refer to Figure 1, *point* FX on the diagonal line represents a strict fixed-exchange regime solution. Indeed, if the exchange rate is not expected to change $(E\{dS \mid \Phi(t)\}/dt = 0)$, Equation (4) implies:

$$S = X \tag{9}$$

If the authorities wish to peg the exchange rate at some level S_0, they must

---

[2] We show below that the fixed rate regime is also the limit of a sequence of narrower and narrower bands.

strictly maintain the fundamentals at a level $X = S_0$.

<u>Target zone solutions</u>: Assuming that the target zone policy has been specified by two bounds on the exchange rate and the size of the interventions (infinitesimal in our case), there is a unique solution to the target zone problem. This solution is characterized by smooth-pasting conditions at the boundaries[3].

The determination of the constants of integration A and B and the bounds on fundamentals implied by the bounds on exchange rates is done by solving simultaneously the following system of four equations with four unknowns A, B, $\underline{X}$, and $\bar{X}$.

$$\bar{S} = \bar{X} + \gamma\mu + Ae^{\alpha\bar{X}} + Be^{-\beta\bar{X}} \tag{10}$$

$$\underline{S} = \underline{X} + \gamma\mu + Ae^{\alpha\underline{X}} + Be^{-\beta\underline{X}} \tag{11}$$

$$0 = 1 + \alpha Ae^{\alpha\bar{X}} - \beta Be^{-\beta\bar{X}} \tag{12}$$

$$0 = 1 + \alpha Ae^{\alpha\underline{X}} - \beta Be^{-\beta\underline{X}} \tag{13}$$

In (10)-(13), $\bar{S}$ and $\underline{S}$ are the upper and lower limits the governments will allow the exchange rate to reach before intervention. $\bar{X}$ and $\underline{X}$ are the implied limits for the fundamentals. Equations (10) and (11) are just a restatement

[3] Flood and Garber (1989) present a model in which the policy is not specified by infinitesimal interventions but by discrete ones. This implies the same exchange rate function for the same bounds placed on the exchange rate. The type of regulation implied by discrete interventions is called impulse control.

of the fact that at the boundaries of the target zone $\bar{S} = S(\bar{X})$ and $\underline{S} = S(\underline{X})$. Equations (12) and (13) are the "smooth pasting" conditions. We solve this system for the general case of *non-zero drift* in fundamentals, in which a symmetric band placed on the exchange rate translates into an *asymmetric band* placed on the fundamentals.

The study of the properties of target zones is based on the solution of the system given by equations (10)-(13). Since the system is linear in the constants of integration, it is straightforward to eliminate them and obtain a non-linear system of two equations with two unknowns $\bar{X}$ and $\underline{X}$:

$$\bar{X} = \bar{S} - \gamma\mu + \frac{-\beta e^{\alpha\bar{X} - \beta\underline{X}} - \alpha e^{\alpha\underline{X} - \beta\bar{X}} + (\alpha+\beta) e^{(\alpha-\beta)\bar{X}}}{-\alpha\beta\left(e^{\alpha\bar{X} - \beta\underline{X}} - e^{\alpha\underline{X} - \beta\bar{X}}\right)} \tag{14}$$

$$\underline{X} = \underline{S} - \gamma\mu + \frac{\alpha e^{\alpha\bar{X} - \beta\underline{X}} + \beta e^{\alpha\underline{X} - \beta\bar{X}} - (\alpha+\beta) e^{(\alpha-\beta)\underline{X}}}{-\alpha\beta\left(e^{\alpha\bar{X} - \beta\underline{X}} - e^{\alpha\underline{X} - \beta\bar{X}}\right)} \tag{15}$$

INSERT FIGURE 1 HERE

Part of our exposition of what happens as one changes the width of the band will refer to Figure 1. We proceed to explain it at this point. The figure is constructed by changing the width of the band around S_0. This means solving the system (14)-(15) for different values of $\bar{S}$ and $\underline{S}$ *positioned symmetrically around* S_0 (= 4.5 in Figure 1). The two straight lines in the middle are the 45° diagonal line which contains the fixed exchange points, and the free float. As we know, the free float is also a 45° line but translated up a distance $\gamma\mu$. The thick line is the locus of tangencies implied by the smooth pasting conditions. Points above S_0 are pairs $(\bar{X}, \bar{S})$; points below S_0 are pairs $(\underline{X}, \underline{S})$. Furthermore, in Figure 1 -- as is clear from the basic Equation (4) which indicates that the interest-rate differential is equal to $(S - X)/\gamma$,-- iso-interest-rate differential lines would also be 45° lines, the diagonal line corresponding to a zero value of the interest-rate differential, while the free-float line corresponds to the level μ of the differential.

As is clear from Figure 1, the following holds:

Statement # 1: The locus of tangency points establishes a monotonic (increasing) relationship between the positioning of the bounds on the exchange rate and the positioning of the bounds on the fundamentals.

Proof: See Appendix B.

Statement # 1 authorizes us, under the current assumption of infinitesimal intervention, to define a target zone in terms of exchange rate bounds. The assumption of declared bounds imposed on the exchange rate rather than on the fundamentals is preferable because, in practice, exchange rates are directly observable by the financial markets, while fundamentals are less easily observable.

III. LIMITING PROPERTIES OF TARGET ZONES UNDER *CONSTANT MEAN* FUNDAMENTALS

III.1 Widening the band

We now study the behavior of exchange rates and interest rate differentials for wide bands. The behavior of the interest rate differential is quite different for wide bands from what it is for narrow ones. We show that:

Statement # 2: For wide enough bands, the distance of $\bar{X}$ from the diagonal line is the same asymptotically as the distance of $\underline{X}$ from the free-float line and that both tend to a constant value.

Proof: See appendix C

INSERT FIGURES 2 AND 3 HERE

The asymptotic behavior of the band described by statement # 2 has two implications. First, it implies that at points such as B of Figure 1 the <u>expected change in the exchange rate</u> (and the interest rate differential) is close to $+\mu + 1/\gamma\beta$, which is also $1/\gamma\alpha$. At points such as C, it is close to $-1/\gamma\beta$. These are also the limits of the two extreme values of the interest rate differential occurring at the edges of the band (see Figure 2).

Figure 3 shows in greater detail an example of an exchange rate curve, an interest-rate differential curve and the free float curve for a given wide band. For values of the exchange rate close to the free float curve, the interest rate differential is constant and equal to μ. As the band is widened, this flat section expands because the exchange rate is closer to the free float over a wider range of fundamentals. Hence, interest rate variability would tend to approach zero. This point has been emphasized by Svensson (1989); it is obviously equally valid in the special symmetric case and in the general case; we do not delve on it further.

<u>III.2 Narrowing the band</u>

Figure 1 can again help in visualizing the process of narrowing the band. As one tightens the band around a given exchange rate value S_0, the system converges to the fixed-rate solution ($X = S = S_0$). The interesting aspect, however, is the rate at which this convergence takes place:[4]

Statement # 3 The relationship between the bounds on the exchange rate and the bounds on the fundamentals is cubic.

Proof: See Appendix D.

Statement # 3 generalizes a similar result obtained by Svensson (1989) in the zero-mean case. This result has an important policy implication. Even a very tight target zone provides some room for the fundamentals to move about: the bounds on the fundamentals are two order of magnitude wider apart than the bounds on the exchange rate! As compared to a strict fixed-rate system, in which fundamentals would be absolutely immutable, a narrow target zone buys a lot of temporary flexibility. Foreign exchange traders do not move the exchange rate in response to a deviation in the fundamentals precisely because, under the target zone intervention policy, they know that this deviation is temporary. The anticipated reversion in the fundamentals, which is bound to be triggered in the near future, is what keeps the current exchange rate from reacting to the current value of the fundamentals.

INSERT FIGURE 4 HERE

As a function of fundamentals, the interest differential, as we narrow the band, has a smaller and smaller flat section over the range within which fundamentals are allowed to oscillate without intervention. In Figure 4, drawn for a given narrow band, the interest differential is practically a straight line at an angle equal to $-1/\gamma$. Hence, as in Svensson (1989), fundamentals volatility translates one-for-one into interest-rate volatility, provided the

[4] We also find below for the mean reversion case that the relationship is cubic.

economy is inside the band; in fact, the standard deviation of the differential, conditional on being at a given point in the band, grows monotonically as one narrows the band.

But, of course, as the band narrows, the supports of the probability distributions of the fundamentals and the interest rate differential shrink dramatically. The overall, unconditional variability of the differential approaches zero as the band shrinks. This fact is vividly illustrated by Figure 2 which also illustrates the rate at which convergence to zero variability takes place. Recall that this figure shows the extreme values of the differential against the extreme values of the fundamentals. The range of fluctuations of the differential drops precipitously as the band is tightened.

IV. *MEAN REVERTING* FUNDAMENTALS

In this section we set up and solve an exchange rate system similar to the fixed trend fundamentals but with a crucial difference: The assumed process for the cumulative disturbance v is mean reverting,[5] as in equation (3). A mean reverting supply disturbance is particularly interesting to study if v is interpreted as a supply shock, as it can represent an error-correction policy on the part of authorities. In particular, intervention on the part of Central banks within the band, prior to reaching the edges, can be modelled that way. This interpretation would fit the fact that 85% of all intervention is done intramarginally. In the earlier constant-drift specification (Sections II and III), it has been possible to interpret v interchangeably as a demand or as a supply shock (see Appendix A). In the present case, we are going to

[5] Other researchers have used this process: Dumas (1989), Miller and Weller (1988), Krugman and Rotemberg (1990) and Froot and Obstfeld (1989a).

distinguish the two interpretations carefullY.

IV.1 The model

Exchange rate Equation (1) remains in force, but, in place of Equation (2), stochastic differential Equation (3) characterizes the process followed by v. a_o is the long-run level of accumulated shocks and ρ is the speed with which the process tends toward this value. This equation implies that the process followed by $X = m - m^* + v$ is given by:

$$dX = -\rho(X - A_0) + \sigma dW - dU + dL \tag{16}$$

where $A_0 = a_0 + m - m^*$. We now distinguish two interpretations of the model.

Interpretation # 1: v is a demand shock. The mean reverting process for v translates into a similar mean reverting process for X. However, while a_o is a constant, the reversion point A_0 for X is not immutable. U and L have the same interpretation as before. Every time intervention is activated at the boundaries, $m - m^*$ changes value and affects A_0. A_0 becomes in effect a new state variable of the system, one, however, which changes only at the boundaries. The initial condition is still $X_o = m0 - m_0^* + v_0$.

Interpretation # 2: v is a supply shock reflecting intramarginal intervention. Here again, the mean reverting process for v translates into a similar mean reverting process for X. The difference with interpretation # 1 arises in the joint behavior of a_0 and A_0. We are no longer forced to consider that A_0 varies over time. If the authorities have decided to enforce, by marginal intervention, a target zone centered on S_0, it would be inconsistent for them to let the target point of the intramarginal intervention wander away from some preset level; they must therefore adjust a_0 as $m - m^*$ changes to keep A_0 constant. This preset level is likely to be precisely $A_0 = S_0$.

Under both interpretations, the differential equation implied by (1) and the process for X given in (17) is:[6]

$$S(X) = X - \gamma\rho(X - A_0)S'(X) + 0.5\gamma\sigma^2 S''(X) \qquad (17)$$

A change of variable $Y = \rho(A_0 - X)^2/\sigma^2$ turns equation (17) into Kummer's equation.[7] The general solution of differential equation (17) is:

$$S(Y(X)) = (X+A_0\rho\gamma)/(1+\rho\gamma) + C_1M[1/2\rho\gamma;0.5;Y] + C_2M[(1+\rho\gamma)/2\rho\gamma;1.5;Y]\sqrt{\rho}(A_0-X)/\sigma \qquad (18)$$

where $M[\cdot;\cdot;\cdot]$ is the confluent hypergeometric function (HGF); C_1 and C_2 are constants of integration to be determined by boundary behavior as in section II.

IV.2 Solutions

The free float solution, corresponding to an absence of marginal intervention, is given by the first term in (18), a straight line in Figures 5 and 6. Unlike the fixed trend fundamental case, this line is not fixed. Its position (but not its slope) depends, via the variable A_0 on the two money supplies and therefore on the two Central banks' levels of assets (including reserves).

The target zone policy implies, as before, the solution of a system of four equations with four unknowns C_1, C_2, $\bar{X}$, $\underline{X}$, given the choice of exchange rate bounds.

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[6]This is, of course, after applying Itô's lemma, and assuming that S(X) is twice continuously differentiable.

[7]See Abramowitz and Stegun (1972), page 504.

$$S(Y(\bar{X})) = \bar{S} \quad (19)$$

$$S(Y(\underline{X})) = \underline{S} \quad (20)$$

$$S'(Y(\bar{X})) = 0 \quad (21)$$

$$S'(Y(\underline{X})) = 0 \quad (22)$$

Consider first the symmetric case, in which exchange rate bounds are placed at an equal distance from the mean reversion point A_0. Direct observation of Equation (18) allows one to conclude that the integration constant C_1 must be equal to zero, since it is the coefficient of the only non-symmetric term. Let $S_0 = A_0$, $\bar{X} = A_0 + \delta$, $\underline{X} = A_0 - \delta$ and $\bar{S} = S_0 + \epsilon$, $\underline{S} = S_0 - \epsilon$. The variable δ must be determined as a function of ϵ, the distance of the bounds from $S_0 = A_0$. The system reduces to one of two equations with two unknowns C_2 and δ.

$$S_0 + \epsilon = (S_0 + \delta + A_0\rho\gamma)/(1+\rho\gamma) - C_2 M[(1+\rho\gamma)/2\rho\gamma;1.5;\bar{Y}]\sqrt{\rho}\delta/\sigma \quad (23)$$

$$0 = 1/(1 + \rho\gamma) - C_2(\sqrt{\rho}/\sigma)\{M[(1+\rho\gamma)/2\rho\gamma;1.5;\bar{Y}] + 2\bar{Y}\, M[(1+3\rho\gamma)/2\rho\gamma;2.5;\bar{Y}]\} \quad (24)$$

where $\bar{Y} = \rho\delta^2/\sigma^2$. Given S_0 and the half width of the band (ϵ) we can obtain C_2 and δ.

Under interpretation # 2 with $A_0 = S_0$ the symmetric case is perfectly natural. Under interpretation # 1, however, it is very special: Even if an exchange rate system starts in a symmetric situation, the first time one country intervenes to maintain the exchange rate within the specified bands, the symmetry will have been eliminated because the mean reversion point A_0

will have been shifted.[8]

It is therefore essential to solve the non-symmetric case as well. For that purpose we define some functions:

$$
\begin{aligned}
&Y(X) = \rho(A_0 - X)^2/\sigma^2 \qquad (25)\\
&M_1(Y) = M[1/2\rho\gamma\ ;\ 0.5\ ;\ Y]\\
&M_3(Y) = M[(1+2\rho\gamma)/2\rho\gamma\ ;\ 1.5\ ;\ Y]\\
&M_2(Y) = M[(1+\rho\gamma)/2\rho\gamma\ ;\ 1.5\ ;\ Y]\\
&M_4(Y) = M[(1+3\rho\gamma)/2\rho\gamma\ ;\ 2.5\ ;\ Y]\\
&N_1(Y) = M_1(Y(X))\\
&N_2(Y) = M_2(Y)\sqrt{\rho}(A_0 - X)/\sigma\\
&NP_1(Y) = 2[(A_0 - X)/\gamma\sigma^2]M_3(Y)\\
&NP_2(Y) = -(\sqrt{\rho})/\sigma\{M_2(Y) + 2Y[(1+\rho\gamma)/3\rho\gamma]M_4(Y)\}\\
&NPP1(Y) = (2/\gamma\sigma^2)M_3(Y) + 4Y[(1+2\rho\gamma)/(3\rho\gamma^2\sigma^2)]M_5(Y)\\
&NPP2(Y) = 2\rho\sqrt{Z}[(1+\rho\gamma)/(3\rho\gamma\sigma^2)]\{3M_4(Y) + 2Y[(1+3\rho\gamma)/(5\rho\gamma)]M_6(Y)\}
\end{aligned}
$$

N1 and N2 are the last two functional forms in the solution (19); NP1 and NP2 are their first derivatives and NPP1 and NPP2 their second derivatives.

With these definitions and some algebra to eliminate the constants of integration in the system (19)-(22) we can write a non-linear system of two variables with two unknowns for $\bar{X}$ and $\underset{-}{X}$, to be solved for given values of $\bar{S}$ and $\underset{-}{S}$:

$$
\begin{bmatrix} \bar{X} + A_0 - \bar{S}(1+\rho\gamma) \\ \underset{-}{X} + A_0 - \underset{-}{S}(1+\rho\gamma) \end{bmatrix} = \begin{bmatrix} N_1(\bar{X}) & N_2(\bar{X}) \\ N_1(\underset{-}{X}) & N_2(\underset{-}{X}) \end{bmatrix} \begin{bmatrix} NP_1(\bar{X}) & NP_2(\bar{X}) \\ NP_1(\underset{-}{X}) & NP_2(\underset{-}{X}) \end{bmatrix}^{-1} \begin{bmatrix} 1 \\ 1 \end{bmatrix} \qquad (33)
$$

[8] For the same reason, the free-float locus moves whenever a country intervenes.

We now draw the implications of this system.

V LIMITING PROPERTIES OF TARGET ZONES UNDER *MEAN REVERTING* FUNDAMENTALS

INSERT FIGURES 5 AND 6 HERE

The set of target zones of different widths is pictured as the thick line locus in Figures 5 and 6. These figures are laid out exactly like Figure 1 but under the assumption of a variable drift. Figure 5 depicts the "symmetric" mean-reversion case in which the exchange rate bands are centered, and then widened or narrowed, around the long-run mean reversion point for fundamentals ($S_0 = A_0$), while Figure 6 depicts the general case in which the same is done around an arbitrary point.

A comparison with the constant-trend case seems worthwhile at this point. For this purpose, one would calibrate a constant-trend analysis to match the values of the drift at the center of the band (e.g. we pick $\mu = 0$ in the symmetric case). It would be found that the constant-trend locus so calibrated is not uniformly inside or outside the mean-reversion locus. One might expect that the market would tolerate wider bands -- i.e. wider deviations in the fundamentals -- when the disturbance is known to have a temporary component than when it is permanent. In fact, the mean-reversion bounds on the fundamentals are inside the mean-reversion bounds for moderate size bands; they are outside them, as expected, only when the band is wide enough.

For the analysis of limiting properties of target zones, the following asymptotic values of the HGF will be useful:[9]

i) For small Y we can approximate $M[a;b;Y] \approx 1 + (a/b)Y$ (27)

ii) For large Y we can approximate $M[a;b;Y] \approx [\Gamma(b)/\Gamma(a)]e^{Y}Y^{a-b}(1+O|Y|^{-1})$ (28)

V.1 Widening the band

The solution of (26) for any band produces a relationship which links the positioning of the band in the fundamentals dimension to the center and width of the band in the exchange rate dimension. Using the limiting value (28) of this HGF, this relationship, at either end, is found to be:

$$\bar{S} = (\bar{X} + A_0\rho\gamma)/(1+\rho\gamma) \qquad \underline{S} = (\underline{X} + A_0\rho\gamma)/(1+\rho\gamma) \tag{29}$$

In other words:

Statement # 4: The asymptotes of the $(\bar{S},\bar{X})$ and $(\underline{S},\underline{X})$ loci in Figures 5 and 6 coincide with the free-float line.

The policy implications of this result are markedly at variance with those obtained for the constant-trend case:[10]

i) A very wide band is approximately the same as a regime without marginal intervention;

ii) For a very wide band, the interest-rate differential is at all times

[9] See Abramowitz and Stegun (1972), especially equations 13.1.2 and 13.1.4. page 504.

[10] Also, under imperfect credibility [as in Delgado and Dumas (1990)], a very wide band would require no reserves, as there would be practically no risk of speculative attacks: Under mean reversion, reaching the edges of a very wide band becomes a zero probability event. But this observation falls outside the topic of the present paper.

practically equal to what it would be under no marginal intervention: $\rho(A_0 - X)/(1 + \rho\gamma)$.

V.2 Tightening the band

The study of narrow bands must be distinguished depending on whether the band is chosen to be symmetric or not.

To study the behavior of narrow <u>symmetric</u> bands ($\bar{S} = S_0 + \epsilon$, $\underline{S} = S_0 - \epsilon$; $\bar{X} = S_0 + \delta$, $\underline{X} = S_0 + \delta$), we can proceed to linearize the system (19)-(22) using the expansion (27) of the HGF. This will give us a system of two equation with two unknowns. Solving for the constant of integration C_2 from (24) and replacing it in (23) yields the following equation which links the distance δ of the limits on fundamentals with the width ϵ of the band.

$$\epsilon = \frac{\delta}{1 + \rho\gamma} - \frac{\delta + \delta^3(1 + \rho\gamma)/(3\sigma^2\gamma)}{(1 + \rho\gamma)[1 + \delta^2((1 + \rho\gamma)/(\sigma^2\gamma))]} \qquad (30)$$

or, simplifying further:

$$\epsilon = (2/3)[(1+\rho\gamma)/(\gamma\sigma^2)]\delta^3. \qquad (31)$$

Hence:

Statement # 5: In the case of narrow symmetric bands, the relationship between the bounds on fundamentals and the bounds on the exchange rate is cubic, as in the case of constant drift.

The fundamentals deviation δ is of order $|\epsilon|^{1/3}$ (witness the flat section of the double-sided locus in Figure 5 near point FX). The fundamentals, here again, have a lot of room to move about.

A comparison of Figures 5 and 6 around point FX provides a hint that this result does not survive to an asymmetry in the band. For the asymmetric case ($\bar{S} = S_0 + \varepsilon$, $\underline{S} = S_0 - \varepsilon$; $\bar{X} = S_0 + \bar{\delta}$, $\underline{X} = S_0 - \underline{\delta}$), the full system (26) is needed. Expand around S_0 using the previously defined functions:

$$
\begin{aligned}
N_1(\bar{X}) &= N_1(S_0) + NP_1(S_0)\bar{\delta} \\
N_2(\bar{X}) &= N_2(S_0) + NP_2(S_0)\bar{\delta} \\
NP_1(\bar{X}) &= NP_1(S_0) + NPP_1(S_0)\bar{\delta} \\
NP_2(\bar{X}) &= NP_2(S_0) + NPP_2(S_0)\bar{\delta} \\
N_1(\underline{X}) &= N_1(S_0) - NP_1(S_0)\underline{\delta} \\
N_2(\underline{X}) &= N_2(S_0) - NP_2(S_0)\underline{\delta} \\
NP_1(\underline{X}) &= NP_1(S_0) - NPP_1(S_0)\underline{\delta} \\
NP_2(\underline{X}) &= NP_2(S_0) - NPP_2(S_0)\underline{\delta}
\end{aligned}
$$

where NPP1 (resp. NPP2) is the derivative of NP1 (NP2) with respect to X. Replacing in (26) we can solve for $\bar{\delta}$ and $\underline{\delta}$ and obtain:

$$\bar{\delta} = \underline{\delta} = 2\varepsilon(1 + \rho\gamma),$$

or: $$\varepsilon = \delta/2(1 + \rho\gamma). \qquad (32)$$

This result is to be compared to equation (31) which was cubic in δ.

Statement # 6: As soon as the band is not exactly centered on the reversion point, the relationship between the bounds on fundamentals and the bounds on the exchange rate is linear.

We loose the policy implication which said that fundamentals have room to move about even when the exchange rate band is narrow.

VI. CONCLUSION

This paper has illustrated the tradeoffs policy makers would face when choosing the width of a band, or when converging to an extremely narrow band in order to shift to a unique currency. These tradeoffs concern the degree of exchange- rate, interest-rate and fundamentals variability. They depend on the assumed process (constant drift or mean reversion) for the disturbances which affect money demand and/or supply.

They also depend on the type of coordination which would take place in case of foreign exchange crisis. In this last respect, we have been careful to make Assumption 2 so as to avoid altogether the problem of speculative attacks and needed reserves. We have assumed that central banks credibly and unconditionally intervene so as prevent speculative attacks. Indefinite intervention is possible if the central bank of the currently strong currency supports the other currency by printing money.

We have generalized the result of Svensson (1989) that the variability of the exchange rate is translated into variability in the interest rate differential.

We have also found that the degree of fundamentals variability which would be tolerated by the market when a target zone is extremely narrow is very large (a difference of two orders cf magnitude) in the case of a constant drift disturbance and in the case of mean reversion with a band exactly centered on the reversion point. The result is lost if the band is not precisely centered there.

APPENDIX A

MODEL INTERPRETATION

It is conceivable to interpret v either as a supply or a demand shock. Consider the following two-country log-linear monetary exchange rate model which has been extensively used in recent work (see for example Delgado and Dumas (1990) and all the references given there).

$$\tilde{m} = \ell n(D + R) + z_1 = m + z_1 \quad \text{(A1)}$$

$$\tilde{m}^* = \ell n(D^* + R^*) + z_1^* = m^* + z_1^* \quad \text{(A2)}$$

$$\tilde{m} - p = \psi y - \gamma i + z_2 \quad \text{(A3)}$$

$$\tilde{m}^* - p^* = \psi y^* - \gamma i^* + z_2^* \quad \text{(A4)}$$

$$i = i^* + E\{dS \mid \Phi(t)\}/dt + z_3 \quad \text{(A5)}$$

All starred variables are the foreign variables corresponding to the non-starred domestic variables. Z_1 being a multiplicative shock which affects (D + R) and is assumed to follow a geometric Brownian motion process, z_1 is the log of Z_1.[11] $\tilde{m}$ is the total money supply that can be broken down into two components, m the controllable money supply, and z_1 the uncontrollable component. The right-hand sides of equations (A3) and (A4) are money demands; z_2 and z_2^* are money demand shocks. p is the price level. y is domestic output. i is the domestic interest rate.

E is the expectations operator. $\Phi(t)$ is the information set used by

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[11] In the classic speculative attack literature [Krugman (1979) and Flood and Garber (1983); see also Dornbusch (1984) and Claessens (198(A3)], shocks came from growth in domestic credit. In our formulation, the terms Z_1 and Z_1^* are shocks applied to the sum of R and D, not to D.

(1989a, b) put it, all information regarding not only the evolution of the variables in the system (A1)-(A5), but the implicit as well as explicit government policies regarding exchange rate regimes in particular and monetary policy in general. Of importance for our purposes is the market perception that once the central bank whose currency is weak runs out of reseves, the other central bank will continue intervention to support the weak currency.

Subtracting (A3) from (A4) and replacing (A1), (A2) and (A3) we can obtain equation (1), where $v = (z_1 - z_1^*) + \psi(y - y^*) + (z_2 - z_2^*) + z_3$ is a cumulative shock. Given that v includes terms in z_1 and z_1^* it can be interpreted as either a demand or a supply shock to money.

APPENDIX B

MONOTONIC RELATIONSHIP BETWEEN THE BAND ON FUNDAMENTALS AND THE BAND ON THE EXCHANGE RATE

For simplicity let's define the following functions:

$$NF(\bar{X},\underline{X}) = -\beta e^{\alpha\bar{X} - \beta\underline{X}} - \alpha e^{\alpha\underline{X} - \beta\bar{X}} + (\alpha+\beta)e^{(\alpha-\beta)\bar{X}} \tag{B1}$$

$$NG(\bar{X},\underline{X}) = \alpha e^{\alpha\bar{X} - \beta\underline{X}} + \beta e^{\alpha\underline{X} - \beta\bar{X}} - (\alpha+\beta)e^{(\alpha-\beta)\underline{X}} \tag{B2}$$

$$DF(\bar{X},\underline{X}) = -\alpha\beta(e^{\alpha\bar{X} - \beta\underline{X}} - e^{\alpha\underline{X} - \beta\bar{X}}) \tag{B3}$$

$$F(\bar{X},\underline{X};\bar{S},\underline{S}) = -\bar{X} + \bar{S} - \gamma\mu + NF(\bar{X},\underline{X})/DF(\bar{X},\underline{X}) = 0 \tag{B4}$$

$$G(\bar{X},\underline{X};\bar{S},\underline{S}) = -\underline{X} + \underline{S} - \gamma\mu + NG(\bar{X},\underline{X})/DF(\bar{X},\underline{X}) = 0 \tag{B5}$$

Using the implicit function theorem for $F(\cdot) = 0$ and $G(\cdot) = 0$ we can obtain the two derivatives $\partial\bar{X}/\partial\bar{S}$ and $\partial\underline{X}/\partial\underline{S}$ which we are looking for.

Defining the following functions

$$F_{x1}(\cdot) = \partial F(\cdot)/\partial\bar{X} \tag{B6}$$

$$F_{x2}(\cdot) = \partial F(\cdot)/\partial\underline{X} \tag{B7}$$

$$G_{x1}(\cdot) = \partial G(\cdot)/\partial\bar{X} \tag{B8}$$

$$G_{x2}(\cdot) = \partial G(\cdot)/\partial\underline{X} \tag{B9}$$

$$F_{s1}(\cdot) = \partial F(\cdot)/\partial\bar{S} \tag{B10}$$

$$F_{s2}(\cdot) = \partial F(\cdot)/\partial\underline{S} , \tag{B11}$$

we can determine the signs of the following expressions

$$\partial\bar{X}/\partial\bar{S} = \begin{bmatrix} F_{s1} & F_{x2} \\ G_{s1} & G_{x2} \end{bmatrix} / J \geq 0 \tag{B12}$$

$$\partial\underline{X}/\partial\underline{S} = \begin{bmatrix} F_{x1} & F_{s2} \\ G_{x1} & G_{s2} \end{bmatrix} / J \geq 0 \tag{B13}$$

where:

$$J = \begin{bmatrix} F_{x1} & F_{x2} \\ G_{x1} & G_{x2} \end{bmatrix} > 0 \tag{B14}$$

Replacing all definitions in (B12) and (B13), and remembering that $1/\alpha - 1/\beta = \gamma\mu$, we obtain the signs of the partial derivatives. Q.E.D.

APPENDIX C

ASYMPTOTIC BEHAVIOR FOR WIDE BANDS UNDER CONSTANT DRIFT

Let us call δ the joint asymptotic value of the distance of $\bar{X}$ from the diagonal line and of the distance of $\underline{X}$ from the free-float line; let us also call 2ϵ the width of the exchange rate band, $\bar{S} = S_0 + \epsilon$ and $\underline{S} = S_0 - \epsilon$. We have:

$$\bar{X} = S_0 + \epsilon + \delta$$

$$\underline{X} = S_0 - \epsilon - \gamma\mu - \delta \qquad \text{and}$$

$$\underline{X} = \bar{X} - 2(\epsilon + \delta) - \gamma\mu$$

To study the behavior of wide bands we can substitute these relationships into (14), simplify, and neglect terms that approach zero as we make $\delta,\ \epsilon \to \infty$. We obtain a simple relationship:[12]

$$\delta = \epsilon - \gamma\mu + 1/\alpha = \epsilon + 1/\beta \qquad \text{(C1)}$$

Q.E.D.

[12] Svensson obtained a similar relationship for the special case of zero drift ($\mu = 0$) in which the two roots are of equal magnitude: $\alpha = -\beta$. The distance from the free-float (confounded in his case with the 45° line) was $1/\alpha = -1/\beta$.

APPENDIX D

CUBIC RELATIONSHIP FOR NARROW BANDS BETWEEN THE BAND ON FUNDAMENTALS AND THE BAND ON THE EXCHANGE RATE UNDER CONSTANT DRIFT

To obtain the relationship between the widths of the bands for small widths we are going to use a linear approximation to the exponential function:

$$e^{\lambda x} \approx 1 + \lambda x + (\lambda x)^2/2! + (\lambda x)^3/3! + \ldots \tag{D1}$$

The expansion is carried out as far as is needed. Additional terms are added if the prior order terms vanish or lead to an identity.

We proceed with the linearization around S_0. The four variables with respect to which the linearization is to be performed can be written as:

$$\bar{S} = S_0 + \epsilon \tag{D2}$$

$$\underline{S} = S_0 - \epsilon \tag{D3}$$

$$\bar{X} = S_0 + \bar{\delta} \tag{D4}$$

$$\underline{X} = S_0 - \underline{\delta} \tag{D5}$$

Replacing (D2)-(D5) in (A14)-(A15) the system is written as:

$$\bar{\delta} = \bar{\epsilon} - \gamma\mu + \frac{-\beta e^{\alpha\bar{\delta} + \beta\underline{\delta}} - \alpha e^{-(\alpha\underline{\delta} + \beta\bar{\delta})} + (\alpha+\beta)e^{(\alpha-\beta)\bar{\delta}}}{-\alpha\beta(e^{\alpha\bar{\delta} + \beta\underline{\delta}} - e^{-(\alpha\underline{\delta} + \beta\bar{\delta})})} \tag{D6}$$

$$\underset{\sim}{X} = \underset{\sim}{S} - \gamma\mu + \frac{\alpha e^{\alpha\bar{\delta} + \beta\underline{\delta}} + \beta e^{-(\alpha\underline{\delta} + \beta\bar{\delta})} - (\alpha+\beta) e^{-(\alpha-\beta)\underline{\delta}}}{-\alpha\beta(e^{\alpha\bar{\delta} + \beta\underline{\delta}} - e^{-(\alpha\underline{\delta} + \beta\bar{\delta})})} \tag{D7}$$

The last two equations can also be written in matrix form as

$$\begin{bmatrix} \epsilon \\ -\epsilon \end{bmatrix} = \begin{bmatrix} \gamma\mu + \bar{\delta} \\ \gamma\mu - \underline{\delta} \end{bmatrix} + \begin{bmatrix} e^{\alpha\bar{\delta}} & e^{-\beta\bar{\delta}} \\ e^{-\alpha\underline{\delta}} & e^{\beta\underline{\delta}} \end{bmatrix} \begin{bmatrix} 1/\alpha & 0 \\ 0 & -1/\beta \end{bmatrix} \begin{bmatrix} e^{\alpha\bar{\delta}} & e^{-\beta\bar{\delta}} \\ e^{-\alpha\underline{\delta}} & e^{\beta\underline{\delta}} \end{bmatrix}^{-1} \begin{bmatrix} -1 \\ -1 \end{bmatrix} \tag{D8}$$

Using $\gamma\mu = 1/\alpha - 1/\beta$ and expanding (D8), the following expression is obtained:

$$\epsilon \approx (\alpha + \beta)^2(\bar{\delta} + \underline{\delta})^3/12 \tag{D9}$$

Q.E.D.

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Legends for figures

Figure 1: Target zones of different widths

The figure is constructed by changing the width of the band around $S_0 = 4.5$. This means solving the system (14)-(15) for different values of $\bar{S}$ and $\underline{S}$ *positioned symmetrically around* S_0. The two straight lines in the middle are the 45° diagonal line which contains the fixed exchange points, and the free float. The thick line is the locus of tangencies implied by the smooth pasting conditions. Points above S_0 are pairs $(\bar{X}, \bar{\ })$; points below S_0 are pairs $(\underline{X}, \underline{S})$. Numerical values of parameters are: $\sigma^2 = 0.25$, $\mu = 0.5$ and $\gamma = 0.5$. Units on the two axes are not the same.

Figure 2: Extreme values of interest rate differential

The figure is constructed by changing the width of the exchange rate band symmetrically around $S_0 = 4.5$. Points above S_0 have abscissae equal to $\bar{X}$ and ordinates equal to the interest rate differential (assumed equal to the conditionally expected exchange rate change) reached when $X = \bar{X}$. Points below S_0 have abscissae equal to $\underline{X}$ and ordinates equal to the interest rate differential (assumed equal to the conditionally expected exchange rate change) reached when $X = \underline{X}$. Numerical values of parameters are: $\sigma^2 = 0.25$, $\mu = 0.5$ and $\gamma = 0.5$.

Figure 3: Exchange rate and interest rate differential

When the band is wide as in the case of this figure ($\underline{S} = 1.999$, $\bar{S} = 7.001$), the exchange-rate curve follows the free-float line and the interest-rate curve is flat over most of the range of allowed variations. Numerical values of parameters are: $\sigma^2 = 0.25$, $\mu = 0.5$ and $\gamma = 0.5$.

Figure 4: Exchange rate and interest rate differential

When the band is narrow as in the case of this figure ($\underline{S} = 4.4999$, $\bar{S} = 4.5001$), the exchange-rate curve is S-shaped and is situated far from the free-float line. The interest-rate curve is practically a straigtht line reflecting the imminent intervention. Numerical values of parameters are: $\sigma^2 = 0.25$, $\mu = 0.5$ and $\gamma = 0.5$.

Figure 5: Target zones of different widths: mean reverting case; symmetric solution with reversion point $A_0 = 7.8$.

The figure is constructed by changing the width of the band around $S_0 = A_0 = 7.8$. This means solving the system (26) for different values of $\bar{S}$ and $\underline{S}$ *positioned symmetrically around* $S_0 = A_0$. The two straight lines in the middle are the 45^o diagonal line which contains the fixed exchange points, and the free float which is not at a 45^o incline in this case. The thin curve is an example of an exchange rate curve. The thick line is the locus of tangencies implied by the smooth pasting conditions. Points above S_0 are pairs $(\bar{X}, \bar{S})$; points below S_0 are pairs $(\underline{X}, \underline{S})$. Observe the flatness of the locus around 7.8. Numerical values of parameters are: $\rho = 0.5$, $\sigma^2 = 0.2$, $A_0 = 7.8$ and $\gamma = 0.5$. Units on the two axes are not the same.

Figure 6: Target zones of different widths: mean reverting, non-symmetric case.

The figure is similar to Figure 5. While the reversion point A_0 is still equal to 4.8, the center of the exchange rate band is now at $S_0 = 9$. The free-float line and the 45^o line would intersect at 7.8. The thin curve is an example of an exchange rate curve. The thick line is the locus of tangencies implied by the smooth pasting conditions. Observe that the locus is not flat around the central point $S_0 = 9$.

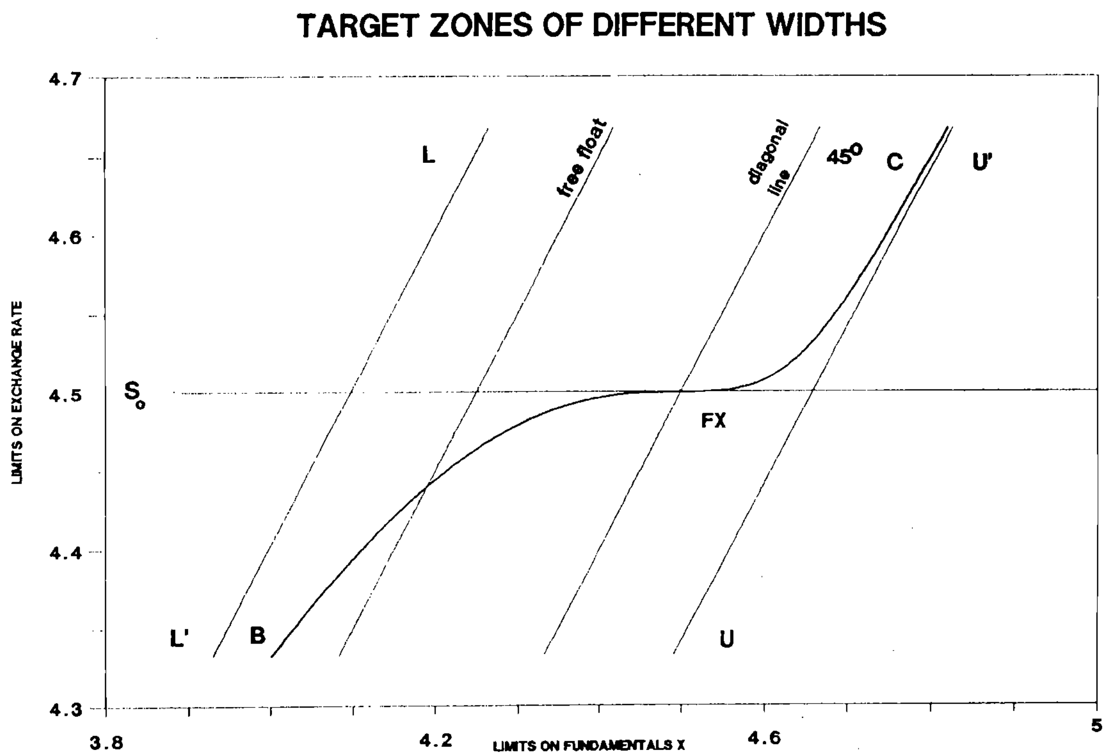

TARGET ZONES OF DIFFERENT WIDTHS
4.7
4.6
4.5
4.4
4.3
LIMITS ON EXCHANGE RATE
3.8
4.2
4.6
5
LIMITS ON FUNDAMENTALS X
L
free float
diagonal line
45°
C
U'
S
FX
L'
B
U

FIGURE 1

EXTREME VALUES OF INTEREST RATE DIFFERENTIAL

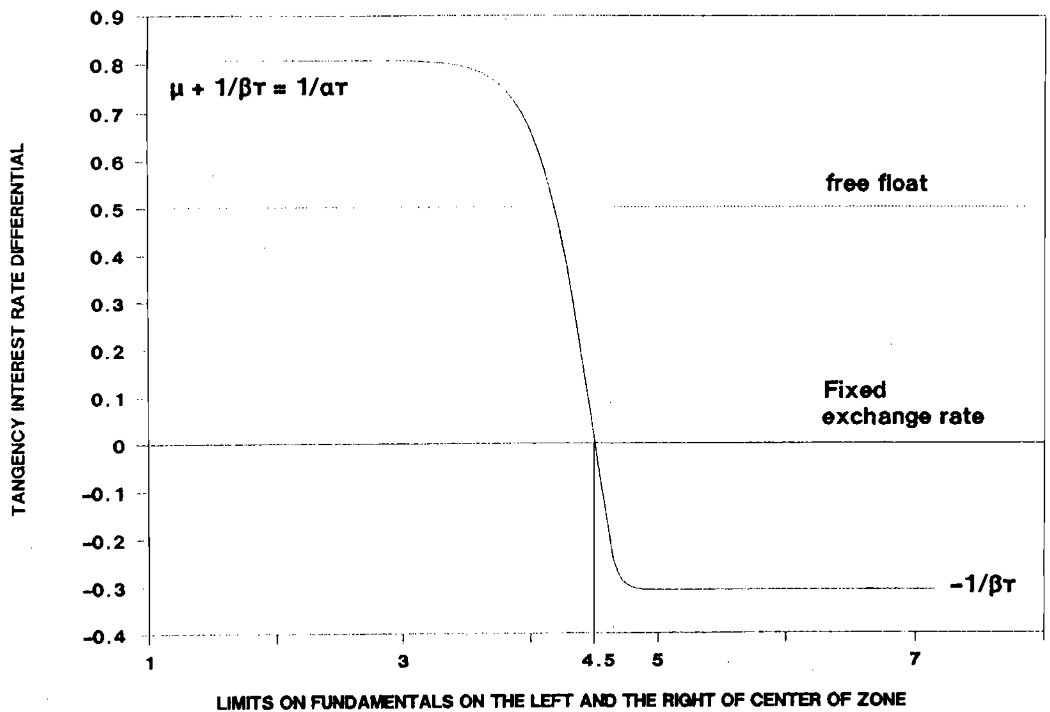


FIGURE 2

EXCHANGE RATE AND INTEREST RATE DIFFERENTIAL

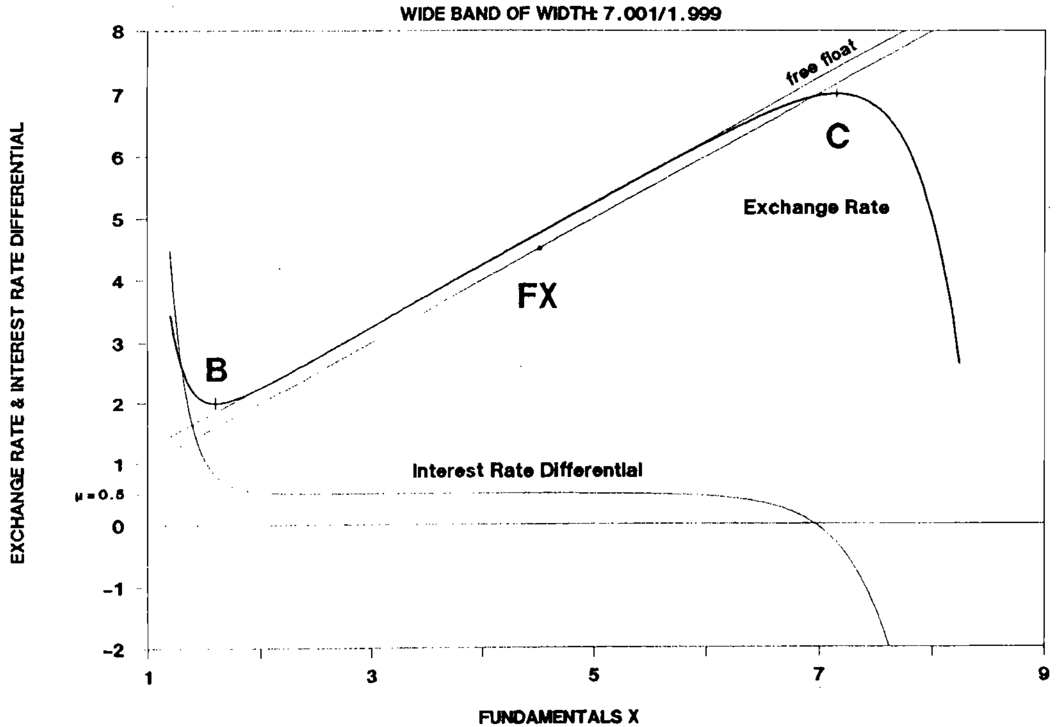


FIGURE 3

EXCHANGE RATE AND INTEREST RATE DIFFERENTIAL

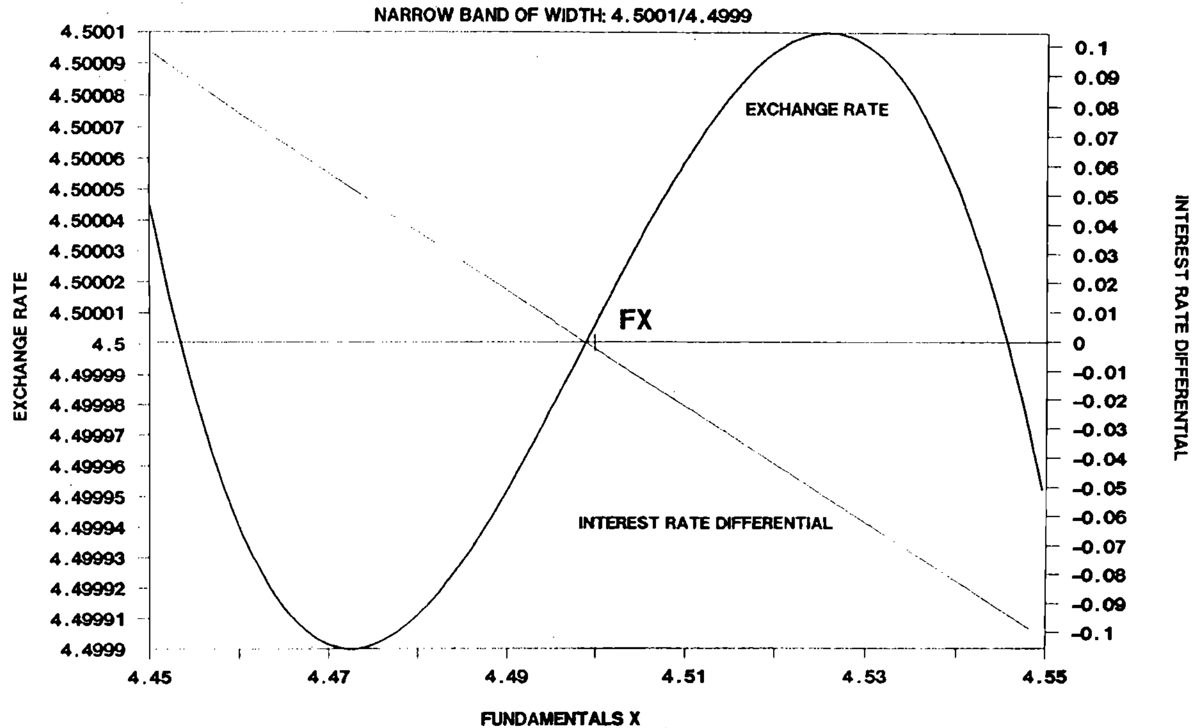


FIGURE 4

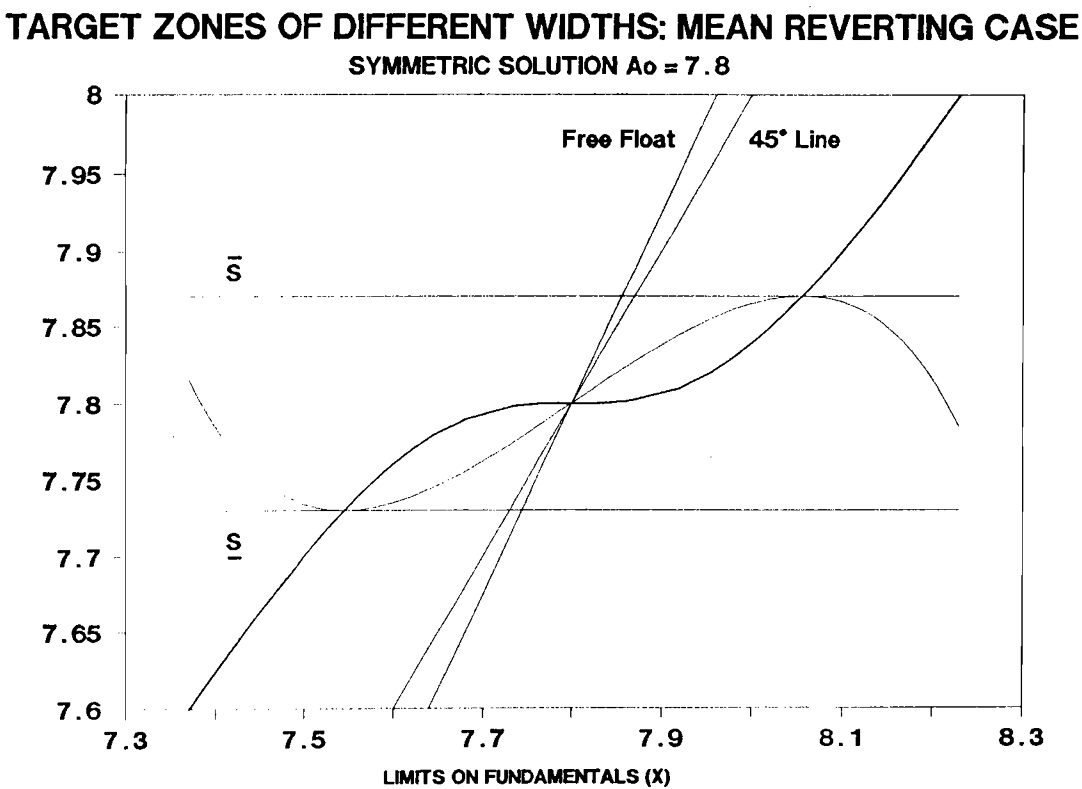
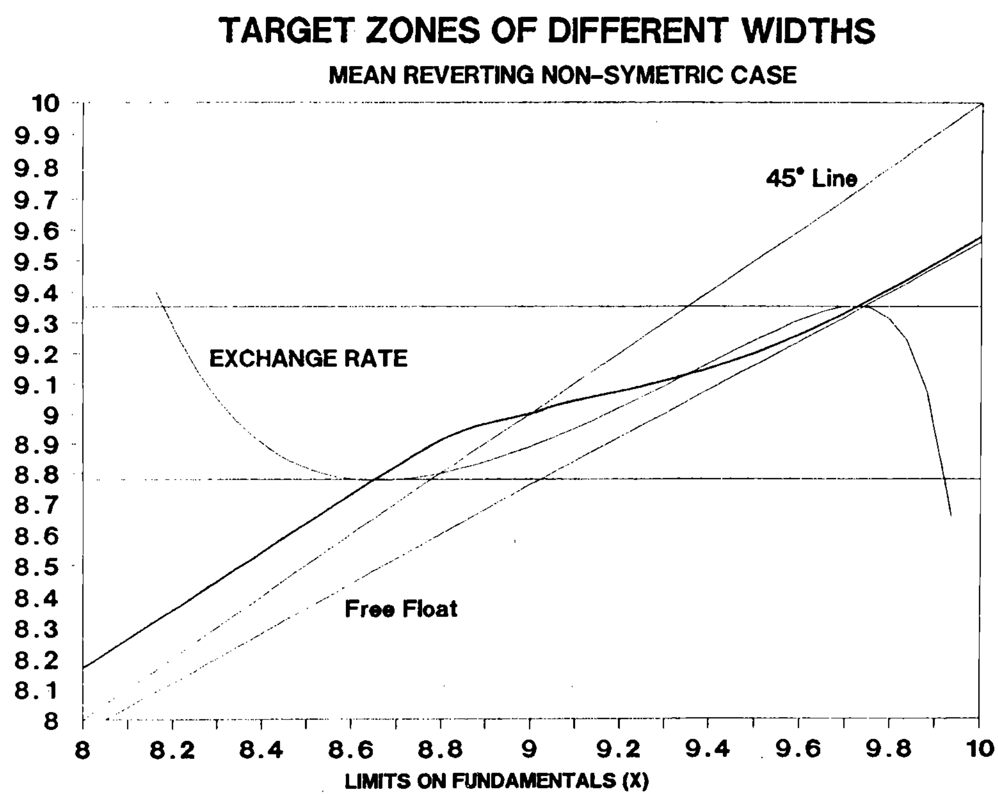

TARGET ZONES OF DIFFERENT WIDTHS: MEAN REVERTING CASE
SYMMETRIC SOLUTION Ao = 7.8
Free Float
45° Line
$\bar{S}$
$\underline{S}$
8
7.95
7.9
7.85
7.8
7.75
7.7
7.65
7.6
7.3
7.5
7.7
7.9
8.1
8.3
LIMITS ON FUNDAMENTALS (X)

FIGURE 5



TARGET ZONES OF DIFFERENT WIDTHS
MEAN REVERTING NON-SYMETRIC CASE
10
9.9
9.8
9.7
9.6
9.5
9.4
9.3
9.2
9.1
9
8.9
8.8
8.7
8.6
8.5
8.4
8.3
8.2
8.1
8
45° Line
EXCHANGE RATE
Free Float
8
8.2
8.4
8.6
8.8
9
9.2
9.4
9.6
9.8
10
LIMITS ON FUNDAMENTALS (X)

FIGURE 6