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Abstract – 94-009D

We examine the effects of endogenously determined realignment expectations in a model of a target zone with sluggish price adjustment. We allow these expectations to be based on a policy rule that generates an increasing probability of realignment as output moves away from full employment. We find that for realistic parameter values, even relatively small misalignments of the currency band lead to strongly skewed conditional distributions for the nominal exchange rate, thus generating pressures for realignment. We show that the reason for this is that the speed of adjustment in the absence of realignments is rather slow. Further, we find that the existence of an equilibrium path for the exchange rate depends on the responsiveness of realignment expectations to economic fundamentals. Paradoxically, higher credibility may increase the probability that a target zone will collapse. This feature of the model provides a possible explanation for the crisis within the exchange rate mechanism of the EMS. A policy of monetary accommodation to real shocks can alleviate the problem but severely constrains a country's ability to pursue counterinflationary measures within the band

Introduction

The theory of managed exchange rate regimes was significantly advanced by the appearance of Krugman's seminal paper on currency bands (1991). He showed that one could derive an explicit solution for the path of the exchange rate within a band in a continuous-time stochastic framework. The model assumed that the monetary authorities adopted a passive stance to the targeting of the exchange rate so long as the rate remained strictly within the interior of the band. Only when the rate reached the margins of the band would the authorities intervene in order to prevent the rate from moving outside its permitted range. In addition, it was assumed that “fundamentals” followed an exogenous white-noise process, and the solution to the model expressed the exchange rate as a time-stationary, non-linear function of fundamentals.

The original model was intentionally a highly stylized representation of the kind of managed regime it sought to capture—namely the exchange rate mechanism (ERM) of the European Monetary System. It provided some key insights into the way that such regimes might operate. In particular, intermittent and state-contingent intervention was shown to stabilize the rate within the band, even when such intervention was not occurring. The anticipation of such activity by the market was sufficient to move the exchange rate closer to the center of the band.

In the simplest case, the band was supposed to be fully credible. In other words, the market did not expect that any realignments of the band would ever occur. In fact, periodic realignments of central parities have been a persistent feature of the ERM. For example, there were six realignments of the French franc against the DM over the period 1979-1992. So it quickly became evident that any complete theory of currency bands would have to incorporate the possibility of such realignments. The first papers to do so (see Miller and Weller (1989), Bertola and Caballero (1992), Svensson (1992) and Bertola and Svensson (1993)) assumed the existence of ad hoc rules or stochastic processes which were known to the market, but which had no explicit economic underpinning. But there is now accumulating empirical evidence that realignment expectations are influenced by economic variables such as the level of output and employment, the real exchange rate and the money supply (Edin and Vredin (1993), Mizrach (1995)).

Our aim is to examine how realignment expectations that are based on a particular policy rule for the government may affect the operation of a target zone. We consider a rule that generates an increasing probability of realignment as output moves away from full employment. The investigation uses a richer and more realistic model of exchange rate determination than the monetary model, which underpins the Krugman approach and its extensions. In addition to describing the adjustment of nominal exchange rates and interest rates, it is capable of generating endogenous dynamics for output, real interest rates and the real exchange rate (Miller and Weller, 1991). The domestic price level takes the place of the velocity of money as the fundamental which drives the exchange rate, and in contrast to the assumption of perfect price flexibility central to the monetary model, it is assumed that prices adjust less than instantaneously to supply side shocks. There are strong arguments to indicate that sluggish price adjustment must play an important role in explaining short-run movements in real and nominal exchange rates (see, for example, Mussa (1986), Krugman (1989, chapter 1), McCallum (1996, chapter 8) and Clarida and Galí (1994)). The endogenous dynamics for output and inflation permit the more realistic approach to modelling realignment expectations described above.

As a benchmark for comparison, we examine the process of adjustment to misalignment when the band is fully credible. We find that for realistic parameter values even relatively small misalignments of the band lead to strongly skewed conditional distributions for the nominal exchange rate. This generates pressures for realignment because the speed of adjustment of output and employment in the absence of realignments is rather slow. This casts considerable doubt on the wisdom of imposing the “discipline” of a target zone with an overvalued central parity as a means of curbing inflation.

Our analysis demonstrates that there may not exist an equilibrium path for apparently plausible endogenous realignment expectations. Whether or not such a problem of sustainability arises depends on the way in which realignment expectations respond to deviations of output from full employment. Paradoxically, lack of sustainability is more likely the higher is the initial level of credibility and the less it erodes in response to deteriorating economic fundamentals. Our model is thus able to reproduce one of the more puzzling features of the EMS crisis in the autumn of 1992, namely that it occurred at a time when the credibility of the regime was historically high. Adopting a policy of monetary accommodation to real shocks can alleviate the problem of sustainability. However, the degree of accommodation required may be very high.

We show that even quite infrequent realignments markedly increase the speed of adjustment to misalignments. The reason for this is that they are most likely to occur when most needed i.e. when output has deviated substantially from full employment, and the period of adjustment under a fully credible band would be prolonged.

The paper is organized as follows. In Section 1 we present the model and introduce a general formulation of the realignment process. In Section 2 we provide motivation for the particular form of endogenous realignment probability we use. In Sections 3.1 and 3.2, we analyze as benchmarks the cases of a freely floating exchange rate and a fully credible target zone. In the fully credible case we conduct simulations to determine the effects of misalignment of the band. In Section 3.3 we examine realignment rules of increasing generality based on an objective function for the government. First, we treat the case where the probability of realignment is a constant. Next, we consider the case where the probability is a step function of the level of output, and finally where it is a continuously variable function of output. In Section 3.4 the effect of introducing forward-looking prices is considered. A policy of accommodating price shocks is examined in Section 3.5. In Section 3.6 simulations of the endogenous realignment rule with variable realignment probability are presented. Summary and conclusions follow in the final section.

1. The Model

The basic model we use is that presented in Miller and Weller (1991), modified to allow for the presence of an endogenously determined realignment probability. It is a stochastic version of the well-known "overshooting" model of exchange rate determination (Dornbusch, 1976). The central feature that distinguishes it from the monetary model is that goods prices are not assumed to adjust instantaneously to clear all markets.

The model consists of the following equations:

$$m(t) - p(t) = \kappa y(t) - \lambda i(t) \tag{1}$$

$$y(t) = -\gamma\,(i(t) - E[dp(t)]/dt) + \eta(s(t) - p(t)) \tag{2}$$

$$E[ds(t)]/dt = i(t) - i^* \tag{3}$$

$$dp(t) = \phi(y(t) - \bar{y})dt + \sigma dz(t) \tag{4}$$

All variables except interest rates are measured in logs. The first equation describes the condition for equilibrium in the domestic money market, where $m(t)$ is the domestic money supply, $p(t)$ is the domestic price level, $y(t)$ is the level of output and $i(t)$ is the (nominal) domestic interest rate. The second equation is a goods market equilibrium condition, in which investment depends negatively on the real interest rate, and output depends positively on the real exchange rate $s(t)$

– $p(t)$. Here, $s(t)$ is the domestic (dollar) price of foreign currency, so that an increase in the value of $s(t) - p(t)$ corresponds to an increase in competitiveness. The third equation is an uncovered interest parity condition, in which the expected rate of depreciation of the domestic currency is set equal to the nominal interest differential. It will incorporate the possibility of jumps in the exchange rate that occur as a consequence of a realignment. The final equation is a simple representation of less-than-instantaneous price adjustment. When output is above its long-run full employment level $\bar{y}$, there is a tendency for prices to rise and vice versa. The speed of price adjustment is captured by the parameter ϕ. The stochastic element of the model consists of a random real shock, where $dz(t)$ is the increment to a standard Wiener process $z(t)$ and σ is a volatility parameter.

In what follows we drop explicit identification of time-dependence unless clarity requires it. The system can then be written:

$$\begin{bmatrix} dp \\ E[ds] \end{bmatrix} = A \begin{bmatrix} (p-m)dt \\ (s-m)dt \end{bmatrix} + B \begin{bmatrix} i^* dt \\ \bar{y}dt \end{bmatrix} + \begin{bmatrix} \sigma dz \\ 0 \end{bmatrix} \tag{5}$$

where

$$A = \frac{1}{D}\begin{bmatrix} -\phi(\gamma+\lambda\eta) & \phi\lambda\eta \\ 1-\kappa\eta-\phi\gamma & \kappa\eta \end{bmatrix}$$

$$B = \frac{1}{D}\begin{bmatrix} 0 & -\phi(\kappa\gamma+\lambda) \\ -D & -\phi\kappa\gamma \end{bmatrix}$$

and $D = \kappa\gamma + \lambda - \phi\gamma\lambda$. To simplify notation, we redefine the variables to be deviations from some initial long-run equilibrium of the deterministic system. The corresponding initial value for the money supply m we normalize to zero. The system can then be written in the following, simpler form:

$$\begin{bmatrix} dp \\ E[ds] \end{bmatrix} = A \begin{bmatrix} (p-m)dt \\ (s-m)dt \end{bmatrix} + \begin{bmatrix} \sigma dz \\ 0 \end{bmatrix} \tag{6}$$

The variable m is now interpreted as a change in the money supply from the initial value. The system can be written in this form because money is neutral in the model <u>in the long run</u>. This, however, does not preclude money from having important real effects in the short run.

We model realignments as driven by a jump process $\nu(t)$, whose mean arrival rate is endogenously determined. We suppose that $\nu(t + dt) - \nu(t)$ is a Poisson-distributed random variable with characteristic parameter $\pi(s - m, p - m)$. Thus $d\nu(t) = 0$ with probability $1 - \pi(s - m, p - m)dt + o(dt)$ and $d\nu(t) = 1$ with probability $\pi(s - m, p - m)dt + o(dt)$. The size of jump is denoted by $\Delta(s - m, p - m)$. Therefore, at this stage, we allow both $\pi(s - m, p - m)$ and the size of realignment to be arbitrary functions of the deviation of the nominal exchange rate and price level from long run equilibrium levels.[1] In Sections 2 and 3.3 we introduce additional structure to these functional relationships.

Solutions to the model are obtained by postulating a deterministic relationship between the nominal exchange rate, the money supply and the price level:

$$s = m + f(p-m) \tag{7}$$

By applying Ito's Lemma, extended to incorporate the presence of the jump process ν,[2] we obtain

$$ds = (\sigma^2/2) f''(p-m)dt + f'(p-m)dp + \Delta(f(p-m), p-m)d\nu \tag{8}$$

[1] We will sometimes refer loosely to the function π as the probability of realignment.

from which it follows that

$$E[ds] = (\sigma^2/2) f''(p-m)dt + f'(p-m)E[dp] + \pi(f(p-m), p-m)\Delta(f(p-m), p-m)dt \tag{9}$$

Substituting for *E[ds]* and *E[dp]* from (6) gives

$$\begin{aligned}&(\sigma^2/2) f''(p-m) + \left[a_{11}(p-m) + a_{12} f(p-m)\right] f'(p-m) - \left[a_{21}(p-m) + a_{22} f(p-m)\right] \\ &+\pi(f(p-m), p-m)\Delta(f(p-m), p-m) = 0\end{aligned} \tag{10}$$

where a_{ij} denotes the appropriate element of the matrix *A*. The solution to this differential equation subject to appropriate boundary conditions provides the necessary characterization of the exchange rate within a target zone.[3]

2. The Endogenous Realignment Probability

In the previous section we introduced a fairly general expression for the intensity of realignment. We now add more structure in order to provide economic content to the specification of the realignment process. Let us first consider the size of realignment. We assume that the width of the target zone is some fixed amount. The position of the zone at time *t* can then be defined in terms of its central parity $c_k(t)$, where *k* is an index of the number of realignments that have occurred since time zero. The size of a realignment at *t* can be written in terms of the change in central parity, $c_{k+1}(t_+) - c_k(t)$.[4] To fix the size of realignment, we assume that when a realignment occurs, there is a simultaneous monetary adjustment sufficient to place the new value of the exchange rate at PPP at the midpoint of the new band. This captures in a simple way the idea that realignments are designed to short-circuit the process of adjustment to long-run

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[2] See, for example Merton (1990), ch.3, p.92.

[3] The nature of these solutions in the fully credible case ($\pi = 0$) is analyzed at length in Miller and Weller (1991, 1995).

[4] We use the notation t_+ to indicate the time just after *t*.

equilibrium with full employment and stable prices. It implies that $c_{k+1}(t_+) = s(t_+) = m(t_+) = p(t)$. Therefore, the jump in the exchange rate caused by the realignment is $s(t_+) - s(t) = p(t) - s(t)$, where $s(t)$ denotes the value of the exchange rate at the instant before the realignment occurs. Similarly, the jump in the money supply is $m(t_+) - m(t) = p(t) - m(t)$. In all cases the variable determining the size of these various jumps is $p(t)$. Note that in general $c_k(t) \neq m(t)$. This is because the money supply may have changed since the last realignment as a consequence of marginal intervention to defend the band.

In the fully credible case where the probability of realignment is zero, the money supply adjusts only as a consequence of infinitesimal adjustment at the margins to defend the band. But where the band is not fully credible, there is a second source of variability resulting from the realignment process.

We move next to considering the determinants of the probability of realignment per unit of time, $\pi(s - m, p - m)$. To avoid unnecessary technicalities, which arise in continuous time, we develop the argument in the context of the discretized version of the model used in the simulations. We suppose that the government's commitment to maintaining a fixed target zone reflects its desire for (long-run) price stability. In other words, the benefits of the target zone are measured in terms of the reduction in price variability resulting from the periodic intervention necessary to defend the zone.[5] We assume that the government trades off the objective of maintaining the target zone against that of stabilizing output at full employment. We capture this in the following loss function:

[5] At the opposite extreme of the policy continuum would be the situation in which the government fully accommodates the exogenous price shocks, in which case output is stabilized at full employment, but the price level follows a Brownian motion, with variance which grows linearly with t.

$$L(t) = (1 - z)\left(|y(t) - \bar{y}| \middle| \text{no realignment}\right) + zC(t) \qquad (11)$$

The first term on the right-hand side represents the component of the loss function accounted for by deviations from full employment at time *t*, conditional on no realignment occurring at time *t*, and the second is a fixed cost associated with a realignment. The variable *z* is an indicator, which takes the value 0 if no realignment occurs at time *t*, and takes the value 1 if a realignment occurs. The fixed cost $C(t) \geq 0$ is assumed to be random and unobservable by market participants. However, we suppose that the market knows its distribution. The decision problem faced by the government is very simple. If, in the absence of a realignment $|y(t) - \bar{y}|$ is less than $C(t)$, no realignment occurs in period *t*. If the first term is greater than or equal to $C(t)$, a realignment occurs and the first term goes to zero. Therefore the optimized value of the loss function can be expressed as:

$$L^*(t) = \min\left(\left(|y(t) - \bar{y}| \middle| \text{no realignment}\right), C(t)\right)$$

We can then calculate the probability of a realignment in period *t* as:

$$P(\text{realignment at time } t) = P\left(C(t) \leq \left(| y(t) - \bar{y} | \middle| \text{no realignment}\right)\right) \qquad (12)$$

This enables us to write the probability of realignment in period *t* as some increasing function of the (absolute value of the) deviation from full employment.[6] The expression in (12) also allows for a separate dependence upon

[6] This formulation is sufficiently general to allow for the possibility of a positive probability of realignment at full-employment output. It requires the assumption of a mass point at zero in the distribution of $C(t)$.

time, as a consequence of changes in the distribution of $C(t)$. Such a change might occur, for example, as a result of a change in government. We choose not to consider the case of time-variation in the distribution of $C(t)$, but write the realignment probability as

$$\pi(|y(t) - \bar{y}|); \qquad \pi' > 0. \tag{13}$$

Although evidently a stylized view of the determinants of a realignment, it nevertheless captures some important features of reality. The idea that there are fixed costs associated with the loss of credibility which comes with a realignment is not new (Froot and Rogoff 1991, Obstfeld 1996). Assuming that the fixed costs are random is a way of expressing the idea that governments are not homogeneous entities, but rather collections of competing interests.[7] With this formulation we abstract from the possibility that the market may learn about the objective function of the government and the associated reputational considerations.

3. A Comparison of Different Regimes

We want to examine the different implications for the behavior of the exchange rate and other economic variables that emerge from our model when it is analyzed under differing assumptions about the exchange rate regime. We consider three scenarios: (i) a freely floating exchange rate, (ii) a fully credible target zone, (iii) a partially credible target zone with endogenously determined realignment expectations. A structural model similar to the one laid out in equations (1) – (4) has been estimated by Ghosh and Masson (1991) on data for the United States and the rest of the world. All parameters other than ϕ, the

[7] This is well illustrated in the case of the U.K., where the influence of the Eurosceptic wing of the Conservative Party has varied considerably over time. Views on the cost

speed of price adjustment, and σ, the instantaneous variability of prices, are the estimates obtained in their paper. The parameter values for the model are given in Table 1. In order to maintain comparability with the simulations reported later in the paper, we assume that the unit of time in the analysis is a quarter.

3.1 The Free Float

The free float is characterized by a fixed money supply and a zero probability of realignment.[8] The differential equation in (10) with $\pi = 0$ has two linear solutions which correspond to the stable and unstable arms of the saddlepath in the deterministic model, where $\sigma = 0$. The stable saddlepath, SS, in Figure 1, (the "free float" solution) is shown with a negative slope. The negative slope is guaranteed if $\kappa\eta + \phi\gamma < 1$, and corresponds to the "overshooting" case.[9] The economy may move in either direction along SS in response to the price shocks modelled by the process $z(t)$. The exchange rate is asymptotically normally distributed with mean equal to the long-run equilibrium value of the associated deterministic model.

Using the parameter values laid out in Table 1 with ϕ set to 0.6, the slope of the stable saddlepath takes on a value of –2.11, implying that a one per cent reduction in real balances is accompanied by an appreciation of 2.11% in the

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associated with a realignment among Eurosceptics would certainly diverge sharply from those in the main body of the party.

[8]In a fully articulated two-country model the money supply would be measured relative to that in the foreign country. A relative money supply of zero allows for the possibility of a constant trend common to both countries.

[9]Overshooting imposes an upper bound on the speed of price adjustment ϕ given values for the other parameters of the model. Note also that saddlepoint stability requires that the determinant of the matrix A be negative. This implies the condition $\phi\lambda < \kappa + \gamma\lambda$. Therefore, even in the absence of overshooting, the speed of price adjustment cannot be allowed to increase arbitrarily without simultaneously reducing the interest semi-elasticity of money demand λ in order to satisfy the bound on the term $\phi\lambda$. We cannot then regard the monetary model as a special case of the one we analyze.

nominal exchange rate.[10] This corresponds to the overshooting case, since in the new long-run equilibrium the exchange rate appreciates by 1.00%. The initial appreciation is therefore followed by a period in which the exchange rate **depreciates** to the new long-run equilibrium.

We can also use the model to describe the process of price adjustment. Since output is a linear function of the price level and the exchange rate, and in the free float the exchange rate is a linear function of the price level, the price adjustment process can be written as:

$$dp = -\rho p dt + \sigma dz \tag{14}$$

where $\rho = \frac{-\phi}{D}(\lambda\eta\theta - (\gamma + \lambda\eta))$ and θ is the slope of the stable saddlepath. For the chosen parameter values ρ has the value 0.30. So prices follow an Ornstein-Uhlenbeck process with speed of mean reversion equal to 0.30. The long-run equilibrium price level is normalized to zero, so that if the value of p is currently p_0, its expected value at some future time t is given by

$$E[p(t)] = p_0 e^{-\rho t}.$$

The variance of p is given by

$$\text{var}[p(t)] = \frac{\sigma^2}{2\rho}(1 - e^{-2\rho t}).$$

[10]This is somewhat rather larger than the figure of – 1.35 implied by the impulse response results to a nominal shock reported by Clarida and Galí (1994) for the US-Germany case.

3.2 The Fully Credible Case

In order to provide an appropriate benchmark against which to compare the effects of various forms of realignment expectations, we consider first the case of a perfectly credible zone initially placed symmetrically about the long run equilibrium value of the exchange rate. The values of the exchange rate at the top and bottom of the band have been chosen to mimic the "narrow" band of the EMS (a permitted range of variation of ± 2.25% around a central parity). The money stock is held fixed so long as the nominal exchange rate stays strictly within the interval $(\underline{s}, \bar{s})$. However, when the rate reaches the limits of its permitted range of variation, the central bank adjusts the money supply to defend the zone. As a consequence, the money supply is subjected to random shocks over time, and each of these brings about a shift in the long-run equilibrium value of the exchange rate. Because a target zone is by assumption fixed in nominal terms, its position relative to the long-run equilibrium value of the exchange rate will shift as the money supply changes. For a given level of the money supply, the (fully credible) solution path for the exchange rate is described by (10), with π set to zero, together with the smooth pasting boundary conditions, which require that the path be tangent to the top and bottom of the zone. As the non-linear solutions to (10) are not obtainable in closed form, we use a numerical "shooting" technique to solve for the equilibrium path of the exchange rate that satisfies the appropriate boundary conditions for varying levels of the money supply. Since the exchange rate follows an Ito process, simulating its movement over time involves using a suitable approximation in discrete time. We use the Euler approximation to the continuous-time process that describes the time path of the price level.

For a given level of the money supply m_0, the stochastic differential equation describing the movement of prices is given by:

$$dp = \left[a_{11}(p - m_0) + a_{12} f(p - m_0)\right]dt + \sigma dz \tag{15}$$

For n periods per unit of time, p^n is the discrete-time process defined by:

$$p^n_{t+1} - p^n_t = \frac{1}{n}\left[a_{11}(p^n_t - m_0) + a_{12} f(p^n_t - m_0)\right] + \frac{1}{\sqrt{n}}\sigma\varepsilon_{t+1} \tag{16}$$

where $\varepsilon_1, \varepsilon_2, \ldots$ is an i.i.d. sequence of standard normal variables. This defines a corresponding discrete-time process for the exchange rate, s^n, through the functional relationship $s^n_t = f(p^n_t - m_0)$.

Determining the distribution of the exchange rate involved the following procedures. First, solution paths for differing levels of the money supply were found. Next, a starting value for the exchange rate was selected at its initial long-run equilibrium value in the centre of the band. Then 100 simulations consisting of 50 time periods were constructed according to the procedure described above. If the exchange rate reached $\overline{s}$, the money supply m would be reduced by a discrete intervention. Conversely, if the exchange rate reached $\underline{s}$, the money supply would be increased by an intervention of the same size. Whenever m changed as a consequence of intervention, the exchange rate would move to a new solution path within the band.

Comparing the exchange rate distributions in Figure 2, one finds that the volatility parameter σ is a central determinant of the shape of the distribution. With σ set at 0.007 in the upper panel, the model generates a U-shaped distribution that is qualitatively very similar to that found in the simple Krugman model. However, with σ set at 0.004 in the lower panel, a very different picture emerges. Lowering the variance of the price shock concentrates the exchange rate distribution in the centre of the band, in accordance with empirical observation.[11] In both cases the real exchange rate is more variable than the nominal rate, reflecting the fact that a rise in relative prices leads to a reduction in real balances and drives up the interest rate and exchange rate. The fall in competitiveness caused by the rise in prices is thus accentuated by a rising exchange rate.

When we consider a wider band in which the rate can vary by ± 5% around a central parity, we find that the larger value for the volatility parameter will still produce a concentration of observations in the middle of the band (see the upper panel of Figure 3). Intuitively, the reason for this result is clear: a wider band allows the intrinsic mean-reverting tendency of the nominal exchange rate to reveal itself without being obscured by the truncating effects of intervention at the edges of the band.

3.2.1. Misalignment of the Band

When the authorities impose a nominal band on the exchange rate, there will inevitably be periods of misalignment during which the band will have an over- or undervalued central parity. Since one of the issues under investigation is the extent to which such misalignments generate pressures for realignment, it is important first to examine the effects when the band is fully credible. The next case to be analyzed, therefore, is one in which the band is centred on an undervalued exchange rate (see the lower panel of Figure 3). The central parity is set at 0.05, which corresponds to an undervaluation of 5%. The distribution of the nominal exchange rate is considerably skewed, more so than that of the real exchange rate or prices. This is a reflection of the fact that an undervalued exchange rate stimulates the level of output, putting upward pressure on prices and interest rates. This causes the exchange rate to strengthen in the band and

[11]This property of the price-inertia model was noted by Sutherland (1994), who derived the distribution of the exchange rate for an arbitrary set of parameter values using series expansions.

increases the frequency with which the monetary authorities have to intervene to defend the band by increasing the money supply. It is this mechanism of adjustment that is of particular interest, because realignments can be seen as a way of "short-circuiting" the process in order to speed up the correction of any misalignment. In Figure 4 we illustrate the process of adjustment to misalignment. The graphs show the plots of the fifth, median and ninety-fifth percentiles of the sample distributions for prices, output, the money supply, nominal and real interest rates and the real exchange rate over time. About half the necessary adjustment to output occurs over eight periods, but the full adjustment takes between fifteen and twenty periods. The pattern of adjustment for the real exchange rate is similar, although full adjustment takes longer. If the value of ϕ is reduced to 0.2, the speed of adjustment is in all cases much reduced. This is illustrated in Figure 5. An exactly symmetric picture emerges in the case of an overvalued exchange rate. In both situations it is of course true that the monetary authority could pursue a path of faster adjustment by suitable intramarginal changes to the money supply. But the point we are making is that such changes are not mandated by the commitment to maintain a fully credible target zone. What this suggests is that relying solely on the equilibrating effects of the adjustments to monetary policy needed to defend an exchange rate band will lead to prolonged periods of over- or undervaluation.

3.3 The Partially Credible Case

The previous section indicates that there are significant costs to allowing the exchange rate to adjust to overvaluation resulting from a misaligned band. These costs take the form of prolonged periods of unemployment. When the misalignment is substantial, the short-run political impact of the costs of gradual adjustment may make a fixed target zone untenable. Because of this, realignments have been a relatively common feature within the EMS.

In order to analyze the effects of possible realignments, we need to return to the model described in Section 1. There we showed that the path of the exchange rate within the band was described by the solution to (10), subject to suitable boundary conditions. The particular parametrization for the function π in (13) that we adopt is:

$$\pi(|y(t)-\bar{y}|) = a(1-e^{-k|y(t)-\bar{y}|})+b\,. \qquad (17)$$

This function has the desired property of being monotonically increasing in deviations of output from full employment. It is also sufficiently flexible to allow the minimum, the maximum, and the rate of change of the realignment probability to be varied.

The appropriate boundary conditions for the solution path are the same smooth-pasting conditions that apply in the fully credible case.[12] However, in sharp contrast to the fully credible case, where the existence of a unique equilibrium path is guaranteed for all bandwidths, subject only to the parameter restrictions required to preserve saddlepoint stability, now it emerges that the existence and nature of equilibrium paths is sensitive to the particular parametrization of the function π. Considering two special cases of the specification of π in (17) sheds light on this result.

3.3.1. A Constant Realignment Probability

If k is set to zero in (17), the rate of realignment becomes a constant. Then we may rewrite (10) as:

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[12]This is because the form of realignment rule requires one to solve for the solution path conditional on no realignment occurring.

$$(\sigma^2/2)\, f''(p-m) + \left[a_{11}(p-m) + a_{12}\, f(p-m)\right] f'(p-m) \\ -\left[(a_{21}-\pi)(p-m) + (a_{22}+\pi)\, f(p-m)\right] = 0 \qquad (10')$$

The value of the constant coefficients on $(p - m)$ and $f(p - m)$ are changed, but otherwise the form of the equation is the same as in the case where π is zero. In particular, there will still exist a linear solution corresponding to the stable saddlepath. The effect, then, upon the solution path of increasing π from zero can be analyzed simply by considering the induced changes in the two coefficients. It is straightforward to show that increasing π rotates the stable saddlepath SS in Figure 1 counterclockwise. Eventually the system moves from the overshooting case ($a_{21} > 0$) to the undershooting case ($a_{21} < 0$). Now, as the price level rises above its long-run equilibrium value, the exchange rate depreciates and the equilibrium path within a correctly aligned band, i.e., whose midpoint coincides with PPP, will be tangent to the top (weak) edge. In the limit, as π is allowed to become arbitrarily large, the band is in effect realigned continuously. At the same time SS approaches the PPP locus. We are back to the case of a free float, but with the important difference that real shocks are instantaneously accommodated. So the nominal exchange rate will wander along the PPP locus driven by the white-noise shocks to the pricing equation.

3.3.2. A Step Function for the Realignment Probability

We next consider a simple step function for π, and analyze it first in the context of an otherwise deterministic model. We suppose that $\pi = 0$ so long as $y' \leq y \leq y''$, and that $\pi = \pi_{\max} > 0$ if $y > y''$ or $y < y'$. The two trigger points for a positive realignment probability are equidistant from the full-employment level of output, so that $y'' - \bar{y} = \bar{y} - y'$. The arbitrage equation takes the form:

$$ds/dt + \pi \bullet (p(t) - s(t)) = i(t) - i^* \qquad (18)$$

where ds/dt is the rate of change of the exchange rate conditional on no realignment occurring. One can think of there being two regimes, one corresponding to the situation where $\pi = 0$, the other to the case where $\pi = \pi_{max}$. The two regimes have stable saddlepaths of SS and S‘S‘, respectively (see Figure 6). In the absence of exogenous shocks only one realignment will ever occur, since when it does the system moves instantaneously to the long-run equilibrium and stays there. What happens at the edges of the band is not of interest to us, and so we assume that all the movements of the system take place in the interior of the band. Then the stable saddlepath will take the form of the locus ABOCD in the figure. Points B and C correspond to $y = y''$ and $y = y'$ respectively. If the system reaches either point without a realignment having occurred, the probability of one taking place drops to zero and the exchange rate adjusts to equilibrium at O along the path SS. The sections AB and CD represent paths in the phase diagram for the system when $\pi = \pi_{max} > 0$. The phase diagram has the stable saddlepath rotated counterclockwise to S´S´. We see that if the economy starts with the price level lying above its long-run equilibrium level, say at p^*, and π_{max} is not too small, there will initially be a period of exchange rate appreciation followed, if no realignment occurs, by a period of depreciation. Had there been no time during which the probability of devaluation was positive, there would have been steady depreciation along SS. And had the realignment probability been everywhere constant at π_{max}, there would have been steady appreciation along S´S´.

We now reintroduce stochastic shocks into the price equation, and consider first a small realignment probability. In the absence of a band we would observe a solution path something like ROR in Figure 7, in which the kinks in the deterministic case are smoothed. There is a regime shift along the locus Y´Y´ where $y = y'$. There will also exist a path such as R´OR´ which passes through a point of inflection when its first derivative is zero. This is the equilibrium path for the maximum sustainable bandwidth.[13] This result can be better understood by considering the following example. Suppose that a fully credible, correctly aligned band with lower margin at $\underline{s}$ has a smooth pasting solution at point A in Figure 8, and that at this point output is at y_0 and the nominal interest rate at i_0. Along the locus $y = y_0$ the relationship between s and p is given by:

$$s = (D/\lambda\eta)(y_0 - \bar{y}) + (1 + \gamma/\lambda\eta)\,p \tag{19}$$

and along the locus $i = i_0$ is given by:[14]

$$s = (D/\kappa\eta)(i_0 - i^*) - [(1 - \kappa\eta - \phi\gamma)/\kappa\eta]\,p \tag{20}$$

Now suppose that when output reaches y_0, the realignment probability π jumps from zero to $\pi_{\max} = (i_0 - i^*)/(p - s)$. This has the effect of introducing an expected increase in s, i.e., a devaluation, which exactly offsets the interest differential. The expected depreciation of the exchange rate within the band conditional on no realignment, given by $(i_0 - i^*) - \pi(p - s)$, is reduced to zero. Next, consider the existence of a solution path smoothly tangent to the margin of a slightly wider band. It is straightforward to rule out as candidates paths lying above OA. But any path lying below it will intersect the locus $y = y_0$ at a point such as B where there is a **lower** interest differential than at A and the size of potential devaluation ($p - s$) is larger, since the slope of the locus of constant output is greater than one. This must imply that the expected appreciation of the exchange rate conditional on no realignment becomes strictly positive. The path switches from being convex in p to being concave in p. Therefore there is no solution path

[13] A regime shift formally similar to the one described here is analyzed in Miller and Weller (1995). The paper also provides a detailed exposition of the qualitative techniques which allow one to deduce the existence of a path such as R´OR´.

through the origin (a necessary property for a correctly aligned band) tangent to the edge of the wider band.

The role of overshooting in this apparently paradoxical result should be stressed. One's intuition suggests that defending a target zone in the presence of significant devaluation expectations is simply a question of committing to raising interest rates to whatever level is needed to compensate holders of the currency for the expected capital loss. But here the price shocks that lead to an overvalued currency also produce the monetary tightening that causes nominal **appreciation** within the band. Thus a defense of the band involves expansionary intervention to check any rise in interest rates that would lead to further appreciation. In the example just presented, such intervention is inconsistent with the arbitrage requirement that interest rates rise in the presence of heightened devaluation expectations.

This result is dependent upon two factors: the point within the band at which the realignment probability jumps, and the level to which it jumps. If the point at which it adjusts is sufficiently close to the middle of the band, and if the level is large enough to give S'S' a positive slope (as in Figure 9), then there will exist equilibrium paths which become tangent to the top (weak) edge of the band. The reason for this is as follows. If the market anticipates a sharp loss of confidence (represented by a jump in the realignment probability) close to the middle of the band, that expectation is sufficient to cause the currency to depreciate in response to a positive price shock at full employment. When the loss of confidence actually occurs, since it is by assumption not accompanied by any change in the nominal interest rate, investors must now expect the currency to appreciate if they are to continue to be willing to hold it. Because the currency is in the weak half of the band, this expectation of future appreciation is

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[14]Note that the slope of the locus described in (20) depends upon whether one assumes that overshooting occurs, in which case $1 - \kappa\eta - \phi\gamma > 0$.

consistent with the effect of marginal intervention to defend the currency at the weak edge of the band.

3.3.3. A Continuously Variable Realignment Probability

Although these examples illustrate the theoretical possibility that endogenously variable realignment expectations may lead either to nonexistence of equilibrium paths within the band, or to a shift from overshooting to undershooting, it is of course important to determine whether these are practical possibilities. For this purpose we return to the more general specification in (17), in which the realignment probability can vary continuously with the deviation of output from full employment. We first compute numerical solutions for the path of the exchange rate within a correctly aligned band placed symmetrically about the long-run equilibrium.

Figure 10 illustrates the possibility that bands wider than some critical value may not be sustainable.[15] The example uses the parameter values of Ghosh and Masson (1991) in Table 1 and sets $\phi = 0.5$ and $\sigma = 0.008$. The upper panel shows two paths for the exchange rate through the origin, one with a very slightly steeper slope there. The lower panel plots the associated values of π. One might question the empirical relevance of this case, given that it requires that devaluing realignments occur when the currency is in the strong half of the band. But a similar situation can arise in a more realistic situation if we allow the band to be centered on an overvalued central parity. For an overvaluation of five per cent we would observe the exact reversal of the case illustrated in Figure 3. The exchange rate distribution is skewed to the weak edge of the band. The equilibrium path lies everywhere below PPP, so that any realignment involves a devaluation. Realignments are now most likely to occur when the exchange rate

[15]We confirm this hypothesis with extensive numerical work which fails to find well-behaved smooth-pasting solutions for wider bandwidths.

is in the weak half of the band when nominal interest rates are high and output is low.[16]

We illustrate in Figure 11 the case of a band whose central parity is 5.25% overvalued. Parameter values are the same as for Figure 10, except that we return for simplicity to assuming a step function for the realignment probability. In the top left panel of the figure we show two paths for the exchange rate. One is the high credibility equilibrium path for the misaligned band (π is constant at 0.05). The other has a step function for π, shown in the bottom right panel. Over most of the band π is set at 0.05 as before. But it now jumps to π_{max} = 0.15 close to the lower edge. This has exactly the effect discussed in the example at the end of Section 3.3.2. The anticipated loss of credibility near the edge of the band renders it unsustainable.

An interesting feature of this example is that it demonstrates clearly how a crisis can occur even when current circumstances do not look particularly bad. If the band is initially sustainable, devaluing realignments will occur relatively infrequently, and will be more likely to be observed when the rate is in the weak half of the band. This is a consequence of the skewed distribution within the band. If the exchange rate is close to the weak edge of the band, output will near its full employment level. Suppose now that the market were to change its expectation of realignment in the event that output were to fall fairly significantly from its present level. Despite the fact that this is rather unlikely it is sufficient to generate a crisis now.

In Figure 12 we return to considering the case of a correctly aligned band. This example illustrates how increasing the sensitivity of the realignment probability to deviations from full employment generates equilibrium paths which undershoot and are tangent to the top edge of the band. If this happens,

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[16] In a comprehensive sample of realignments within the EMS over the period 1979-93, we found, using daily data, that in only 22% of cases had the exchange rate been above

intervention now has an effect consistent with arbitrage requirements in the currency market and the problem of sustainability disappears. The parameters used to generate the solution path shown are the same as in Figure 10 except that the realignment probability is dramatically increased. In order to compare the two cases we note that the value of the parameter π is the expected number of realignments per quarter. In Figure 10 the realignment probability is never more than 0.025 per quarter. Given that there are roughly sixty trading days in a quarter, in Figure 12 the daily realignment probability rises rapidly to over 0.08 per day. So although this example shows that it is possible to avoid the problem of sustainability, it suggests that one can only do so by assuming counterfactually high frequencies of realignment.

We argue that the example presented in Figure 11 can be used to provide at least a partial explanation for the events of the EMS crisis in the autumn of 1992. Its essential features are (i) an initially high level of credibility; (ii) a band centered on a moderately overvalued exchange rate; (iii) a change in the market's perception of the credibility of the band in a situation other than the current one. This is consistent with the circumstances surrounding the EMS crisis in September 1992. There had been a steady decline in the frequency of realignments against the German mark, as illustrated in Figure 13 for the Italian lira. This had the effect of boosting the credibility of the regime. In addition, there was no evidence of a decline in credibility as reflected in currency option prices or interest differentials until very shortly before the crisis (Campa and Chang, 1995; Malz, 1996; Rose and Svensson, 1994). Finally, the rather moderate change in credibility required in the event of significant deterioration in the level of economic activity seems plausible in the light of the strain imposed on EMS discipline by the effects of German re-unification.

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its central parity on at least one day during the two weeks preceding a devaluing realignment.

It might be objected that this story ignores a crucial factor, namely the ability of the government to make a large discrete change in the money supply in response to a collapse in credibility. In the context of the example in Figure 11, it would be possible to re-establish the existence of an equilibrium path with a suitable discrete reduction in money supply, *given that* π_{max} *is unaffected by the change in the money supply*. But in the more general case where π adjusts continuously to changes in output that will not happen. The jump in interest rates will be accompanied by a fall in the level of output, and this in turn will increase the probability of realignment. So long as the realignment probability increases sufficiently fast in response to the fall in output, the regime will not be sustainable. This argument throws further light on why the conventional wisdom on the use of interest rates to defend a currency band may fail. In the absence of sustainability problems (and this of course does not rule out the occurrence of periodic realignments) only small monetary adjustments are required at the edges of the band. But if a large increase in interest rates occurs in response to a loss of credibility, the interest rate increase itself accentuates the loss of credibility because of its impact on output and employment. Thus the policy of increasing interest rates dramatically in the face of a sudden loss of credibility may quite easily turn out to be futile, as proved to be the case at the time of the EMS crisis in 1992.

3.4 Forward-looking Prices

Thus far we have worked with a rather simple form of price adjustment equation which depends upon the level of contemporaneous excess demand or supply in the economy. But it could plausibly be argued that in an environment where the market anticipates realignments of the band, agents should also anticipate the effect that these realignments will have on price inflation. One way of doing this is to modify the price adjustment equation in the following way:[17]

$$dp = \phi(y - \bar{y})dt - \pi(s - m, p - m)(s - p)dt + \sigma dz \qquad (4')$$

If the band is correctly aligned about long-run equilibrium, a series of positive inflationary shocks causes the nominal interest rate to rise, leading to exchange rate appreciation and falling output. The consequent downward pressure on prices forces the system back towards long-run equilibrium. But if wage and price setters in the economy expect a devaluing realignment, this will reduce the deflationary impact on prices, and this effect will be greater the higher the probability and the larger the size of the realignment. These considerations are captured in equation (4').

We found that introducing this modification to the model had the effect of narrowing the width of sustainable band by a small margin, but made little difference to the realignment simulations described below. Consequently we do not report separate results for this case. The explanation for this finding can be found by examining the effect on the coefficients of the *A* matrix. The coefficients affected are a_{11} and a_{12}, which have values of -0.1422 and 0.0733 respectively. A ten per cent probability of a ten per cent devaluation when $p = 0.05$ and $s = -0.05$ changes these values only by 0.005. We have already shown that high realignment probabilities resolve the problem of sustainability, and so we conclude that our results on sustainability are robust to the introduction of more realistic forward-looking price setting behavior.

3.5 Monetary Accommodation

Our model assumes that the nominal money supply is held fixed while the exchange rate remains within the interior of the current band. If a

[17]We are grateful to Marcus Miller for suggesting this formulation.

realignment occurs, there is a discrete adjustment in the money supply designed to move the currency immediately to its PPP value at the midpoint of the new band. But since we have identified overshooting as the source of the potential sustainability problem, this suggests that if the price shocks were at least partially accommodated, then the difficulty would disappear. This indeed turns out to be the case. We introduce accommodation by reformulating (1) as:

$$m - (1-\alpha)p = \kappa y - \lambda i \tag{1'}$$

where α is the coefficient of accommodation. If $\alpha = 0$, there is no accommodation, and if $\alpha = 1$, there is complete accommodation and changes in the price level have no effect on the level of the real money supply. It can then be shown that there will always exist some value of $\alpha < 1$ at which the model shifts from overshooting to undershooting. In the undershooting case the free float solution (locus SS in Figure 1) is positively sloped. As the price level rises above its long-run equilibrium value, the nominal exchange rate depreciates, and the equilibrium path in a partially credible band will be tangent to the weak edge of the band. Here the intervention to defend the band reinforces rather than counteracts the interest premium needed to compensate for an expected devaluing realignment.

However, for the parameter values used to generate the paths in Figure 10, α has to be significantly above 0.9 to ensure the existence of an equilibrium path. In other words, there has to be a very high degree of monetary accommodation to real shocks if problems of sustainability of a target zone are to be avoided. Of course, this result relies upon the assumption that the realignment probability function is not itself influenced by the change of policy. In practice, a policy of increased monetary accommodation is likely to be associated with higher realignment probabilities, and this will have the effect of reducing the amount of accommodation required.

3.6 The Simulation of Realignments

In this section we assume that the sustainability problems associated with partial credibility do not arise. As was demonstrated above, this imposes certain restrictions on the form of the function π.[18] Given these restrictions, we wish to compare the performance of the fully credible regime with one in which the market expects that realignments will occur from time to time. We consider first the effect of introducing realignment expectations in a situation where the band is symmetrically placed about long-run equilibrium. It is interesting to compare the upper panel of Figure 2 with Figure 14. The only difference between the two cases is the existence of symmetric realignment expectations. Despite the fact that the frequency of realignment was only 14.4%, the distributions of the nominal exchange rate and the exchange rate within the band are markedly changed.[19] Identical by definition in the fully credible case, the distributions diverge substantially when realignments are permitted. Both become hump-shaped, as is observed in the data. But the nominal exchange rate, not surprisingly, becomes significantly more variable, whereas the exchange rate within the band becomes significantly less variable. The real exchange rate also becomes significantly less variable, as does output.

Finally, Figure 15 plots the mean and the 5th and 95th percentiles of the distributions of the variables over time. When compared with Figure 4 it shows clearly how periodic realignment increases the speed of adjustment. It is of course not surprising that there should be some effect given the nature of realignment rule we have assumed. However, the magnitude of the effect is a consequence of the endogenous adjustment of the realignment probability. Realignments occur when they are most needed i.e. when relying on the process of automatic adjustment associated with a fully credible band would lead to prolonged periods when output was far from its full employment level.

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[18] In the simulations we interpret π as the realignment probability per period, which requires us to restrict its value to be less than one.

[19]The parameters for π needed to generate this frequency were: a = 0.35, b = 0.03, k = 100.The frequency of 14.4% is not unrealistic in the light of ERM experience where there were six realignments of the French franc against the DM over a period of fourteen years.

What this analysis suggests is that, although a target zone may be a desirable regime for limiting exchange rate variability when central parities are close to being correctly aligned, it is not particularly well-suited to dealing with significant misalignments. The period of adjustment is likely to be lengthy and the consequent pressures for a realignment ultimately overwhelming. This is an argument for reconsidering the original target zone proposal put forward by Williamson (1985), that envisaged a band on the real exchange rate. Such an arrangement avoids the accumulating pressure for large discrete changes in central parity by allowing for more frequent adjustments at the margins of the real exchange rate band.

4. Summary and Conclusion

We have analyzed a model of a target zone that explicitly incorporates sluggish price adjustment and the formation of endogenous realignment expectations based on a policy rule for the government which weighs the cost of realignment against the benefit of a quicker return to full employment. We show that the process of adjustment towards equilibrium in the case of a fully credible band is rather slow. This suggests that a realistic model of a target zone must incorporate a realignment process that is driven by economic fundamentals. We consider the case where the government faces random fixed costs in the event of a realignment, and trades off those costs against the benefits of a realignment designed to return the nominal exchange rate to PPP and output to its full employment level. This produces a probability of realignment that increases with deviations of output from its full employment level. When the probability of realignment is low, and relatively insensitive to changes in economic fundamentals, bands of a width which have been observed in the EMS may become unsustainable, in the sense that there is no intervention policy which can be used to defend the band successfully. We suggest that the model may provide at least a partial explanation for the EMS crisis. In particular, we are able to explain the observation that the crisis occurred when credibility was historically high and when the level of fundamentals at the time did not seem to warrant it.

A policy of monetary accommodation can alleviate the problem of sustainability. But this is possible only at the cost of a severe curtailment in the ability of a country to pursue counterinflationary measures within the band. Finally, we show that even relatively infrequent realignments can markedly speed the process of adjustment to misalignment, indicating that a policy of attempting to maintain high credibility in the face of substantial shocks may ultimately prove self-defeating.

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Figure 1

The free float solution.

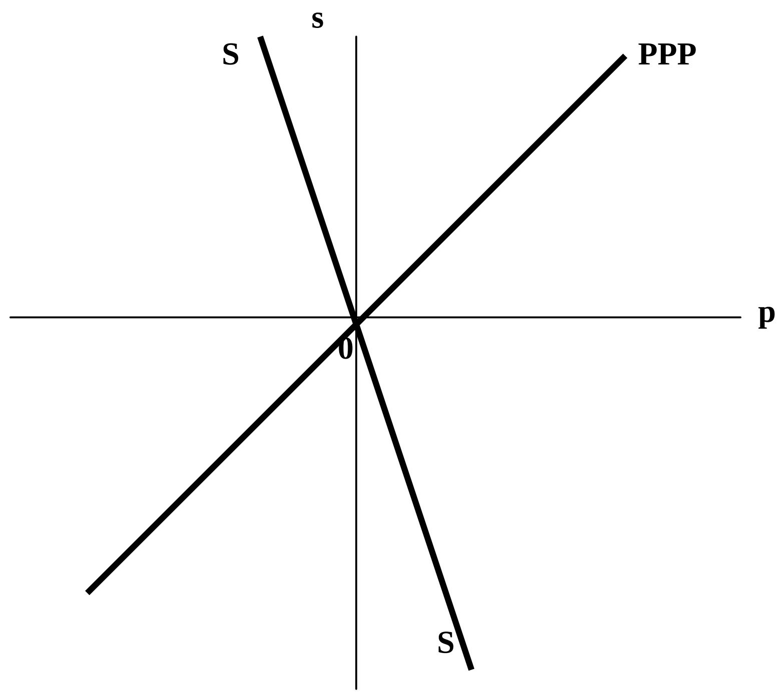


Table 1

Parameter values for the simulation of the model.

Parameter	γ	κ	η	λ	ϕ	σ
value	0.152	0.225	0.114	1.419	0.6	0.004
					0.2	0.007

All parameters except ϕ and σ are taken from Ghosh and Masson (1991).

Figure 2

The distribution of the exchange rate for a perfectly credible band: σ = .007 (upper panel) and σ = .004 (lower panel).

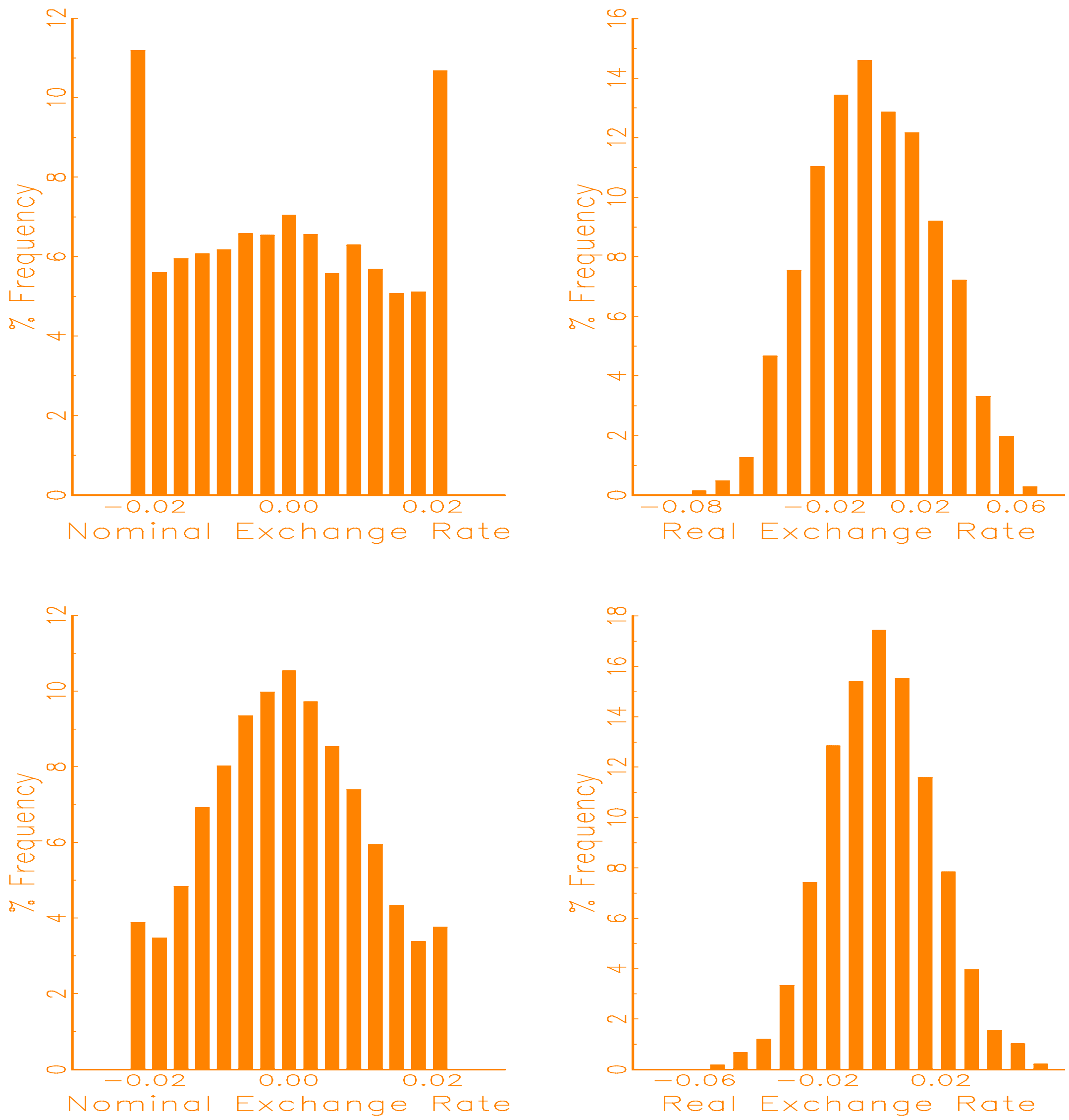


Figure 3

Distributions for a wide band (upper panel, σ = .007) and a misaligned band (lower panel, σ = .004).

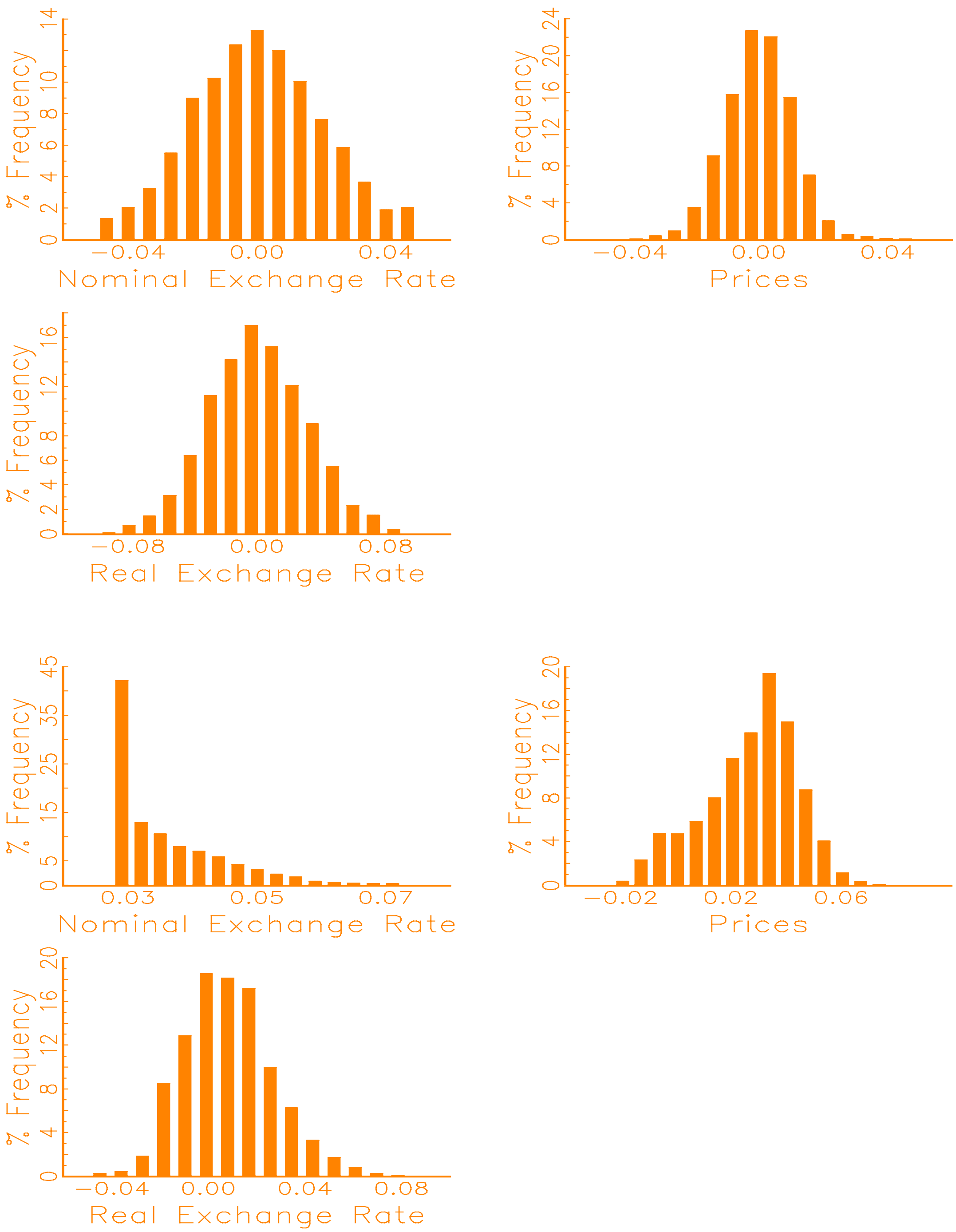


Figure 4
The speed of adjustment to misalignment (ϕ = .6)

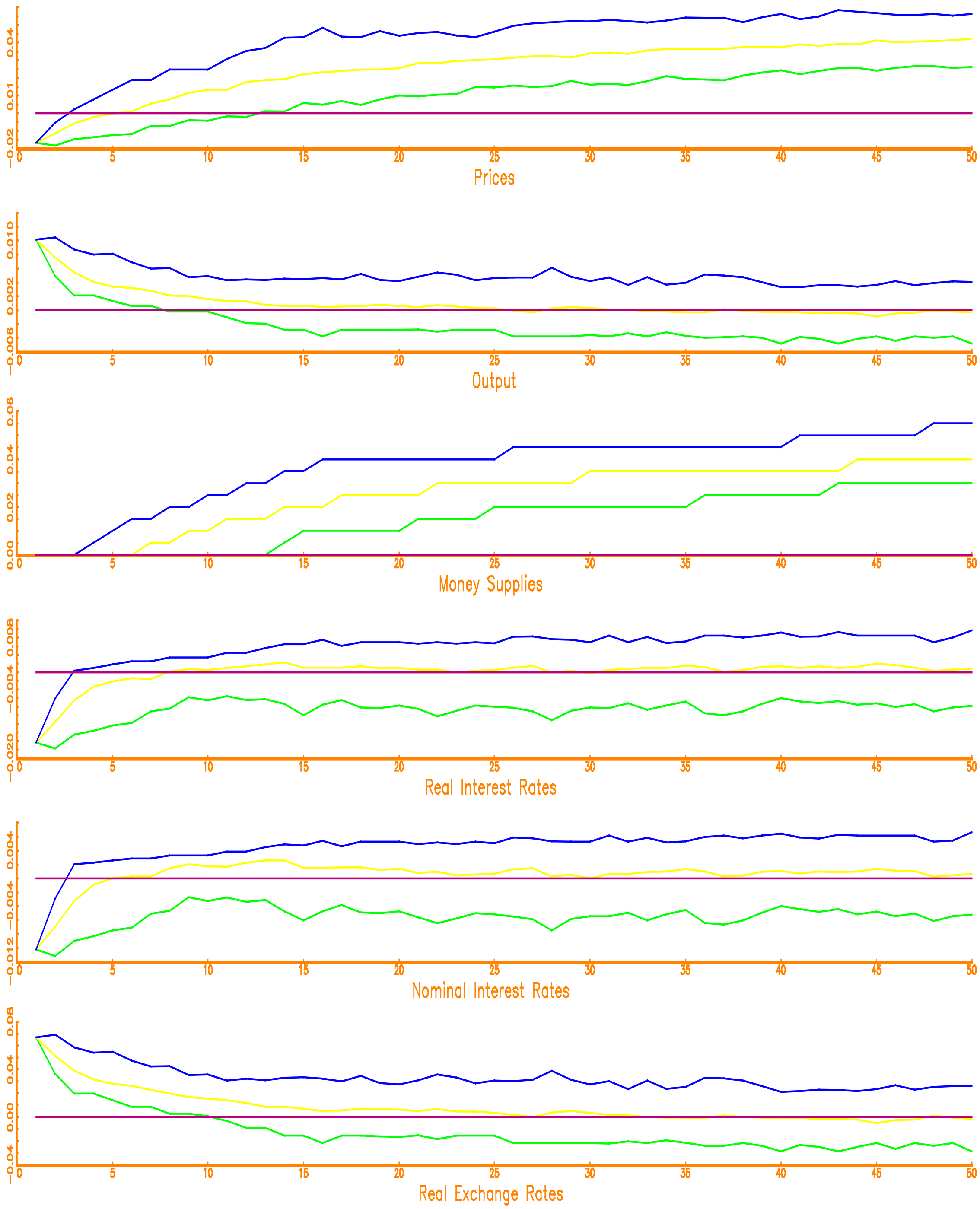


Figure 5
The speed of adjustment to misalignment (ϕ = .2)

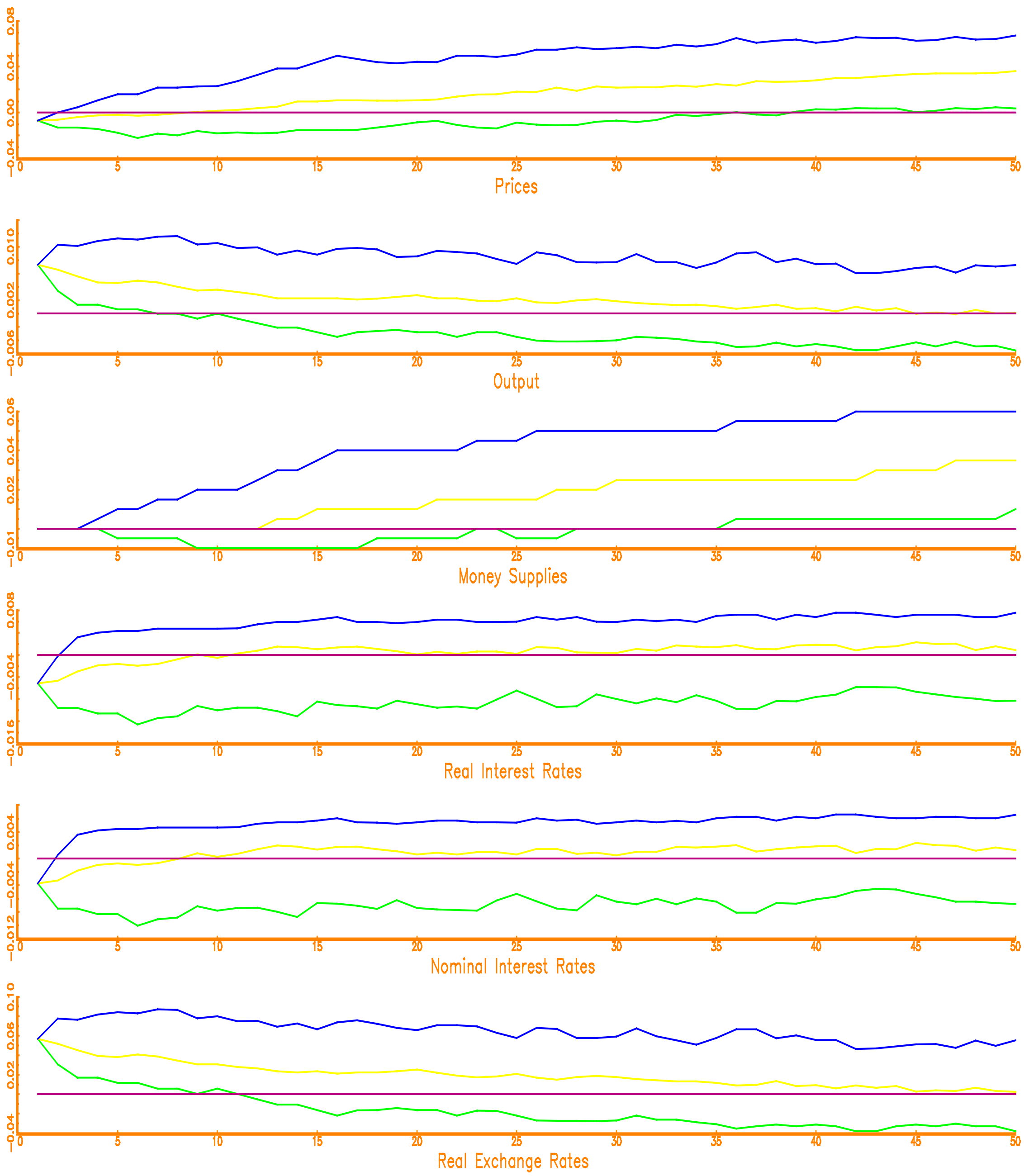


Figure 6

The stable saddlepath for the deterministic model with a step function for the realignment probability

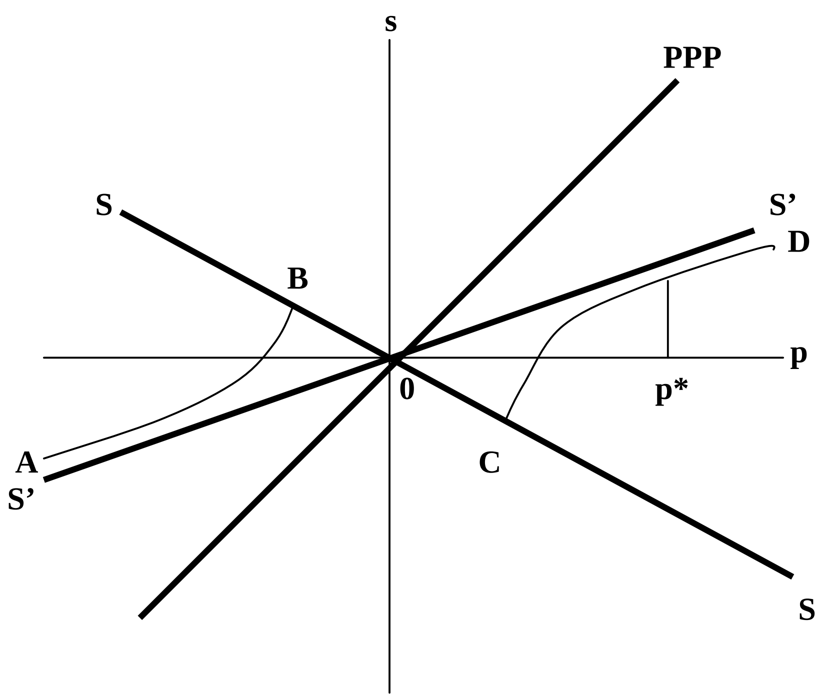


Figure 7

Equilibrium paths for the stochastic model with a step function for the realignment probability when the probability is small.

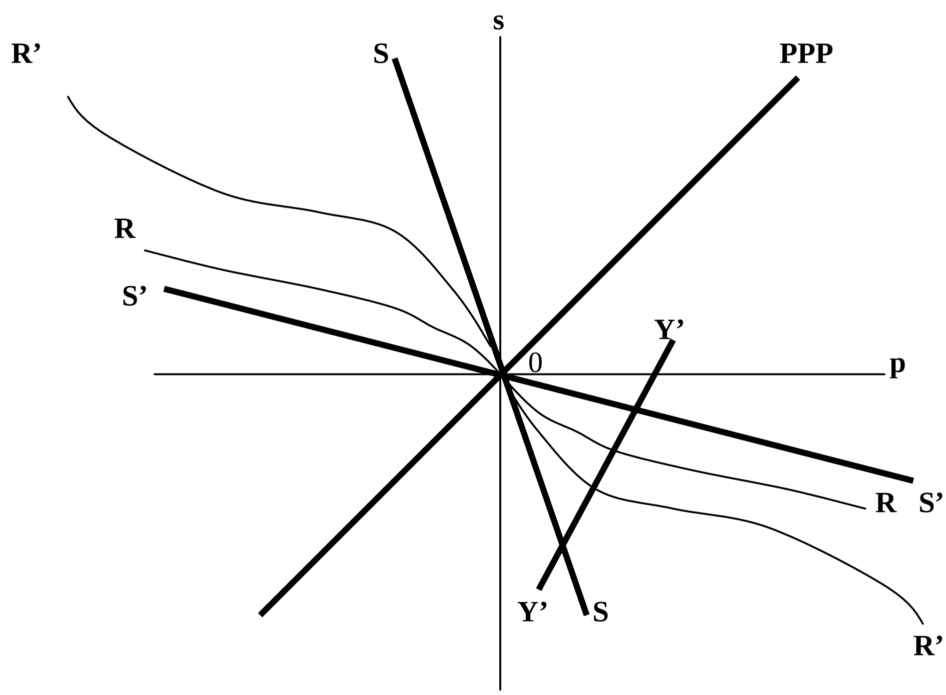


Figure 8

An example of a maximal bandwidth

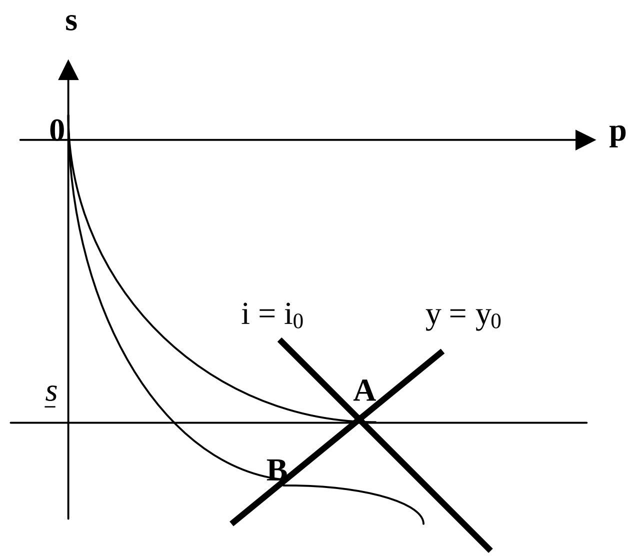


Figure 9

Equilibrium paths for the stochastic model with a step function for the realignment probability when the probability is large.

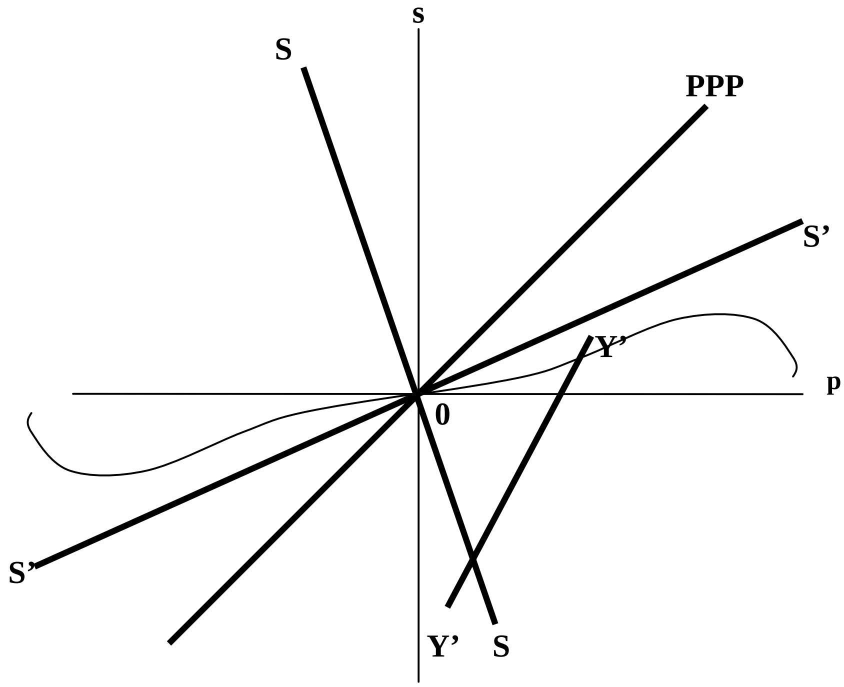
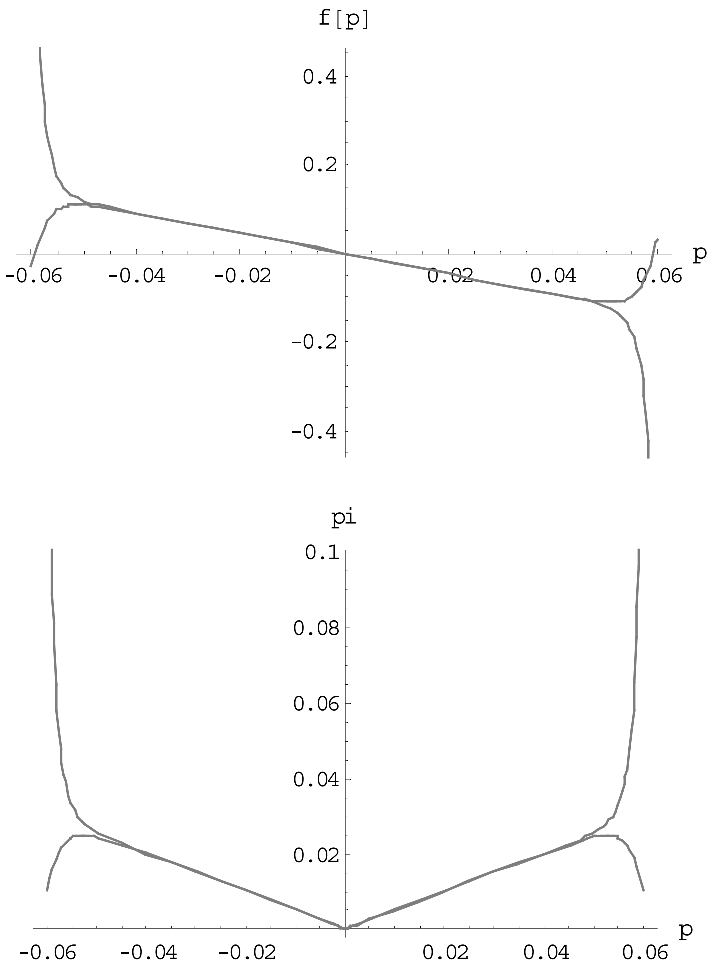


Figure 10

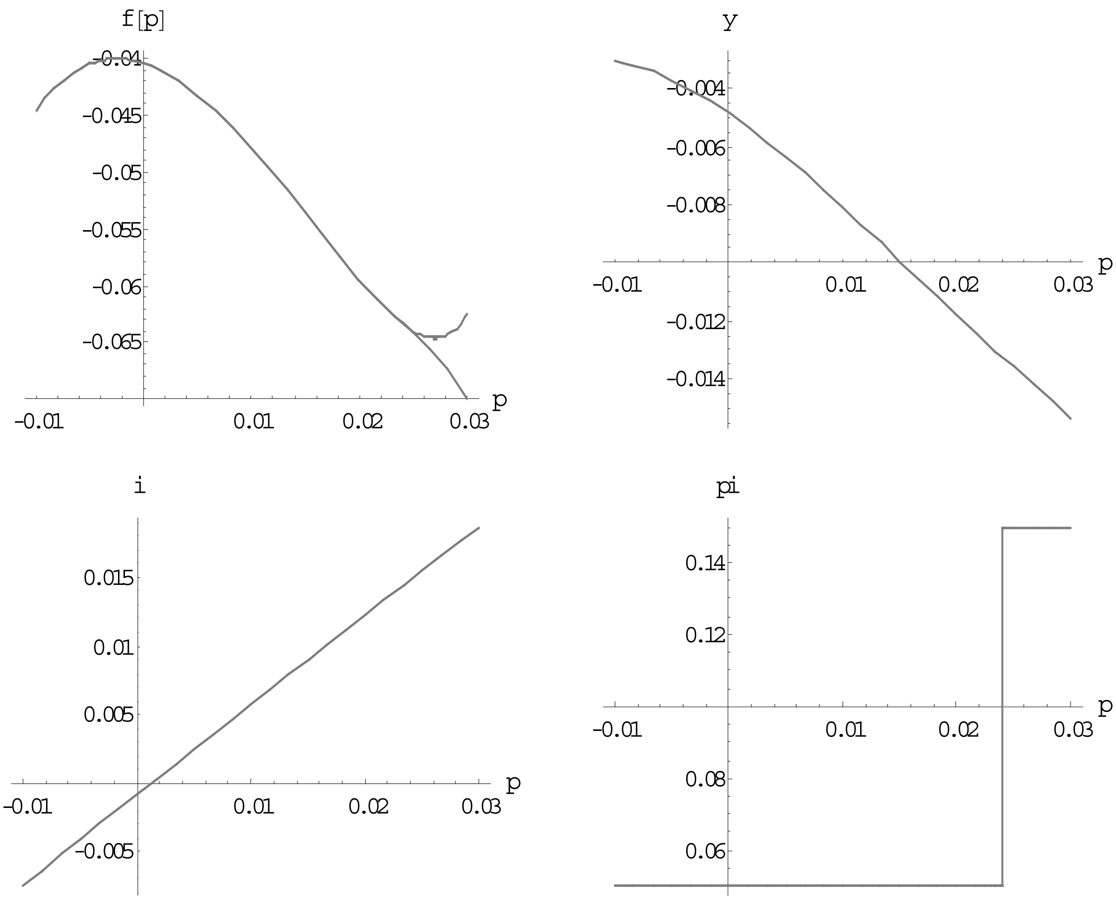
A critical sustainable bandwidth; equilibrium paths for the exchange rate



Parameter values are as in Table 1, except that $\phi = 0.5$, $\sigma = 0.008$. Also, $a = 1$, $b = 0$ and $k = 1$.

Figure 11

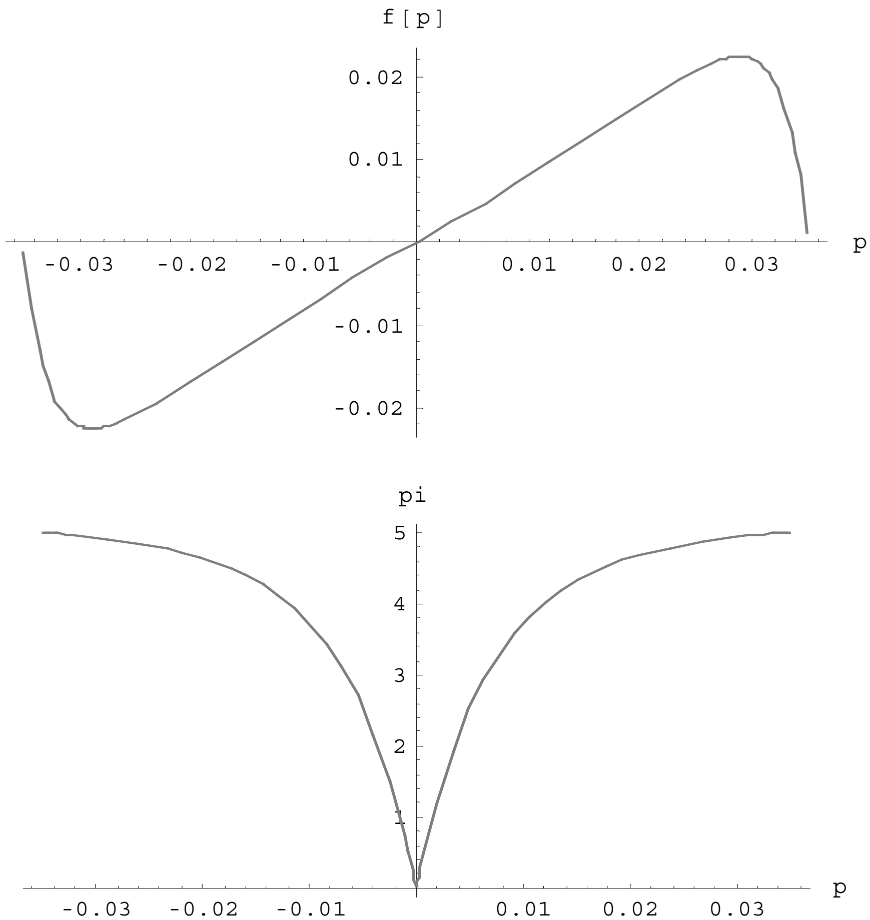
An unsustainable band with variable realignment probability: the case of an overvalued central parity



Parameter values are as in Table 1, except that $\phi = 0.5$, $\sigma = 0.008$.

Figure 12

The shift from overshooting to undershooting with high realignment probability



Parameter values are as in Table 1, except that $\phi = 0.5$, $\sigma = 0.008$. Also, $a = 5$, $b = 0$, $k = 1000$.

Figure 13

The ITL/DEM exchange rate and its central parity within the exchange rate mechanism of the EMS: 1979-1993

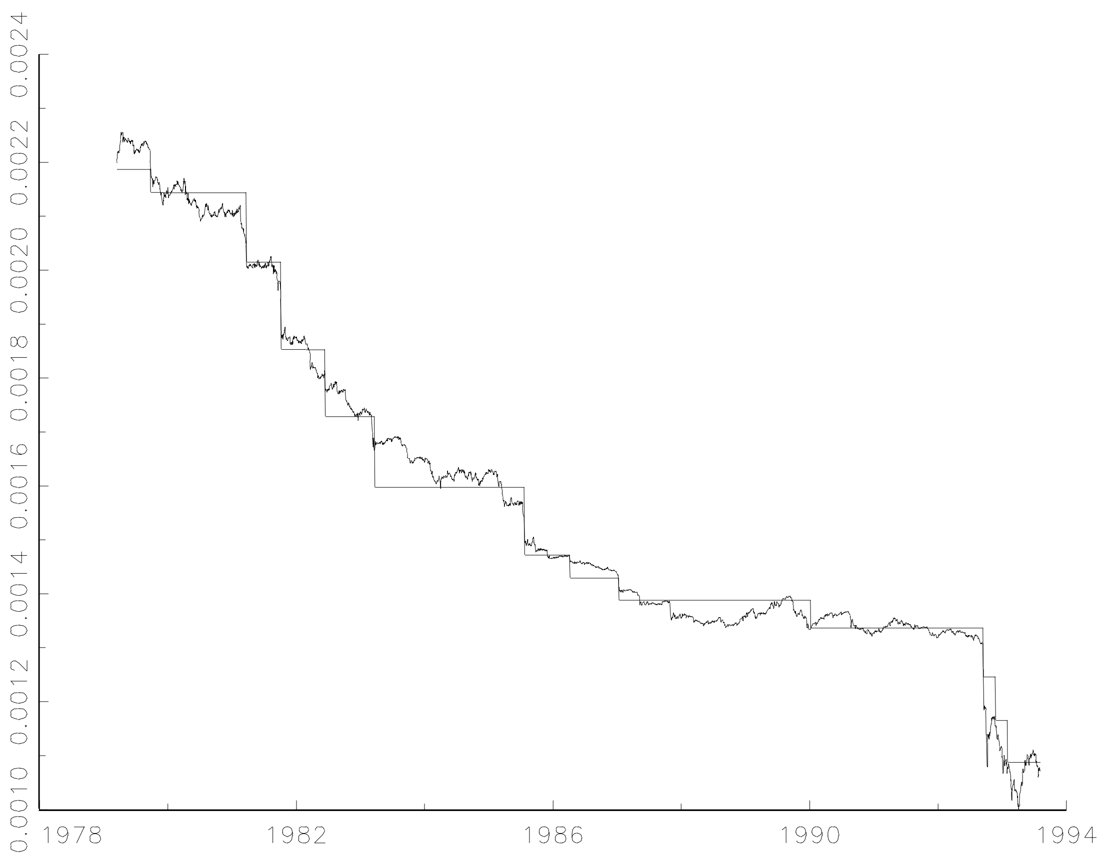


Figure 14

A target zone with endogenous expectations.

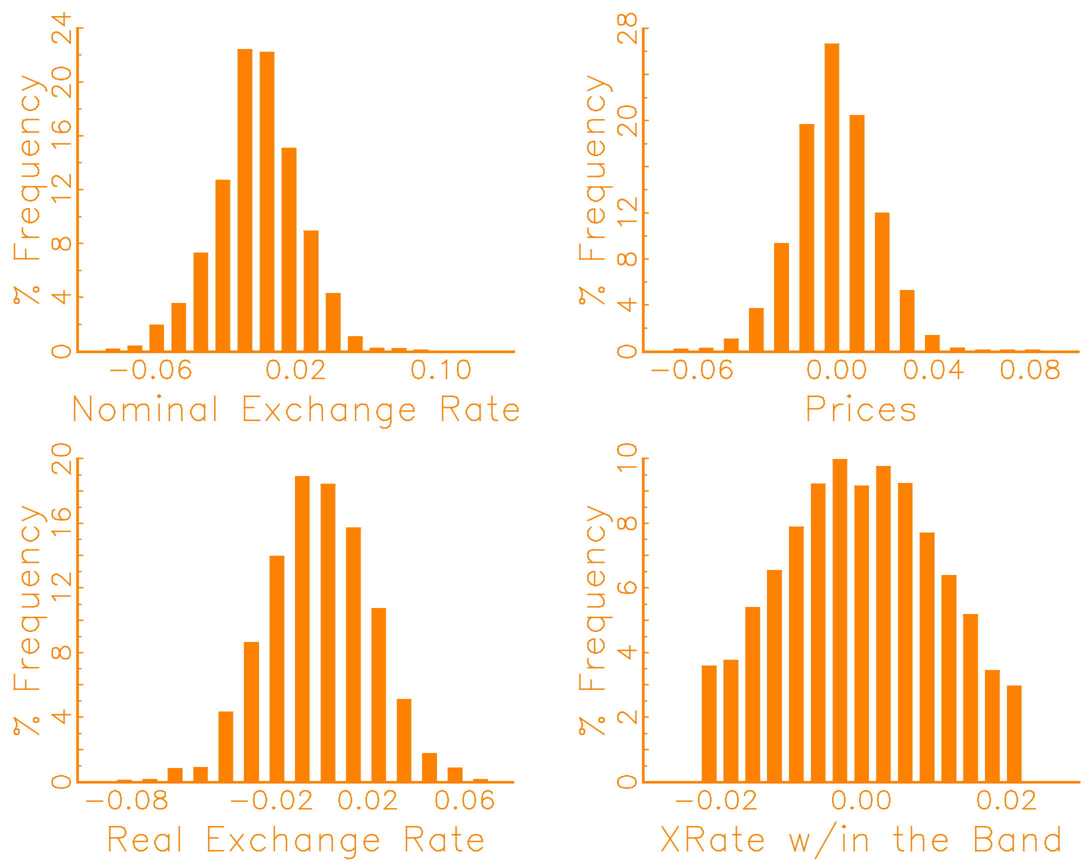


Figure 15

Speed of adjustment with realignment (ϕ=0.6).