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INTRAMARGINAL INTERVENTIONS, BANDS AND THE PATTERN OF EMS EXCHANGE RATE DISTRIBUTIONS

by Roel M.W.J. Beetsma and
Frederick van der Ploeg

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Intramarginal Interventions, Bands and the Pattern of EMS Exchange Rate Distributions

Roel M.W.J. Beetsma
University of Limburg, Maastricht

Frederick van der Ploeg
University of Amsterdam and CEPR

ABSTRACT

Following Bertola and Caballero (1992), we document an empirical puzzle for EMS exchange rates during a period in which these exchanges rates were (almost) credible, i.e. exchange rate distributions are hump-shaped rather than U-shaped as predicted by the standard target zone model. We offer an explanation which is based on the combination of two realistic features, namely the presence of intramarginal interventions and wage/price sluggishness.

Keywords: Exchange rate bands, monetary accommodation, intramarginal interventions, wage and price sluggishness, EMS, unconditional exchange rate distributions.

JEL code: E0, F3, F4.

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1. Introduction

The seminal paper of Krugman (1991) was the first to explicitly analyse the effects of exchange rate bands on exchange rate behaviour. However, as a modeling vehicle for the European Monetary System (EMS), there is strong evidence that it fails to account for a number of stylised facts, of which the most important is the evidence on the empirical distributions of most EMS exchange rates in their bands. These unconditional distributions tend in practice to be hump-shaped, with most of the probability mass concentrated inside the band, while theory predicts on the basis of the Krugman (1991) model that these distributions should be U-shaped, i.e. with a large concentration of probability mass close to the boundaries (see Svensson, 1991a). For example, Bertola and Caballero (1992) present empirical evidence about the hump-shaped feature of the distribution of the French franc against the Deutsche Mark (the Ffr/DM rate) for the period April 1979 - December 1987. They offer an explanation which is based on repeated realignments of the exchange rate and also provide empirical evidence on interest rate differentials, which at times indicate expectations of future realignments.

We argue, however, that for the Netherlands, for the period April 1983 - November 1991, and for the other EMS countries, for the period February 1987 - November 1991, offshore interest differentials with Germany show quite a different pattern. On average, they have decreased dramatically compared to the preceding period, indicating a strong increase in the credibility of the exchange rate bands. Still, the empirical distributions of the exchange rates against the Deutsche Mark continue to be hump-shaped. This is, in particular, the case for the Dutch guilder against the Deutsche Mark (Dfl/DM), which is generally considered as the most credible exchange rate in the EMS. The reason for choosing these particular sample periods is that they are prolonged periods in which realignments did not occur[1], and it was generally believed that the exchange rate bands were becoming more and more credible. This belief was expressed by statements of EMS governments never to devalue again and by the progress on plans for a Economic Monetary Union in Europe (EMU) (e.g., the Delors Committee). Our period of investigation ends just prior to the Maastricht Summit in December 1991[2], because it was precisely at this moment, when criteria were negotiated for participation in an EMU, that doubts rose about the eligibility of a number of countries to participate in an EMU. These doubts were reinforced by political difficulties in the ratification of the Maastricht Treaty (witness the Danish vote) and the recent successful speculative attacks on the Italian lira and pound sterling. There is thus a potential danger that the whole Treaty, including the agreements on an EMU, will never be ratified.

It is thus not clear that the explanation of the hump-shaped feature of unconditional exchange rate distributions offered by Bertola and Caballero (1992) is appropriate for the sample periods that we consider, mainly because the anticipation of repeated realignments did not seem to be much of an issue prior to Maastricht. We offer therefore an alternative and realistic explanation of the observed hump-

[1] Except for a change in the central parity of the Italian lira on January 8, 1990. However, this was a special case, because it occurred when the band width of the lira was reduced from ±6% to ±2.25%.

[2] Even though the Dfl/DM rate does not show any qualitative difference in behaviour for the period after that.

shaped distribution of the exchange rates, which is based on the presence of intramarginal interventions (i.e. monetary accommodation within the band). See Giavazzi and Giovannini (1989) for a discussion of the empirical relevance of intramarginal intervention during earlier periods of the EMS[3]. To have an interesting role for intramarginal interventions, we allow for transitory unemployment caused by nominal price and wage inertia. Our analysis is conducted within the context of a stochastic version of the Dornbusch (1976) overshooting model, following the Miller and Weller (1990) extension of Krugman (1991), with shocks to aggregate supply. Hence, three realistic features are added to the Krugman (1991) model: (i) home and foreign products are imperfect substitutes in consumption so that purchasing power parity is relaxed, (ii) prices and wages are sluggish, and (iii) there are intramarginal as well as inframarginal (i.e., at the edges of the band) interventions in the foreign exchange market[4]. Most of the existing work on nominal exchange rate bands lacks these features. Many studies, for example, assume purchasing power parity[5]. If there is a unique relationship between the exchange rate within the band and its fundamental, there are two factors contributing to the explanation of the hump-shaped feature of the exchange rate distribution: the shape of the exchange rate solution in terms of the fundamental (on which the explanation of Bertola and Caballero (1992) is based[6]), and mean-reversion in the fundamental. Our proposed explanation is based on a combination of both these factors[7]. The objective of this paper is thus

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[3] Lewis (1990) analyses a specific type of intramarginal intervention (i.e. at each point in time there is a non-zero probability that the Brownian motion of the fundamental is stopped) within the context of a monetary model with purchasing power parity and full employment.

[4] Apart from being based on more realistic features, i.e. price sluggishness and intramarginal intervention, this way of modeling has other advantages as well. The presence of sluggish prices and, therefore, of temporary unemployment, allows one to study the trade-off between price variability and variability of employment under an exchange rate band (see Beetsma and van der Ploeg, 1992). Moreover, if one allows for imperfect substitution between home and foreign goods, one can study the effects of a band on the real exchange rate (see also Miller and Weller, 1990, 1991).

[5] Krugman's (1991) minimalist stochastic specification can be derived from a monetary model of exchange rates where purchasing power parity and full employment prevails (e.g., Froot and Obstfeld, 1991; Svensson, 1991a). However, it can also be interpreted as the reduced form of a target zone model with imperfect substitution between home and foreign goods and an upward-sloping aggregate supply schedule (see Sutherland, 1992b).

[6] Bertola and Caballero (1992) show that if realignment risk is strong enough, the standard S-shaped exchange rate solution turns into an inverted S-shape which is steeper near the boundaries than around the central parity. With a process for the fundamental, which is (conditional on the money supply) uniformly distributed in its band, this leads to a concentration of the probability mass of the exchange rate around its central parity.

[7] Lindberg and Söderlind (1992) allow for repeated realignments and mean-reverting intramarginal interventions and generate a hump-shaped pattern for the exchange rate distribution as well. The disadvantage of their model is that it assumes purchasing power parity and that net cumulated interventions will be non-stationary (due to velocity being Brownian motion). In our analysis, even though cumulative interventions can reach any level with positive probability, the global stability of the model ensures that borrowed reserves can always be paid off in the future. Delgado and Dumas (1991) introduce mean-reversion in the uncontrollable part of the fundamental. The difference with Lindberg and Söderlind

to show that mean-reversion introduced by sluggish adjustment of prices and wages combined with a degree of intramarginal intervention can result in a hump-shaped exchange rate distribution and thereby explain the empirical evidence. We show that the hump-shape is more likely to occur when the degree of monetary accommodation is close to what is needed to peg the nominal exchange rate (so that the fundamental has to move far away from its mean for the exchange rate to reach its boundaries). We thus argue that hump-shaped distribution functions for EMS exchange rates may be due to EMS countries engaging in intramarginal as well as inframarginal interventions.

The remainder of the paper is as follows. In section 2, we document the empirical puzzle. Section 3 presents our model. In section 4, we first consider, as a benchmark for comparison, the case of an unrestricted dirty float without a nominal exchange rate band. In section 5, we analyse the effects of a nominal exchange rate band. In section 6 we explain how the hump-shaped feature of exchange rate distributions can be reproduced and provide an illustration based on Monte Carlo simulations. In section 7 we summarise the results and offer suggestions for further research.

2. Empirical evidence for EMS exchange rates

As already mentioned in the previous section, we will study the EMS exchange rates against the Deutsche Mark for the subperiod February 1987 - November 1991. However, we study the Dfl/DM rate for a somewhat longer period, i.e. April 1983 - November 1991.

Figures 1(a) and 1(b) show one-month offshore interest rate differentials[8] against the position of the French franc/Deutsche Mark (Ffr/DM) rate in its band for the subperiods March 1979 - January 1987 and February 1987 - November 1991, respectively. Figures 2(a) and 2(b) do the same for the Dfl/DM rate for the subperiods March 1979 - March 1983 and April 1983 - November 1991, respectively. The area between the pairs of diagonal lines is the set of combinations of exchange rate position in the band and interest rate differential for which the predicted future exchange rate does not lie outside the current band, i.e. under the assumption of uncovered interest parity the sum of the interest rate differential plus the deviation of the current exchange rate from central parity must be within the ±2.25% or ±6% band. Going from the early EMS to the more recent EMS subperiod, for both countries interest rate differentials with Germany have decreased dramatically on average. In fact, this effect is even stronger (although not visible

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(1992) is that the mean of the mean-reverting fundamental process shifts (in the opposite direction of the movement of the uncontrollable part of the fundamental) when intervention takes place. Hence, the relationship between fundamental and exchange rate in the band is non-unique. The implications for the unconditional exchange rate distribution still need to be worked out. For narrow bands, it might well be the case that the tendency for mean reversion is so strong, if net accumulated interventions are nonzero, that, for most of the time, the exchange rate settles near the edges of its band, which would result in a U-shaped unconditional exchange rate distribution (a similar reasoning applies to the Miller and Weller, 1991, model with continuous interventions at the boundaries; see footnote 15).

[8] We use daily observations. Interest rate differentials are computed from spot and forward exchange rates under the assumption of covered interest parity.

in the figures) towards the end of the more recent EMS subperiod. For the other EMS countries the pattern of change of interest rate differentials is similar (the corresponding figures have been omitted to save space). The second outstanding feature for France is that the positive correlation between the position of the nominal exchange rate in the band and the interest rate differential, which is clearly present during the early EMS subperiod (as is also reported by Bertola and Caballero, 1992), has vanished during the more recent EMS period. For other countries we have been unable to detect a clear correlation between the interest rate differential and the exchange rate position for either of the two EMS subperiods.

Figures 3 and 4 show, for the more recent EMS subperiods, kernel estimates of the unconditional density functions of the Ffr/DM and Dfl/DM rate, respectively, in their bands[9]. Both estimates clearly indicate a concentration of probability mass in the interior of the band. Although not shown here, other EMS exchange rates show a pattern for the unconditional exchange rate density function which is roughly similar. Hence, despite the fact that interest rate differentials have largely been eliminated during the more recent EMS subperiod thus indicating a significant decrease in devaluation risk, the hump-shaped pattern of the empirical distributions of the EMS exchange rates in their bands continues to be present, both during the early and the more recent EMS subperiods. This suggests that the explanation offered by Bertola and Caballero (1992) might be less relevant for the more recent EMS subperiod (April 1983 - November 1991 for the Dfl/DM, February 1987 - November 1991 for the other exchange rates).

3. Transitory unemployment in a small open economy

Most of the existing work on nominal exchange rate bands is based on Krugman (1991), and adopts the unrealistic assumptions of purchasing power parity and fully flexible wages and prices, and thus assumes full employment. Notable exceptions are Miller and Weller (1990, 1991), who extend Krugman (1991) to a stochastic version of the familiar exchange rate overshooting model of Dornbusch (1976), thus allowing for sluggish price movements and imperfect substitution between home and foreign goods in consumption. Our model of a small open economy extends Miller and Weller (1990) to allow for different types of nominal exchange rate regimes, each one of them characterised by a particular feedback rule for the money supply. In particular, in section 4, when we introduce a nominal exchange rate band, we extend Miller and Weller (1990) by allowing for intramarginal accommodation and intervention in the foreign exchange market. Our model may be summarised by the following equations:

$$y = -\eta\,(i - \pi) + \delta\,(e + p^* - p), \quad \eta>0,\ 0<\delta<1 \tag{3.1}$$

$$m - p = y - \lambda\, i, \quad \lambda>0 \tag{3.2}$$

$$dp = \phi\,(y - y^F)dt + \pi dt + \sigma dz, \quad dz \sim IN(0,dt),\ \phi>0 \tag{3.3}$$

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[9] The choice of the kernel was based on the standardnormal density function, while the choice of the window width was based on minimizing the mean integrated square error (e.g., see Silverman, 1986).

$$E_t(de) = (i - i^*)\,dt \tag{3.4}$$

$$m = m(p) \tag{3.5}$$

where m, y, y^F, p, p^*, e and dz denote logarithms of the nominal money supply, the level of aggregate demand, the full-employment level of output, the home price level, the foreign price level, the nominal exchange rate (price of one unit of foreign currency in terms of domestic currency units) and a supply shock, respectively, i and i^* denote the home and foreign nominal interest rate, respectively, and π denotes the rate of core inflation.

The home country specialises in the production of a good with price p and the foreign country specialises in the production of a good with price p^*. There is imperfect substitution between home and foreign goods. Equation (3.1) is the IS-curve and shows that aggregate demand increases when the real interest rate declines or the real exchange rate depreciates. The real interest rate is simply the nominal interest rate minus the core inflation rate. Equation (3.2) is the LM-curve and says that the velocity of circulation increases with the nominal interest rate. Equation (3.3) is the Phillips-curve, which shows that inflation in wages and producer prices occurs when there is excessive demand for goods, and that deflation occurs when there is unemployment. The speed at which the labour market clears, i.e the degree of price and wage flexibility, corresponds to the parameter ϕ. For convenience, the full-employment level of output is assumed to equal λi^* (i.e. $y^F=\lambda i^*$)[10]. Supply shocks (z) follow a Brownian motion and correspond to positive shocks to nominal wages; z follows an independent Wiener process with zero mean and instantaneous standard deviation equal to σ. Producer prices are a constant mark-up on unit labour costs, so that supply shocks may be interpreted as negative shocks to labour productivity. The money supply is stable in steady state, so core inflation (π) being the trend rate of inflation is zero[11]. Equation (3.4) is the uncovered interest parity condition. Risk-neutral arbitrage ensures that an interest differential in favour of the domestic country can only be sustained if the currency is expected to depreciate in the future, i.e. if the currency is currently over-valued. Finally, equation (3.5) is the feedback rule for money supply in response to price changes. All exchange rate regimes considered in the sequel are characterised by a special case of this feedback rule for monetary policy.

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[10] This guarantees that in steady state, i.e. when the expected change in the price level and the exchange rate is zero, nominal money supply and the price level are both equal to μ [see equation (4.1)]. It also ensures that, if there is full monetary accommodation, i.e. a PPP exchange rate rule (see section 4.2), the real exchange rate is pegged, other real variables are constant as well, and expected price and nominal interest rate changes are zero.

[11] The advantage of this simple specification is that one can unambiguously determine that the system is saddlepath stable. If aggregate demand depends on the real consumption interest rate, i.e. the nominal interest rate minus the rational expected rate of change in the CPI, there is a possibility of an unstable spiral (i.e. higher inflation depresses the real interest rate, boosts aggregate demand and thus induces even higher inflation). Our definition of core inflation in the definition of the real interest rate avoids these indeterminacies and simplifies the algebra.

4. Unrestricted dirty float: The case of no band on the exchange rate

To facilitate comparison with a regime in which an exchange rate band is present, we first consider the case of an unrestricted dirty float. Hence, there is no exchange rate band and the money supply rule is linear:

$$m = \mu + \beta\,(p - \mu) = (1-\beta)\,\mu + \beta\,p, \quad \beta < 1. \tag{4.1}$$

This feedback rule says that, when prices exceed their long-run value μ (i.e. the exogeneous component of the money supply), the monetary authorities accommodate and raise the money supply. The degree of monetary accommodation is given by the coefficient β.

For simplicity, and without any loss of generality, we normalise all foreign variables to zero. Alternatively, we could redefine all domestic variables as deviations from their steady state. Using (4.1), the reduced form equations of the model under a dirty float are given by:

$$dp = \phi(\eta+\lambda)^{-1}\{-[\delta\lambda+\eta(1-\beta)]p+\delta\lambda e+\eta(1-\beta)\mu\}dt \; + \; \sigma dz \tag{4.2}$$

$$E_t de = (\eta+\lambda)^{-1}[(1-\beta-\delta)\;p + \delta\;e - (1-\beta)\;\mu]\;dt. \tag{4.3}$$

The price level is a predetermined, backward-looking variable, whilst the exchange rate is a non-predetermined, forward-looking variable which jumps if private agents suddenly anticipate a change in future policy. The rational expectations equilibrium must therefore be a stable saddlepath solution. This requires one eigenvalue with a negative real part and one eigenvalue with a positive real part, which is ensured as long as $\beta<1$ holds. To find the unique, non-explosive rational expectations solution, we postulate a linear saddlepath:

$$e - \text{mean}(e) \;=\; \omega\;[p - \text{mean}(p)] \tag{4.4}$$

where $\text{mean}(p)=\text{mean}(e)=\mu$. Upon substitution of (4.4) into (4.2) and (4.3) and equating coefficients on p, we find:

$$\omega \;=\; \left[\frac{\phi\eta(1-\beta)+\delta(1+\lambda\phi)-\sqrt{[\phi\eta(1-\beta)+\delta(1+\lambda\phi)]^2+4\lambda\phi\delta(1-\beta-\delta)}}{2\lambda\phi\delta}\right]. \tag{4.5}$$

In fact, there is another solution for ω as well. However, that solution can be ruled out because it does not satisfy the requirement that the adjustment of prices along the saddlepath is a stable process.

The slope ω of the saddlepath increases if the coefficient of monetary accommodation (β)

increases[12]. For low degrees of monetary accommodation, i.e. $\beta<1-\delta$, there is a negative correlation between the nominal exchange rate and the price level, i.e. the saddlepath slopes downwards. This implies that the nominal exchange rate overshoots in response to an unanticipated and permanent change in the long-run money supply (cf., Dornbusch, 1976). For high degrees of monetary accommodation, $1-\delta<\beta<1$, the saddlepath slopes upwards, which implies undershooting of the nominal exchange rate. The turning point between overshooting and undershooting of the nominal exchange rate in response to an unanticipated permanent change in the money supply corresponds to the coefficient of monetary accommodation that ensures a fixed nominal exchange rate (i.e. $\beta=1-\delta$), so that $\omega=0$. This nominal exchange rate regime will be referred to as a **peg**.

It is easy to see that for $\beta<1-\delta$, ω is increasing in ϕ, while for $1-\delta<\beta<1$, ω is decreasing in ϕ. Therefore, as ϕ increases, the relationship between ω and β pivots around the peg ($\beta=1-\delta$) towards the horizontal axis. In the extreme case of a classical model with full employment (i.e. $\phi\rightarrow\infty$), $\omega\rightarrow0$ and all transitional dynamics disappear.

4.1. Special case: fixed exchange rates

Under a peg the monetary authorities use unsterilised interventions to fix the exchange rate. If the foreign interest rate exceeds the domestic interest rate, there is an incipient capital outflow and pressure for the currency to depreciate. Under a peg, the central bank defends the exchange rate by selling foreign reserves and buying its own currency. As a result, the money supply falls until the domestic interest rate is pushed up to the level of the foreign interest rate. Hence, a peg corresponding to $e=e_P$ implies that the domestic interest rate is anchored to the foreign interest rate, and that an independent domestic monetary policy is infeasible:

$$m = (1-\delta)\, p + \delta\, e_P \equiv \beta\, (p - \mu) + \mu. \qquad (4.6)$$

Hence, a peg at $e=e_P$ corresponds to a very specific (linear) money supply rule, namely an accommodation coefficient of $\beta=1-\delta$ and a long-run component of the money supply of $\mu=e_P$. Upon substitution of these results in (4.2), we find that prices follow an Ornstein-Uhlenbeck process (Karlin and Taylor, 1981, p.172):

$$dp = -\,\phi\, \delta\, (p - e_P)\, dt + \sigma\, dz \qquad (4.7)$$

which is a mean-reverting process. Clearly, the asymptotic mean of this process is mean$(p)=\mu=e_P$. The expected speed of mean-reversion towards the steady state increases while the variances of output and prices (i.e. var$(y)=\delta^2$var$(p)=\frac{1}{2}\sigma^2\delta/\phi$) decrease with the degree of labour market flexibility (ϕ). In a

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[12] If $\beta=1-\delta$, then $\omega=0$. If $\beta=1$ and $\phi\lambda\leq1$, then $\omega=1$. If $\beta=0$ and $\delta\geq\frac{1}{2}$, $\omega>-1$.

classical world in which markets clear instanteneously the variances of output and prices are zero. If aggregate demand is more sensitive to relative prices (higher δ), the variance of output is higher but the variance of the price level is lower. The variance of inflation over the unit interval (say, Δp) is given by $\mathrm{var}(\Delta p)=2[1-\exp(-\phi\delta)]\mathrm{var}(p)$. Full employment ($\phi \rightarrow \infty$) implies that both the variance of the price level and of the inflation rate are zero.

4.2. Clean float versus PPP exchange rate rule

Other special cases are zero monetary accommodation ($\beta=0$), which will be referred to as a **clean float** and *inter alia* always implies exchange rate overshooting, and, at the other extreme, **full accommodation** ($\beta=1$). Under a clean float the monetary authorities do not give in to wage and price demands and thus keep the nominal money supply fixed, while with full accommodation they accommodate all wage and price shocks. It is easy to see that in the latter case all transitional dynamics are eliminated and that the real exchange rate is fixed at zero. Hence, 100% monetary accommodation corresponds to a rule which ensures that the domestic interest rate is pegged to the foreign interest rate, that the real exchange rate is fixed ($p^{*}+e-p=0$) and thus that employment and output are at their natural rates. This special case ($\beta=1$) is also referred to as a **PPP exchange rate rule** (e.g. Dornbusch, 1982; Alogoskoufis, 1991)[13], and induces non-stationarity in the nominal price level and exchange rate ($\mathrm{var}(p)$, $\mathrm{var}(e) \rightarrow \infty$).

4.3. Unrestricted dirty float

More general degrees of monetary accommodation correspond to a situation in which deviations of prices from their steady state are partially accommodated ($0<\beta<1-\delta$ or $1-\delta<\beta<1$) and will be termed an **unrestricted dirty float**. The exchange rate adjusts instantaneously to ensure equilibrium on the balance of payments, but nevertheless some intramarginal intervention in the foreign exchange market occurs.

The steady state corresponds to the mean of the asymptotic distributions. In the long run relative purchasing power parity holds and money is neutral, independent of the monetary accommodation coefficient (β). However, in the short run the qualitative properties of the rational expectations equilibrium depend very much on the coefficient of monetary accommodation (β). An increase in the exogeneous or long-run component of the money supply (μ) induces overshooting (cf., Dornbusch, 1976) of the exchange rate for low degrees of accommodation ($\beta<1-\delta$). The market expects an interest rate differential in favour of abroad and thus over time a gradually appreciating exchange rate, so that the exchange rate must on impact over-react. However, for large coefficients of monetary accommodation ($1-\delta<\beta<1$), the exchange rate undershoots on impact. A gradual increase in prices is accompanied by a gradual expansion

[13] A higher degree of nominal exchange rate indexation gives more stability in the real exchange rate and the levels of demand and employment, but on the other hand it amplifies the effects of wage disturbances and other supply shocks on prices. Alogoskoufis (1991) extends Dornbusch (1982) by highlighting the effects of monetary and exchange rate accommodation on the forward-looking behaviour of wage- and price-setters, and suggests that more persistence in inflation may arise from a higher degree of accommodation in floating exchange rate regimes.

of the money supply, so that the anticipated gradual rise in interest rates is less pronounced. Consequently, the exchange rate depreciates less and the interest rate falls less on impact thus leading to undershooting rather than overshooting of the exchange rate.

5. Dirty float with a nominal exchange rate band

As already mentioned, one of the crucial elements in the explanation of the observed hump-shaped distributions of EMS exchange rates within a nominal exchange rate band is the presence of intramarginal interventions in the foreign exchange market. Hence, below we introduce a band on the exchange rate and to capture the presence of intramarginal interventions we allow for a non-zero coefficient of monetary accommodation (β), cf. the rule (4.1), if the exchange rate is inside the band. We assume, for ease of notation, that the long-run component of the money supply is zero (i.e. μ=0). In order to solve for the exchange rate solution within its band, we postulate instead of the linear saddlepath solution (4.4) a twice differentiable function for the solution:

$$e = \Omega\,(p). \tag{4.4'}$$

Use of Ito's Lemma, $d\Omega = \Omega'\, dp + \frac{1}{2}\sigma^2\, \Omega''\, dt$, yields a second-order nonlinear differential equation:

$$\tfrac{1}{2}\sigma^2\, \Omega''(p) + \phi(\eta+\lambda)^{-1}\, \{-[\delta\lambda+\eta(1-\beta)]\, p + \delta\lambda\, \Omega(p)\}\, \Omega'(p) - (\eta+\lambda)^{-1}\, [(1-\delta-\beta)\, p + \delta\, \Omega(p)] = 0. \tag{5.1}$$

This equation yields a time-invariant relationship between the nominal exchange rate and the price level. Note that there are only two linear solutions, which correspond exactly to the stable and the unstable arm of the saddlepath solution of the unrestricted dirty float discussed in section 4. These linear solutions are, of course, not compatible with the presence of finitely wide nominal exchange rate bands.

To solve for the exchange rate when it is inside the band, it is necessary to specify the nature of the interventions undertaken by the monetary authorities when the exchange rate reaches the boundaries of its band. The band on the nominal exchange rate consists of an upper bound (e^U) and a lower bound (e_L). The authorities ensure that the exchange rate does not move outside this band by imposing thresholds $p^U \equiv \Omega^{-1}(e^U)$ and $p_L \equiv \Omega^{-1}(e_L)$ on the price level (the "fundamental"). We focus only on exchange rate solutions symmetric about the origin by normalizing the central parity to zero and assuming that $p^U = -p_L$ (so that $e^U = -e_L > 0$). If the price is between p^U and p_L, the exchange rate is inside its band and the degree of monetary accommodation or intramarginal intervention to price changes is β, while, beyond these thresholds, the degree of accommodation switches to the one (i.e. $1-\delta$) that is needed to keep the exchange rate fixed at the upper, respectively, lower boundary of its band (see section 4.1). The complete description of the money supply rule which supports this policy is given by the following piecewise-linear monetary accommodation rule[14]:

$$m = \beta p, \text{ for } p^U < p < p_L \text{ if } 0 \leq \beta < 1-\delta \text{ and } p_L < p < p^U \text{ if } 1-\delta < \beta < 1,$$

$$m = (1-\delta)p + \delta e_L, \text{ for } p \geq p_L \text{ if } 0 \leq \beta < 1-\delta \text{ and } p \leq p_L \text{ if } 1-\delta < \beta < 1, \tag{5.2}$$

$$m = (1-\delta)p + \delta e^U, \text{ for } p \leq p^U \text{ if } 0 \leq \beta < 1-\delta \text{ and } p \geq p^U \text{ if } 1-\delta < \beta < 1.$$

Note that (5.2) makes use of $\Omega' < 0$ for $0 \leq \beta < 1-\delta$, and $\Omega' > 0$ for $1-\delta < \beta < 1$, which correspond to an inverted and regular S-shaped solution of $\Omega(.)$, respectively (see Figure 5(a)). The switch points $p^U \equiv \Omega^{-1}(e^U)$ and $p_L \equiv \Omega^{-1}(e_L)$ follow implicitly from the smooth pasting conditions, which are the appropriate boundary conditions (cf. Miller and Weller, 1990)[15,16]. If the price level crosses p^U (or p_L) from the interior of its band, the nominal interest rate differential, i.e. $i-i^*$, jumps from a negative (positive) value to zero. Hence, the monetary authorities have to implement a discrete contraction (expansion) of the nominal money supply in order to raise (depress) the interest rate and prevent the exchange rate from moving outside its band. Because the market anticipates this regime switch at the boundaries of the band, the exchange rate solution bends and becomes horizontal as the economy approaches the boundaries. This is what is known as the "honeymoon effect".

6. Reproduction of the stylised pattern of EMS exchange rate distributions

6.1. An explanation for the hump-shaped pattern

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[14] This piecewise-linear specification does not allow intramarginal interventions to depend on how close the exchange rate is to the edges of the band. Allowing for this complicates the solution without changing the qualitative features of the analysis much.

[15] In Miller and Weller (1991) the band is sustained by infinitesimal adjustments of the money supply if the exchange rate reaches the boundaries of its band. However, independent of the amount of cumulated intervention, the exchange rate always returns inside its band if the price movement reverses after intervention. This intervention policy implies a non-unique relationship between the price level and the exchange rate, namely one that depends on the current level of money supply. Although the implications for the unconditional distribution of the exchange rate in its band still need to be worked out further, Sutherland (1992a) suggests that the distribution is U-shaped rather than hump-shaped. The intuition is that changes in the money supply, as a result of interventions, temporarily change the long-run equilibrium consistent with the current level of money supply. Hence, the exchange rate solution in the band shifts and becomes relatively steep in the middle of the band. Combined with the global mean-reversion in the price level, this implies a concentration of probability mass near the edges of the band.

[16] Although it is not possible to obtain a closed-form expression for all solutions to differential equation (5.1), one can characterize the solutions qualitatively (cf. Miller and Weller, 1989). It follows that there is a unique solution in the band which fulfills the smooth pasting conditions (for $1-\delta < \beta < 1$ this is guaranteed if $\phi\lambda \leq 1$). For $0 \leq \beta < 1-\delta$ the solution is downward sloping and for $1-\delta < \beta < 1$ it is upward sloping. It is strictly concave in the upper half of the band, and strictly convex in the lower half of the band.

In this section we explain how sluggish wage/price movements and intramarginal interventions within a nominal exchange rate band combine to offer a potential explanation for the observed hump-shaped pattern of EMS exchange rate distributions. It is important to understand how the monetary accommodation coefficient (β) and the degree of labour market flexibility (ϕ) affect the shape of the solution of the exchange rate in terms of the price level and the degree of mean-reversion of the economy. Let us first investigate how the *shape* of the exchange rate solution is affected by changes in parameter values, in particular by the degree of intramarginal accommodation (β) and the degree of labour market flexibility (ϕ).

Figure 5(a) shows, for given $\phi>0$, the exchange rate solution for various degrees of monetary accommodation (β) within the band. For a low degree of accommodation, $0\leq\beta<1-\delta$, $\Omega'<0$ and thus $p^U<p_L$, so that the exchange rate solution is an inverted S-shape. The point is that very low prices induce an expansion of the real money supply and thus a depreciation of the currency, possibly forcing it beyond the upper bound. For high degrees of accommodation, $1-\delta<\beta<1$, the upper bound e^U translates into an upper bound on the price level, $p^U>0$, and the exchange rate solution has a regular S-shape. The inward shift in the LM-curve arising from high prices is now attenuated by accommodation, but the IS-curve shifts back a lot. The result is an incipient interest rate differential in favour of the foreign country and pressure on the currency to depreciate on impact, possibly forcing it outside the band.

Thus, increasing the degree of intramarginal intervention from a low value ($0\leq\beta<1-\delta$), increases the gap between the switch points p^U and p_L, beyond which the exchange rate is pegged at the boundaries of its band, as the solution for the exchange rate becomes flatter. This gap goes to infinity if one approaches the point at which the exchange rate is pegged ($\beta=1-\delta$). Increasing the coefficient of intramarginal accommodation further, beyond $1-\delta$ towards full accommodation, the bandwidth for the price level again monotonically decreases from infinity. The relationship between the coefficient of intramarginal accommodation (β) and $p^U=\Omega^{-1}(e^U)$ is depicted in Figure 5(b).

Section 4 showed that an increase in labour market flexibility (ϕ) causes the saddlepath to become more horizontal, i.e. its slope increases when $0\leq\beta<1-\delta$ and its slope decreases when $1-\delta<\beta<1$. With a band on the nominal exchange rate, this means that the implied gap between the price limits, beyond which the exchange rate is held on the boundaries of its band, increases.

Finally, note that both a higher variance (σ^2) and a higher value of the semi-elasticity of the demand for money with respect to the interest rate (λ) induce a stronger honeymoon effect. For a higher variance, the intuition is that the expected time towards stabilisation of the exchange rate at its boundaries is shorter. The prospect of future stabilisation strengthens the exchange rate now when it is in the upper half of its band, and weakens the exchange rate when it is in the lower half of the band. Similarly, a higher value for λ adds to the forward-looking character of the solution and increases the response of the current spot exchange rate to changes in the expected rate of change in the future (cf. Krugman, 1991). Hence, the imminent stabilisation at the boundaries of the band has a stronger stabilising effect on the exchange rate now.

The extent of mean-reversion of the system is directly affected by the degree of labour market flexibility. It is therefore instructive to see first what happens in case of complete wage and price rigidity (i.e. ϕ=0). Prices then follow a Brownian motion. The reduced form equation for the exchange rate has a similar format as in Krugman (1991):

$$e = [(\beta+\delta-1)/\delta]\ p + [(1-\beta)/\delta]\ \mu + [(\eta+\lambda)/\delta]\ E_t(de)/dt. \tag{6.1}$$

The band on the exchange rate translates into a band on the fundamental $f \equiv [(\beta+\delta-1)/\delta]\ p + [(1-\beta)/\delta]\ \mu$, with limits $f_L=\Omega^{-1}(e_L)$ and $f^U=\Omega^{-1}(e^U)$. At its boundaries the authorities use infinitesimal adjustments of μ, while inside the band, for given μ, there is intramarginal intervention, which again takes the form of monetary accommodation of price shocks. As a function of the fundamental (f), the solution for the exchange rate has the familiar S-shape. Hence, for given μ, the exchange rate decreases in the price level if $0\leq\beta<1-\delta$ and increases in the price level if $1-\delta<\beta<1$. However, as Svensson (1991a) has shown, a fundamental which is a Brownian motion (without drift) in its band, is uniformly unconditionally distributed in its band. Hence, under complete price rigidity (ϕ=0), the exchange rate distribution in its band must be U-shaped. To explain the empirical puzzle, one thus needs some degree of wage and price flexibility (i.e. $\phi>0$). It is easy to see that both under a dirty float and under a peg the degree of mean-reversion increases in ϕ, because the (negative) root of the reduced form system [equations (4.2) and (4.3), respectively (4.7)], which determines the expected speed of the economy to its long-run equilibrium, decreases in ϕ. However, to see how the degree of mean-reversion is affected by a change in labour market flexibility (ϕ) if there is a band on the nominal exchange rate, the nonlinearity of the exchange rate solution forces us to resort to Monte-Carlo simulations.

6.2. Monte-Carlo simulation results

Because we do not have analytical closed-form solutions for the unconditional exchange rate distributions when there is a band on the exchange rate, we use Monte Carlo simulations to reproduce the hump-shaped pattern of the EMS exchange rate distributions. Details about the simulation procedure are available upon request. The choice of parametervalues is determined by the considerations outlined above. Given the variance (σ^2), which determines the overall variability of the system, one needs an accommodation coefficient (β) which is close enough to 1-δ, and at the same time a degree of labour market flexibility (ϕ) which is not too small. Various experiments suggest that there is a wide range of parameter values consistent with a hump-shaped pattern of the exchange rate distribution. Moreover, we conjecture that for a given degree of labour market flexibility ($\phi>0$), it is always possible to choose β so close to 1-δ, that the implied bandwidth for the price level (i.e. the gap between p_L and p^U) becomes so large that the percentage of time that the exchange rate is at its boundaries is negligible. In our simulations reported here we have set $\sigma=0.1$, $\eta=\delta=\lambda=\frac{1}{2}$. We also assume a symmetric exchange rate band of

±2.25%, which is the bandwidth of EMS exchange rates[17].

Figure 6 portrays simulated distributions[18] of the nominal exchange rate. In the cases of no intramarginal intervention (see Figure 6(a); β=0, ϕ=0.5) and almost full accommodation (see Figure 6(b); β=0.98, ϕ=0.5), the gap between the switch points p_L and p^U is relatively small, so that the exchange rate distribution is U-shaped. However, if β is close to 1-δ, the combination of a large gap between p_L and p^U and the mean-reversion induced by the (sluggish) wage/price response to excess demand/supply, leads to an exchange rate distribution which is hump-shaped (see Figure 6(c); β=0.46, ϕ=0.5). As expected, the hump-shaped pattern is more pronounced for the higher degree of labour market flexibility. In the case where ϕ=1 and β=0.46 (see Figure 6(d)), the simulated distribution clearly resembles the empirical distribution of the Dfl/DM rate giving support for the view that De Nederlandsche Bank engages in a fair amount of intramarginal interventions as well as trying to keep the guilder inside its band.

Figures 7 shows simulated unconditional distributions of the interest rate differential for the same combinations of β and ϕ. When the degree of intramarginal accommodation is far from 1-δ, the exchange rate spends a relatively large part of the time on the boundaries of the band where the interest rate differential is zero. This explains the sharp contrast between the amount of probability mass in the middle class of the histograms and the other classes, when β=0 and β=0.98. When β is close to 1-δ, the distribution has a hump-shaped pattern, which becomes more concentrated around zero if goods and labour markets are more flexible. In fact, the empirical distributions of the interest differentials in the EMS generally also have a hump-shaped character.

7. Concluding remarks

Following Bertola and Caballero (1992), we have provided additional evidence of an empirical puzzle concerning EMS exchange rates, namely that the stylised pattern of their empirical distributions tends to be hump-shaped rather than U-shaped, as predicted by the standard target zone model. Our evidence is based on the subperiod April 1983 - November 1991 for the Dutch guilder and the subperiod February 1987 - November 1991 for the other exchange rates against the Deutsche Mark. During these periods the EMS exchange rates were relatively credible, as may be witnessed from the interest rate differentials. Hence, for this period, the explanation offered by Bertola and Caballero (1992) seems less appropriate as it is based on expectations of repeated realignments. We have offered an alternative explanation which is valid even when there is no probability of realignment. Our explanation is based on the combination of two realistic features, namely that wages and prices are not fully flexible and that there are intramarginal interventions.

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[17] Except for the Italian lira before 8 January 1990, when the bandwidth was ±6%.

[18] The reason why we present the simulated distributions as histograms, is that they have a mixed discrete-continuous nature, because in the long-run distribution there is a positive probability that the exchange rate is exactly located on its boundaries. Of course, for β "close to 1-δ", the relative amount of time spent at the boundaries of the band is negligible.

As shown by the interest rate differentials with Germany, the credibility of the exchange rate bands has increased a lot during the more recent EMS period under consideration. Although close to zero on average, interest rate differentials were still positive. Moreover, there still seemed to be some noise in the relationship between the position of the exchange rate in the band and the interest rate differential, which may indicate a slight residual (stochastic) devaluation risk. Hence, future research may combine the expectations of realignments stressed by Bertola and Caballero (1992) with the combined effects of price sluggishness and intramarginal interventions. This extension may benefit from recent work by Svensson (1991a,b) and Bertola and Svensson (1993). Such a richer framework will help to understand the hump-shaped pattern of exchange rate distributions during earlier periods in the EMS and the more recent period we studied, as well as the very recent speculative attacks on the Italian lira and the British pound that forced these currencies to leave the EMS.

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igure 1(a): Danger realignment Ffr/DM rate
(March 1979 - January 1987)

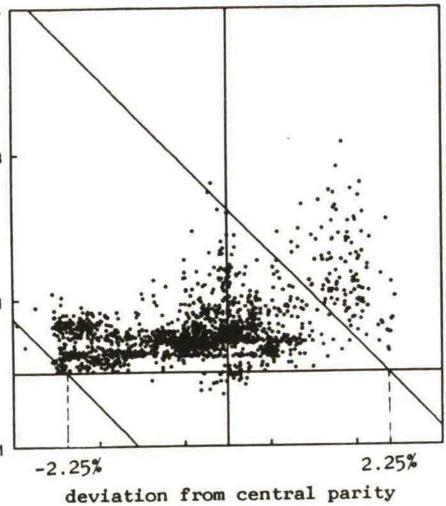


Figure 1(b): Danger realignment Ffr/DM rate
(February 1987 - November 1991)

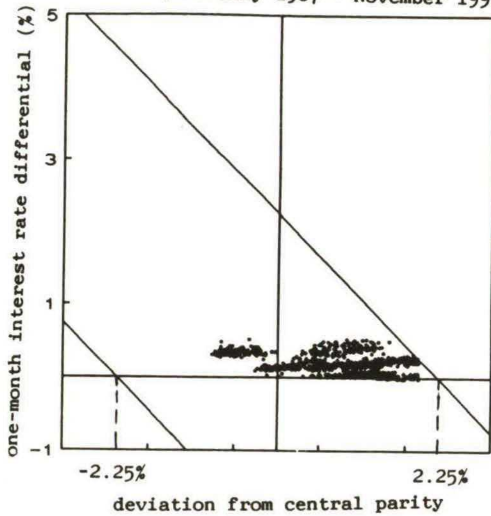


Figure 2(a): Danger realignment Dfl/DM rate
(March 1979 - March 1983)

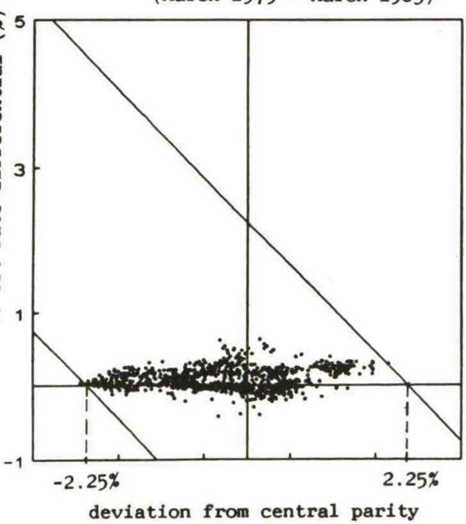


Figure 2(b): Danger realignment Dfl/DM rate
(April 1983 - November 1991)

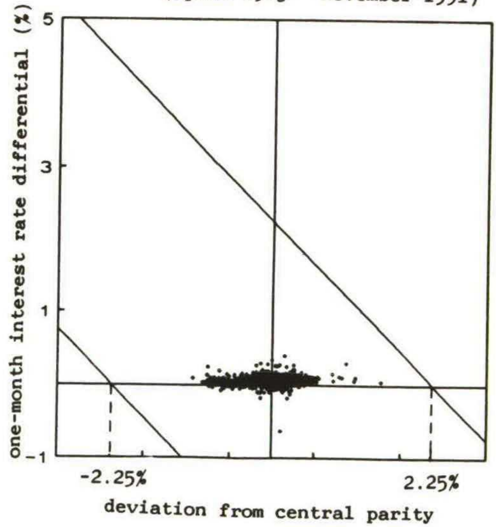


Figure 3: Unconditional density estimate Ffr/DM rate
(February 1987 - November 1991)

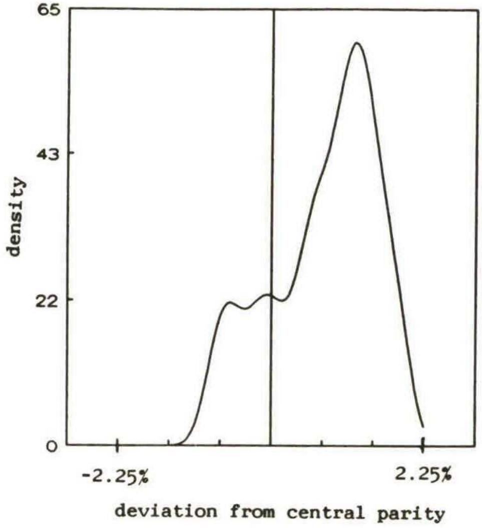


Figure 4: Unconditional density estimate Dfl/DM rate
(April 1983 - November 1991)

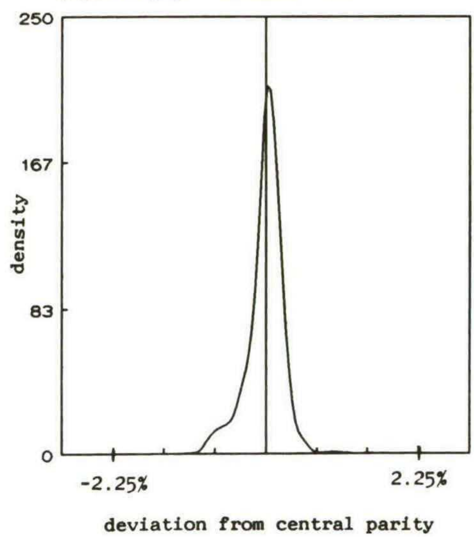


Figure 5(a): Solutions (e=Ω(p)) and the degree of intramarginal accommodation

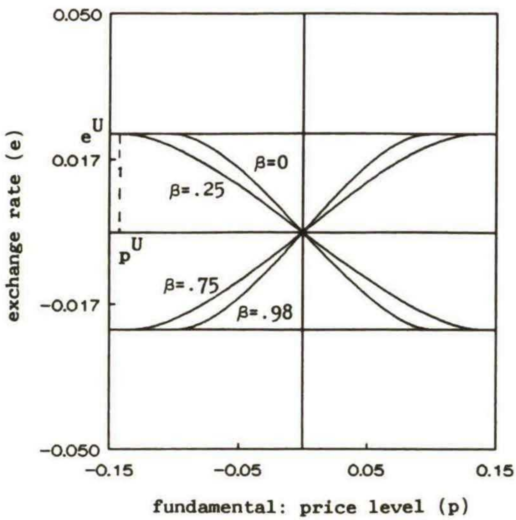


Figure 5(b): Price bands and the degree of intramarginal accommodation

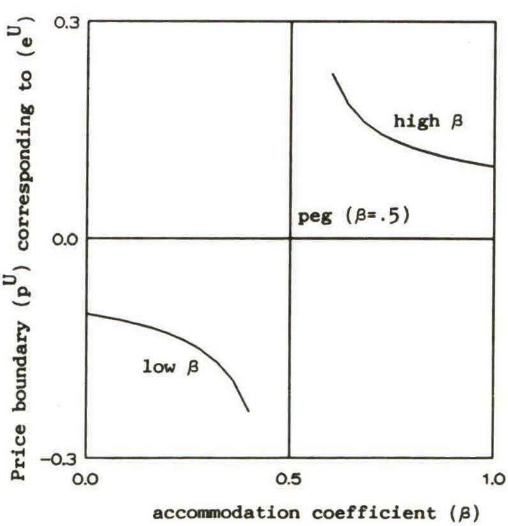


Figure 6: Simulated exchange rate distributions under a band

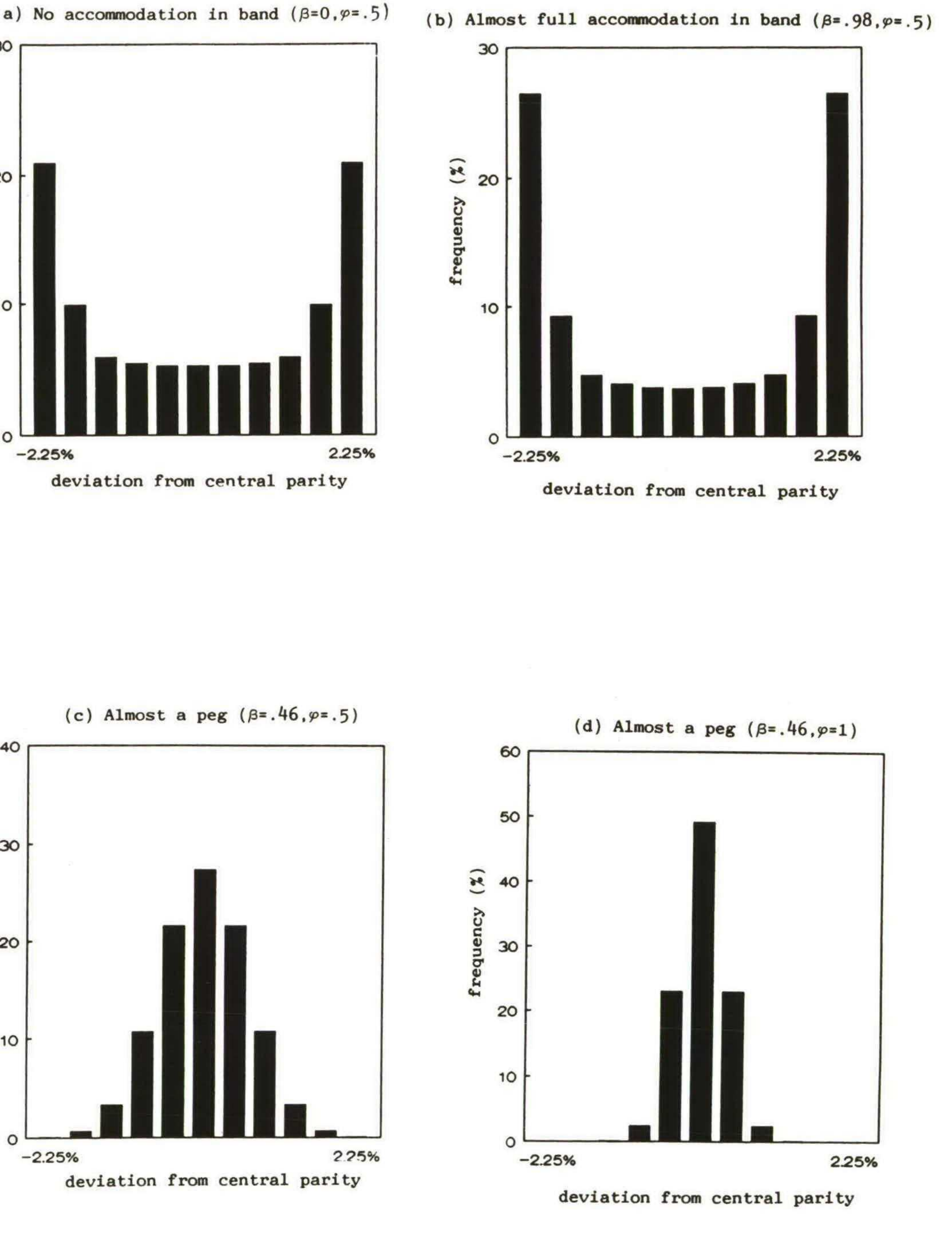
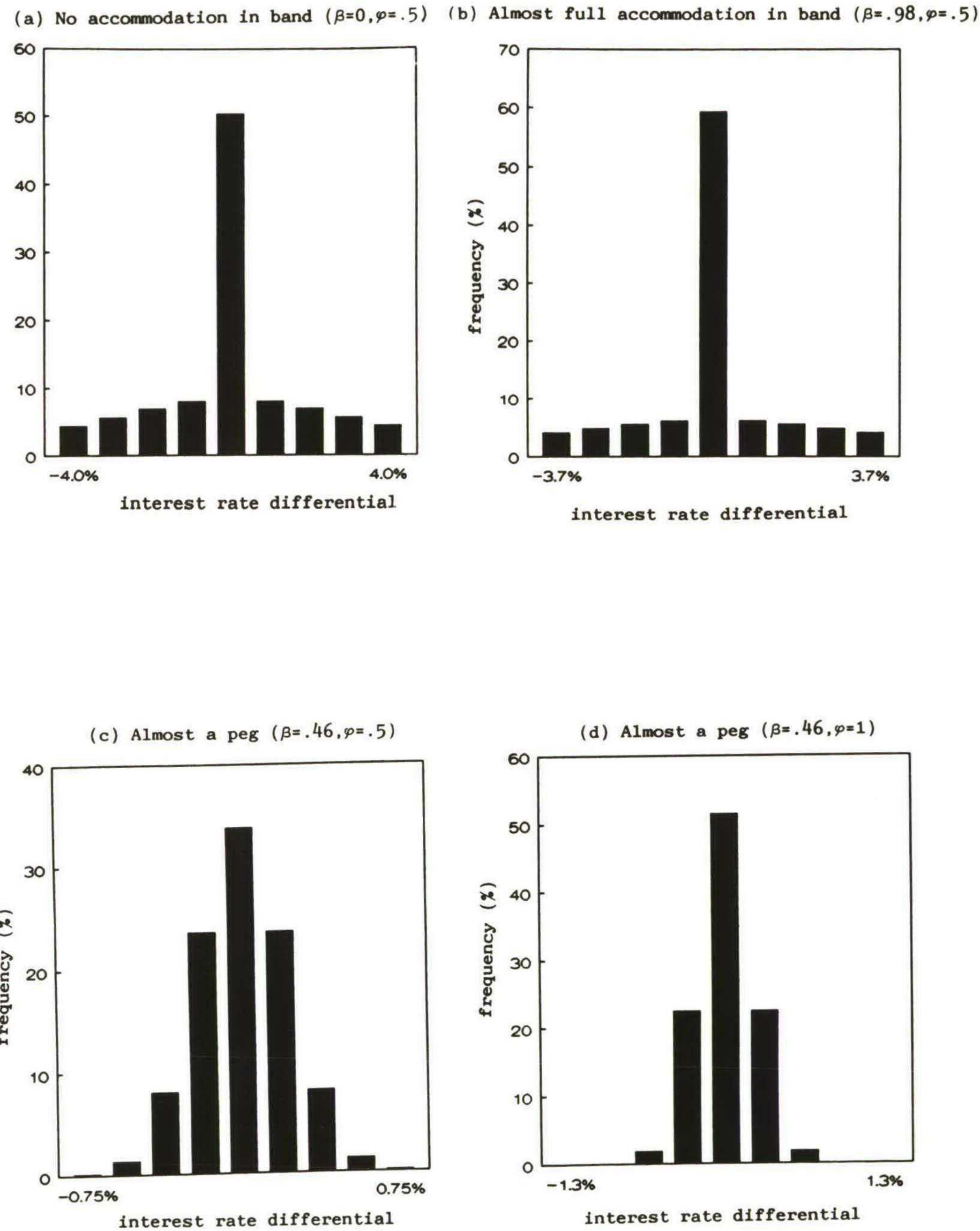


Figure 7: Simulated distributions of interest rate differential under a band



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