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## Exchange rates dynamics in a target zone: a heterogeneous expectations approach

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# EXCHANGE RATES DYNAMICS IN A TARGET ZONE – A HETEROGENEOUS EXPECTATIONS APPROACH

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# EXCHANGE RATES DYNAMICS IN A TARGET ZONE – A HETEROGENEOUS EXPECTATIONS APPROACH

## Abstract

The target zone model of Krugman (1991) has failed empirically. In this paper, we develop a model of the exchange rate with heterogeneous agents in a free floating and a target zone regime. We show that this simple model mimics the empirical puzzles of exchange rates: excessive volatility, fat tails, volatility clustering, and disconnection from the fundamentals. In addition, the target zone regime replicates a reduced nominal volatility for the same level of fundamental volatility as in the free floating regime and the distribution of the exchange rate within the band is hump-shaped.

JEL Code: F31, F41.

Keywords: exchange rate, heterogeneous agents, target zones.

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## 1. Introduction

The day-to-day behavior of exchange rates remains a perpetual puzzle for both the academic community and policy makers. As the recent downward trend of the yen appears to be unrelated to the fundamentals, a renewed discussion among policy-makers at the G7 meeting in Singapore has emerged about acceptable exchange rate movements. This included suggestions to reimpose exchange rate bands among the major currencies. Besides, the recent currency crises in emerging markets have lead to a revival of so-called managed floats in south-east Asia, while the membership in the EMS II is a prerequisite for the introduction of the Euro in accession countries of the European Community enlargement process. From a policy-maker's perspective, a target zone seems to be a reasonable measure in order to prevent economies from persistent misalignments, excess volatility or even currency crisis.

In the academic literature, a large body of theoretical work on target zones now has emerged starting with Krugman's (1991) seminal derivation of the honeymoon effect.<sup>1</sup> Most of the modifications to the basic target zone model try to account for empirical regularities such as hump-shaped distributions or very limited honeymoon effects.<sup>2</sup> While stressing the role of imperfect credibility (Bertola and Svensson, 1993, Tristani (1994), and Werner, 1995), intramarginal intervention (Lindberg and Söderlind, 1994, Iannizzotto and Taylor, 1999, and Taylor and Iannizzotto, 2001), or price stickiness (Miller and Weller, 1991) the models generally stick to the representative agent/rational expectations framework.<sup>3</sup> Within this setting the stabilizing effect of the target zone on exchange rates results from tying down the hands of future monetary policy. However, as pointed out by Krugman and Miller (1993), the efficient market assumption is

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<sup>1</sup> For survey, see Svensson (1992) and Garber and Svensson (1995).

<sup>2</sup> Sarno and Taylor (2002) briefly survey the empirical literature on target zones.

<sup>3</sup> The only exemption the authors are aware of is Krugman and Miller (1993) and Corrado et al. (2006).

particularly misleading as policy-makers introduced target zone arrangements precisely because empirical research convinced them that exchange rates exhibit persistent misalignments (Rogoff, 1996) and excess volatility (Flood and Rose, 1995). In order to overcome this contradiction Sarno and Taylor (2002) suggest the analysis of target zone with the allowance for heterogeneous agents.

Of course, a growing number of heterogeneous agents models succeeded in replicating the above time series properties of exchange rates (Farmer and Joshi 2002, Frankel and Froot 1986, Brock and Hommes 1998, Lux and Marchesi 2000). Particularly, in De Grauwe and Grimaldi (2005a,b, 2006) traders switch between fundamental and chartistic rules dependent on their past profitability. This creates an exchange rate dynamics, which accounts for the exchange rate disconnect from fundamentals. According to the chartist-fundamentalist approach, the price process is therefore not only driven by exogenous news, but is at least partially due to an endogenous nonlinear law of motion.<sup>4</sup> If the interaction of heterogeneous traders can indeed be blamed for the observed financial market 'anomalies', then economic policy measures may be beneficial by reducing misalignments and excess volatility and should be reconsidered within the new framework.

In this paper, we present a simple behavioral model with chartists and fundamentalists where the switching depends on the current misalignment of the exchange rate. Our model replicates the empirical stylized facts about exchange rates, like excessive volatility, fat tails, volatility clustering and the disconnection of fundamental and nominal exchange rate. We then compare the time series properties of exchange rates within the regime of free floating and the target zone regime. The latter regime significantly reduces exchange rate volatility by reducing speculative activity in the FX market. In addition, the exchange rate remains for a considerably long period in

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<sup>4</sup> Ahrens and Reitz (2005), Reitz and Westerhoff (2003), and Vigfusson (1997) provide some empirical evidence.

the center of the band albeit the fundamental exchange rate does not exhibit mean reversion tendencies. The resulting hump-shaped distribution of the exchange rate greatly reduces the frequency of central bank intervention.

The paper is organized as follows. In section 2, we develop a simple chartist-fundamentalist model. Section 3 presents both analytical and Monte Carlo simulation results. The final section concludes the paper.

## **2. Setup of the model**

### **2.1. Market maker's pricing behavior**

A sensible starting point of our agent based analysis of exchange rates in target zones is the market maker's pricing behavior. As pointed out in LeBaron (2006) asset prices depend critically on the broker dealers trading behavior ensuring liquidity and continuity of asset markets. Therefore, the primary function of the market maker is to mediate transactions out of equilibrium, i.e. to provide market counterpart for excess demand that is otherwise not matched (Kyle, 1985; Farmer and Joshi, 2002). Within the market microstructure literature it now has become a standard building block to assume that the market maker receives random order flow from both informed and uninformed traders. Due to this information asymmetry the market maker generally increases the exchange rate when confronted with positive excess demand in order to maximize expected profits and keeping inventory risks at a low level. Though the optimal price setting behavior of the market maker has been derived for a wide range of informational and institutional settings (Lyons, 2001) there is currently no contribution dealing with market makers' behavior within target zone models. So how would a rational market maker behavior look like in a fully credible target zone? To answer this question, it turns out to be useful first to start with describing the underlying exchange rate dynamics when the target zone has not yet been introduced.

A risk neutral market maker is supposed to aggregate the orders and to clear all trades at a single price (Kyle, 1985). The assumption of risk neutrality implies that the market maker utility does not vary with inventory, which is in contrast to the empirical observation indicating that FX dealers manage inventory intensively. Moreover, the batch clearing of orders does not allow for bid-ask spreads as they arise naturally in sequential trade models (Glosten and Milgrom, 1985) or, more recently, in simultaneous-trade models like Lyons (1997). Since the focus of this paper is on investigating daily (or lower frequency) exchange rates before and after the introduction of a target zone, the simplifications made here seem to be reasonable. The orders are submitted anonymously and come from both informed and uninformed sources. As outlined above, the orders from  $N$  traders  $x_i(t)$ ,  $i=1,...,N$ , are collected by the market maker in an anonymous way, so that  $x(t) = \sum_{i=1}^N x_i(t)$  denotes the excess demand for foreign currency arising from the surplus of buy orders over sell orders. Due to this batch clearing process the market maker is unable to determine the source of a given order. However, since informed orders reflect current or future changes of the exchange rate's fundamentals, the market maker will increase prices when excess demand from traders is positive and vice versa. While absorbing traders' excess demand for foreign currency the market maker's speculative position changes accordingly. We define the open position  $p(t)$  of the market maker by the (log of) cumulative order flow from traders at any moment in time so that  $p'(t)=x(t)$ . In order to keep track of his position the market maker additionally considers the future expected changes of the exchange rate when setting today's price of foreign currency:

$$(1) \quad s(t) = \pi p(t) + \gamma \frac{E[ds(t)]}{dt},$$

where  $s(t)$  is the log of the current spot price of foreign exchange. From eq.(1) we may expect that nominal exchange rates are highly correlated with the cumulative order flow from traders, which is supported by empirical evidence (Evans and Lyons, 2002). Without loss of generality it will be convenient to represent the current exchange rate in

terms of deviations from its initial value,  $s(t) = \log(S(t)/S_0)$ , and suggest that the market maker had a balanced position when started his business,  $p(0)=0$ . More important, we assume that the market maker perceives changes in his position to be random, so that

$$(2) \quad dp(t) = \sigma dz(t).$$

Assuming that order flow is driven by the increment of a standard Wiener process  $dz(t)$  implies a Brownian motion on  $p(t)$ . As a result, there should be no predictable change in the change of the exchange rate, i.e.  $E[ds(t)]/dt = 0$ , if the exchange rate is allowed to float freely. Based on the hybrid model of Evans and Lyons (2002) we may interpret the second term in the exchange rate eq. (1) as the news arrival process regarding standard macroeconomic fundamentals. However, fundamentals are poorly related to exchange rates (Engel and West, 2005) so that our modeling choice seems to be reasonable. As a result positive aggregate excess demand of traders drives the exchange rate up and negative excess demand drives it down

$$(3) \quad \frac{ds(t)}{dt} = \pi \cdot x(t),^5$$

which is consistent with the results of market microstructure research. For example, Evans and Lyons (2002) show that regressing daily changes of log DM/\$ rates on daily order flow produces an  $R^2$  statistic greater than 0.6. In general, the parameter  $\pi$  considers the exchange rate's elasticity with respect to changes of market maker's position. It measures the extent to which the market maker raises the price of foreign currency when confronted with excess demand of traders. However, for analytical convenience we set  $\pi$  equal to unity. The price setting behavior of the market maker earns zero expected profits preventing potential competitors from entering the market. The unit root behavior of the market maker's position implies that the exchange rate contains a unit root either. Note

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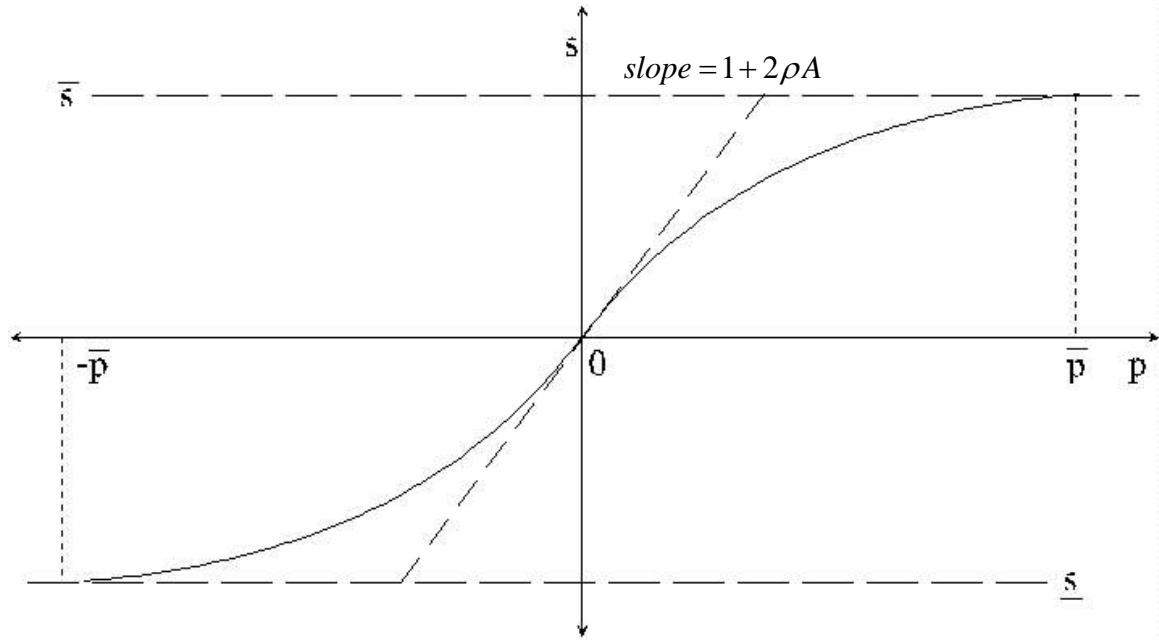
<sup>5</sup> Negative exchange rates caused by negative excess demand of traders are to be interpreted as exchange rates below initial value.



that the empirical literature provides strong evidence for the unit root behavior of short-run exchange rates (Meese and Rogoff, 1983). Thus, for modeling short-run dynamics of foreign exchange rates this seems to be a sensible approximation.

Crucial for our agent based model is the market maker's behavior when monetary authorities decided to introduce a target zone that bounds the exchange rate between an upper edge  $\bar{s}$  and a lower edge  $\underline{s}$  of the band, whereby the symmetry assumption restricts  $\bar{s}$  to be  $-\underline{s}$ . Of course, confronted with an excess demand of traders the market maker will increase the exchange rate according to the first term of eq. (1). But due to the target zone the expected appreciation of the exchange rate must be lower than the expected depreciation so that the expected change of the exchange rate is negative in the aftermath of the considered trading activity. The nonzero future expected exchange rate change together with the no-entry condition forces the market maker to accept a larger short position than in the case of free floating. Taken by the same logic, the given excess demand is associated with a lower increase of the exchange rate, which can be interpreted as a decrease in  $\pi$ . Clearly, the closer the exchange rate comes to the upper edge of the band, the larger is the negative effect on the elasticity. In the limit, when the exchange rate reaches  $\bar{s}$ , the market maker will accept any short position in his inventory so that the elasticity  $\pi$  has an arbitrarily small value. In case of negative excess demand from traders it is straightforward to show that the resulting expected future appreciation of the exchange rate led the market maker to accept larger long positions for a given quote than in the case of free floating. When the exchange rate approaches the lower bound, every excess supply is absorbed by the market maker without any further depreciation. Plotted in a diagram we find that the relationship between the market maker's open position and the spot rate exhibit the typical S-shaped curve.

Figure 1: Exchange rate target zone



From the extensive literature on target zones started by Krugman (1991) it is well known that the analytical form of the S-curve is defined by

(4)  $s(t) = p(t) + A[e^{\rho p(t)} - e^{-\rho p(t)}]$ , where  $\rho$  depends on the volatility of the fundamentals  $\sigma^2$  and the impact  $\gamma$  of the future expected changes of the exchange rate on the current exchange rate.<sup>6</sup>

The integration constant  $A < 0$  is determined by smooth pasting conditions, which ensure that the S-curve is tangent to the edges of the target zone:

$$(5) \quad \bar{s} = \bar{p} + A[e^{\rho \bar{p}} - e^{-\rho \bar{p}}],$$

$$(6) \quad 0 = 1 + \rho A[e^{\rho \bar{p}} + e^{-\rho \bar{p}}],$$

<sup>6</sup> As is standard in this literature, we will assume random walk fundamentals for the standard model in our simulations. This assumption does not inflict with the credibility of the target zone regime for a limited time horizon.

where  $\bar{p}$  denotes the value of the excess demand at which the exchange rate reaches the upper bound  $\bar{s}$ . As is already mentioned in Krugman (1991), the exchange rate dynamics in a target zone described by eq. (4) may be derived from option pricing theory as well (Dixit, 1989). From this perspective the owner of foreign currency is long in a put option that prevents the value of his asset to fall below the strike price  $\underline{s}$  and is short in a call option, which ultimately defines the maximum price  $\bar{s}$  of foreign exchange. The term  $Ae^{pp(t)}$  is due to the short position in the call option and is negative for all  $p(t)$ , while  $-Ae^{-pp(t)}$  depicts the value of the long position in the put option and is positive for all  $p(t)$ .<sup>7</sup> Again, the pricing behavior of the market maker is “regret free” in the sense that the opportunity cost of selling foreign currency is zero, i.e. holding foreign currency by herself instead of going short earns zero expected profits.

## 2.2. Marginal interventions of the central bank

The market maker’s price setting behavior, particularly the willingness to long or short unlimited positions of foreign currency, is a result of the risk neutrality assumption. Existing bank regulations clearly prohibit extensive short or long positions enforcing the market maker to pass at least some of the traders’ orders onto the central bank. This implies that the current excess demand of traders is partly matched by central bank interventions. As a result the market maker’s inventory is the sum of traders’ cumulative excess demand and cumulative central bank intervention of opposite sign. Thus, the S-curve in Figure 1 describing the market maker’s pricing behavior has to be generalized to

$$(7) \quad s(t) = p(t) + p^{CB}(t) + A \left[ e^{\rho(p(t) + p^{CB}(t))} - e^{-\rho(p(t) + p^{CB}(t))} \right].$$

The variable  $p^{CB}(t)$  denotes the cumulative amount of central bank’s foreign exchange intervention at time  $t$  and can be considered as a shift parameter. When the

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<sup>7</sup> At the center of the band the values of the options cancel each other out so that  $s(t) = p(t) = 0$ .

central bank is forced by the market maker to sell at the upper bound of the band the stock of foreign currency in the hands of private agents increases so that the S-curve is shifted to the right. Thus, eq. (7) defines a whole family of S-curves.

### **2.3 Excess demand of speculators**

In the recent decade a large number of survey studies such as Taylor and Allen (1992) and Menkhoff (1998) uniformly confirm that speculators in foreign exchange markets generally do not rely on mathematically well-defined econometric or economic models, but instead follow simple trading rules, particularly in the short run. We will assume that traders define their orders using a trading rule supplied by financial analysts. These trading rules, often issuing simple buy or sell signals rather than sophisticated measures of the asset's intrinsic value, are generally proposed by two groups of financial analysts, so-called chartists and fundamentalists. To compare the different forecasting strategies before and after the introduction of the target zone, it is important to mention that the predictability of exchange rates is based on the time series properties of the underlying order flow.

Chartists may be defined as traders relying on technical analysis. They believe that exchange rate time series exhibit regularities, which can be detected by a wide range of technical trading rules (Murphy, 1999). Technical analysis generally suggests buying (selling) when prices increase (decrease) so that chartist forecasting is well described by extrapolative expectations (Takagi, 1992).

#### *2.3.1 Chartists' rule in a floating regime*

Of course, due to the one to one relationship between the exchange rate and the order flow (eq. 1) the chartist techniques may be applied directly to the exchange rates, but its forecasting success is rooted in the time series properties of the order flow. The

expected value of the exchange rate at the end of the incremental forecasting horizon ( $\hat{s}_C^f$ ) is a function of the exchange rate and its current change:<sup>8</sup>

$$(8) \quad \hat{s}_C^f = s(t) + \alpha_C s'(t).$$

Assuming that chartists' excess demand for foreign currency is linear in the expected profit, their current order in a floating exchange rate setting is

$$(9) \quad x_C^f(t) = \beta_C (\hat{s}_C^f - s(t)) = \beta_C \alpha_C s'(t),$$

where  $\beta_C$  measures influence of expected profits on excess demand for foreign currency.

### 2.3.2 Chartists' rule in a target zone

In a target zone, however, the exchange rate is constrained to stay within the range between  $\bar{s}$  and  $\underline{s}$ , and the its expected change depends nonlinearly on the current level. Thus, for any predicted future order flow, the associated expected  $s'(t)$  will be significantly lower in the target zone regime than it is within free floating. To anticipate this target zone effect, chartists calculate  $\hat{s}_C^{TZ} = s^{TZ}(\hat{p}_C)$  using  $\hat{p}_C = p(t) + \alpha_C p'(t)$ . For the sake of simplicity, we expand the target zone exchange rate equation (4) in a Taylor series of degree one  $s(\hat{p}) \approx s(p) + s'_p (\hat{p} - p)$  yielding

$$(10) \quad \hat{s}_C^{TZ} = s(t) + s'_p \cdot \alpha_C p'(t),^9$$

where  $s'_p \equiv ds/dp$ . Using the fact that  $s'(t) = s'_p \cdot p'(t)$  we may formulate a chartist forecasting in target zones very similar to the case of flexible exchange rates:

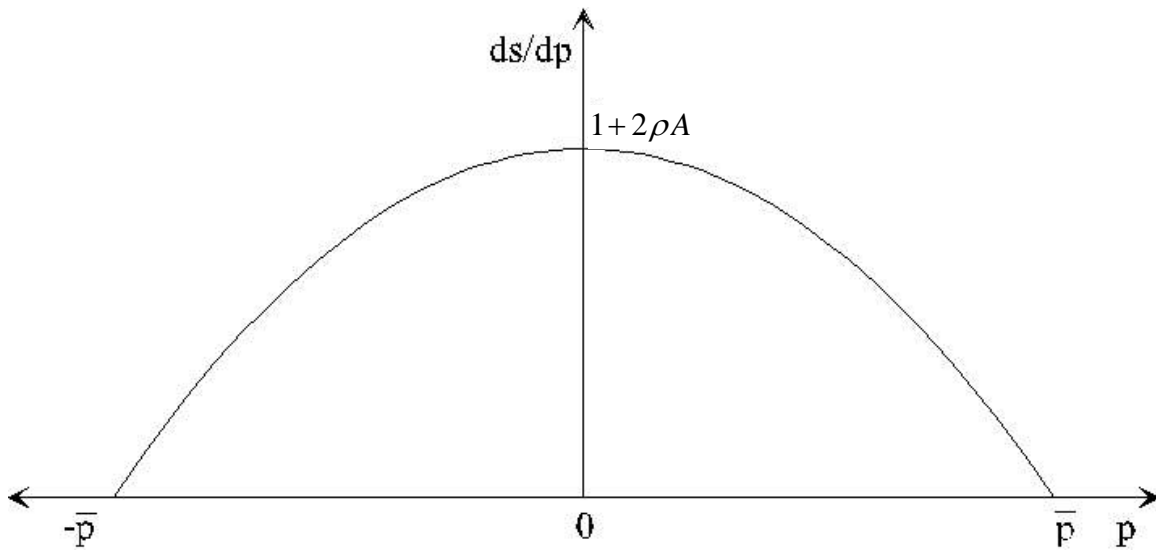
<sup>8</sup> The superscript f indicates that the expected value is valid in case of floating.

<sup>9</sup> Note that the first order Taylor expansion is only appropriate for small changes of order flow. For larger changes of order flow the change of the option values have to be taken into account. In case of extrapolating a deviating exchange rate the associated changes of the option values further reduce the forecasted appreciation. However, chartist forecasting is as well applicable for exchange rates approaching to the center of the band. In this case, the according changes of the option values tend to increase the forecasted exchange rate change. This asymmetry based on second order effects may be represented by a time varying coefficient  $\alpha_C$  and provides additional stabilization of the exchange rate path.

$$(11) \quad \hat{s}_C^{TZ} = s(t) + \alpha_C s'_{TZ}(t)$$

To compare eq. (11) with eq. (8) it is useful to remember that  $s'_p = 1$  in case of floating and  $s'_p = 1 + \rho A(e^{\rho p(t)} + e^{-\rho p(t)})$  in case of the target zone. Obviously, a given order flow generally generates a lower change of the exchange rate in the target zone than in case of free floating, which has to be taken into account by chartist traders. The magnitude of this effect depends on the derivative  $s'_p$  and is investigated in more detail using the following Figure 2.

Figure 2: Impact of Excess Demand on the Exchange Rate



In case of a balanced position we know from eq. (4) that the exchange rate is at the center of the band. Any excess demand has a maximum impact ( $s'_p = 1 + 2\rho A$ ) on the exchange rate. For higher levels of excess demand the S-curve gets flatter implying lower values of the first derivative. At the top of the band, when  $s(t) = \bar{s}$ , the first derivative equals zero and excess demand of traders has no impact on the exchange rate.<sup>10</sup>

<sup>10</sup> The same argumentation holds for negative open positions.

Consequently, the potential for extrapolative forecasting diminishes when approaching to the edges of the band. In contrast, when the exchange rate tends back to the center of the band, the exchange rate change increases steadily implying a rise in speculative positions.<sup>11</sup> The excess demand of chartists is

$$(12) \quad x_C^{TZ}(t) = \beta_C(\hat{s}_C - s(t)) = \beta_C \alpha_C s'_{TZ}(t),$$

which is as well hump-shaped with respect to the current value of the exchange rate.

### 2.3.3 Fundamentalists' rule in a floating regime

In contrast to the extrapolative expectations of chartists, fundamentalists have in mind some kind of long-run equilibrium exchange rate to which the actual exchange rate reverts with a given speed over time. In empirical contributions to the exchange rate literature the long-run equilibrium value is repeatedly described by purchasing power parity (ppp). Takagi (1991) provides evidence from survey data that foreign exchange market participants accept ppp as a valid long-run relationship. This view has recently been supported by Taylor and Peel (2000) and Taylor et al. (2001), showing that, due to its nonlinear dynamics, the exchange rate reverts to the ppp level, but only in the long run. However, since the objective of this paper is to study the dynamics of deviations from any form of fundamental value we assume it to be exogenously given.

Since fundamentalists are aware of traders with different forecasting techniques they will expect a slow mean reversion of the exchange rate. Another explanation for a smooth adjustment of the exchange rate to its long-run equilibrium value is proposed by Osler (1998). Speculators, submitting orders to exploit the current deviation of the exchange rate from its fundamental value, anticipate the impact of closing their position. If the exchange rate is actually perceived to be overvalued fundamentalists' current short position has to be closed by buying orders later, which, of course, drives the exchange

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<sup>11</sup> The conjectured asymmetry introduced by the nonlinear relationship between market maker's open position and the exchange rate clearly is only present in case of higher order Taylor expansion.

rate up to some extent. In this partial rational expectation framework, the mean reversion of the exchange rate is weaker the more speculators are in the foreign exchange market.

In order to derive an excess demand function of fundamentalist speculation in either regime we continue to assume that the stochastic process of the market maker's position is perceived to exhibit some regularities, which means mean reversion for fundamentalist forecasting. In case of floating the perfect co-movement of exchange rates and inventory allows for a simple translation into an exchange rate based forecast. Due to the finite speed of adjustment, fundamentalists expect the exchange rate to be

$$(13) \quad \hat{s}_F^f = s(t) + \alpha_F(\hat{s}_{lr} - s(t)),$$

where  $\hat{s}_{lr}$  is the fundamentalists' long-run equilibrium value. The superscript  $f$  again indicates that the expected value  $\hat{s}_F^f$  is valid in case of floating. The development of the long-run equilibrium is concretized below for the Monte Carlo simulation. For the theoretical model, we leave it unspecified. Typical examples for processes describing fundamentals are constants or random walks as in De Grauwe and Grimaldi (2006), or more general stationary ARMA processes.

The fundamentalists' excess demand is determined by

$$(14) \quad x_F^f(t) = \beta_F(\hat{s}_F^f - s(t)) = \beta_F \alpha_F(\hat{s}_{lr} - s(t)).$$

#### 2.3.4 Fundamentalists' trading rule in a target zone

Within a target zone, however, a large expected change of market maker's inventory may lead only to a minor change of the exchange rate, which takes place particularly when the current exchange rate is near the edges of the band. The fundamentalists take the market maker's calculation into account for their expectation of the exchange rate. As exchange rate and inventory do not perfectly correlate like in the free floating regime, they base their expectation on the expected order flow  $\hat{s}_F^{TZ} = s^{TZ}(\hat{p}_F)$ . The fundamentalists expect the order flow to show a tendency towards its



long-run equilibrium value  $\hat{p}_{lr}$  which describes the fundamentalists' perception of the long-run equilibrium exchange rate, i.e.  $\hat{p}_F = p(t) + \alpha_F (\hat{p}_{lr} - p(t))$ . If the long-run equilibrium exchange rate is in the center of the band, i.e.  $\hat{s}_{lr} = 0$ , the fundamentalists expect a balanced inventory in the long run, i.e.  $\hat{p}_{lr} = 0$ . As long as the long-run equilibrium exchange rate remains within the band  $(\underline{s}, \bar{s})$ , so does the long-run equilibrium value  $p_{lr}$ . We again expand the target zone exchange rate equation (4) in a Taylor series yielding

$$(15) \quad \hat{s}_F^{TZ} = s(t) + s'_p \cdot \alpha_F (\hat{p}_{lr} - p(t)).$$

The excess demand of fundamentalists is well hump-shaped with respect to the current value of the exchange rate.

$$(16) \quad x_F^{TZ}(t) = \beta_F (\hat{s}_F - s(t)) = \beta_F \alpha_F s'_p (\hat{p}_{lr} - p(t)),$$

Aggregating the orders of chartist and fundamentalist yields the excess demand of speculators

$$(17) \quad x_S(t) = m(t)x_C(t) + (1 - m(t))x_F(t).$$

In eq. (17) the variable  $m(t)$  is the weight assigned to chartist forecasts. If the exchange rate is at least weakly co-integrated with its fundamentals, then every misalignment must vanish in the long run. To motivate interaction between chartists and fundamentalists that result in globally stable exchange rate dynamics, we follow the modeling strategy introduced by De Grauwe et al. (1993). Assuming that there is uncertainty about the fundamental equilibrium of the exchange rate, fundamentalists' expectations about its true value are symmetrically dispersed around the true value. The trading activity of the group of fundamentalists produces a zero excess demand when the exchange rate is at its fundamental value. The heterogeneity of beliefs diminishes when

the exchange rate becomes increasingly over- or undervalued. Based on this behavioral approach to modeling the interaction between chartists and fundamentalist, we define

$$(18) \quad m(t) = \frac{1}{1 + \delta s(t)^2}.$$

The dynamics of  $m(t)$  imply a small weight on fundamentalist forecasts in the neighborhood of the long-run equilibrium value, a "band of agnosticism" for fundamentalist speculation is suggested accordingly (De Grauwe et al., 1993). This is confirmed by Kilian and Taylor (2003) reporting a nonlinear mean reversion of the exchange rate with weak mean reversion for exchange rate values close to ppp and strong mean reversion for large misalignments. The coefficient  $\delta$  is a measure of fundamentalist homogeneity. If, for instance,  $\delta$  is small, then fundamentalists do not agree on the fundamental value of the exchange rate and their trading activity cancels out to a large degree. In contrast, for high values of  $\delta$ , the dispersion of expectations around  $\hat{s}_{lr}$  is small implying a stronger impact on exchange rate as a group of speculators.

#### 2.4. Current account traders

Besides speculators who submit orders on the basis of chartist and fundamentalist forecasts, there are so-called current account traders in the foreign exchange market. The current account traders submit orders reflecting cross border transactions such as exports and imports of goods and services and/or capital. Excess demand of current account traders is exposed to shocks to the underlying fundamentals so that the excess demand of current account traders may be described by

$$(19) \quad x_{CA}(t)dt = \sigma_{CA}dz(t),$$

where  $dz(t)$  is the increment of a standard Wiener process.<sup>12</sup> Current account traders are not assumed to speculate on foreign exchange markets as they are specialized in their exporting and importing business. As a result current account traders do not form exchange rate expectations implying that their trading behavior is not altered when introducing a target zone.

### 3. Exchange Rate Dynamics

In order to investigate whether or not a fully credible target zone is able to stabilize short-run exchange rates within our agent based setting we first provide some analytical results.

#### 3.1 Some Analytical Results

##### 3.1.1 Floating

In the case of floating, we derive the following nonlinear stochastic first order differential equation for the exchange rate from the excess demand of speculators (17) and current account traders (19), and insert it into the price impact function (3):

$$(20) \quad ds(t) - \frac{(1-m(t))\beta_F\alpha_F}{1-m(t)\beta_C\alpha_C}(\hat{s}_{lr} - s(t))dt = \sigma_{CA}dz(t)$$

Due to the nonlinear weighing of speculators' market share the exchange rate may exhibit quite complex dynamics, but it is useful to consider first the two 'extreme' regimes that appear when either chartist or fundamentalist are providing exchange rate forecasts to speculators. If the exchange rate is currently close to the equilibrium value, then, according to (16), speculators exclusively adhere to chartist forecasting ( $m(t) \rightarrow 1$ ), implying

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<sup>12</sup> In our model, current account traders are modeled as noise traders. Alternatively, we could model chartists and fundamentalists in a noisy fashion as in De Long et al. (1990) or Bauer and Herz (2005) and omit the current account traders from the model.

$$(21) \quad ds(t) = \sigma_{CA} dz(t).$$

Eq. (21) represents a random walk. Randomly occurring deviations drive the exchange rate away from its fundamental value. When reaching the 'outer' regime more and more traders switch to fundamentalist forecasting, because the exchange rate becomes increasingly misaligned. In the limit speculative trading is only based on fundamentals, i.e.  $m(t) = 0$ . Consequently, the exchange rate exhibits strong mean reversion and current misalignments are diminished over time:

$$(22) \quad ds(t) - \beta_F \alpha_F (\hat{s}_{lr} - s(t)) dt = \sigma_{CA} dz(t).$$

Thereby, the exchange rate comes closer to the fundamental value and chartists regain popularity. This endogenous switching between chartist and fundamentalist trading should be capable of providing the empirical observed time series properties of floating exchange rates.

### 3.1.2 Target Zone

In the case of the target zone, we derive the following system of nonlinear stochastic first order differential equations for market maker's inventory and the exchange rate:

$$(23) \quad dp(t) - \frac{(1-m(t))\beta_F \alpha_F s'_p}{1-m(t)\beta_C \alpha_C s'_p} (p_{lr} - p(t)) dt = \frac{\sigma_{CA}}{1-m(t)\beta_C \alpha_C s'_p} dz$$

$$(24) \quad dp(t) - \frac{1}{s'_p} ds(t) = 0.$$

In eq. (24), we made use of the fact that the price setting behavior of the market maker can be rewritten in form of derivatives, i.e.  $s'(t) = s'_p \cdot p'(t)$ . The stability

properties of the endogenous dynamics may be investigated to some extent analytically by calculating the non-trivial root of the characteristic equation:<sup>13</sup>

$$(25) \quad r = -\frac{(1-m(t))\beta_F\alpha_F s'_p}{1-m(t)\beta_C\alpha_C s'_p}.$$

Starting by analyzing the inner regime of foreign exchange dynamics, defined by only minor exchange rate misalignments, we find that both  $m(t)$  and  $s'_p$  are close to their maximum value, i.e.  $m(t)=1$  and  $s'_p=1+2\rho A$ . In this case the properties of exchange rate dynamics are similar to those in free floating albeit the elasticity of the exchange rate on changes of the fundamentals is less than unity (honeymoon-effect). The only stabilizing force is provided by current account traders. When the exchange rate deviates from the central parity and reaches the outer regime, a decreasing value of  $s'_p$  reduces the impact of speculators' orders on the exchange rate.<sup>14</sup> In the limit,  $s'_p=0$ , implying that the exchange rate is prevented from going beyond the edges of the band. Of course, if the target zone should provide measurable stabilization, the formal band introduced by the monetary authorities has to be defined narrower than the informal band provided by fundamentalist speculation. As an endogenous source of stabilization, agents' shifting from chartist to fundamentalist forecasts further enforces the adjustment process via a decreasing  $m(t)$ . This effect on the exchange rate is even stronger when the target zone is able to anchor traders' expectations so that the value of  $\delta$  in eq. (18) increases. Although the analysis of the 'inner' and 'outer' regime provides useful first insights into our agent based model of the foreign exchange market, we now turn to a more rigorous Monte Carlo analysis.

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<sup>13</sup> We assume that the fundamentalists' expectation of long run inventory remains constant  $\bar{p}_{lr} \equiv 0$ .

<sup>14</sup> Consequently, the exchange rate volatility will decrease as well.

### 3.2. Monte Carlo Analysis of the model

We proceed with the following steps. First, it is important to derive the exchange rate dynamics of the benchmark floating exchange rate regime and assess whether the time series properties are replicated by the model. As the simulated time series of the model exhibit the main features such as persistent misalignments, fat tails, heteroskedasticity, and excessive volatility,<sup>15</sup> we may be convinced that the model replicates the main driving forces of the foreign exchange market. In a second step we then introduce the target zone and compare the derived time series properties with those of the benchmark floating exchange rate regime. We find, that the simulation replicates the typical features of exchange rates within a band, i.e. reduced volatility (disconnection of fundamental and nominal volatility), leptokurtosis, heteroskedasticity, persistent misalignments, and most important a hump-shaped distribution of the exchange rate within the band.<sup>16</sup> The heterogeneous agent setting implies mean reversion of the exchange rate without the need for a mean reverting fundamentals process. A sensitivity analysis concludes this section.

#### 3.2.1 Floating

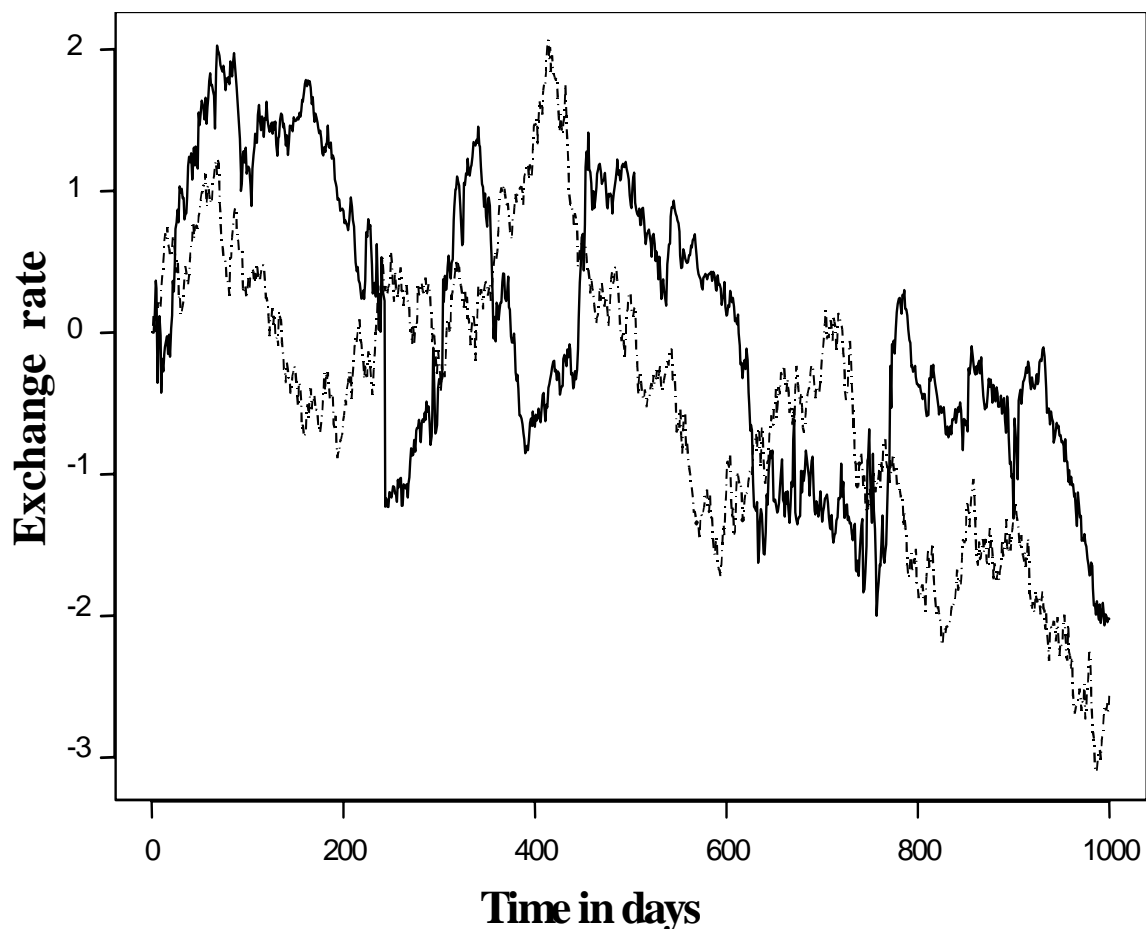
We simulate the development of the fundamental exchange rate and the shocks to the liquidity traders over 1000 periods and calculate the exchange rate according to equation (20). We then rerun the entire simulation 100,000 times to derive statistically significant conclusions on the applied statistics. The benchmark set of parameters for the simulation is  $\pi = 1$ ,  $\sigma_{CA} = 0.05$ ,  $\alpha_C = 0.9$ ,  $\beta_C = 1$ ,  $\alpha_F = 0.01$ ,  $\beta_F = 1$ , and  $\delta = 1$ . The fundamental exchange rate is simulated as a random walk, i.e.  $\hat{s}_{lr}(t) = \hat{s}_{lr}(t-1) + \varepsilon_{f,t}$  with standard deviation of the innovations  $\sigma_{fund} = 0.1$ . Figure 3 compares the

<sup>15</sup> De Grauwe and Grimaldi (2005a,b, 2006) provide a concise literature overview on the empirical characteristics of exchange rates. Their simulation studies also replicates these stylized facts.

<sup>16</sup> See Sarno and Taylor (2002) for a brief literature overview on the empirical properties of exchange rates in target zones.

fundamental to the nominal exchange rate for the first set of innovations to the fundamental exchange rate process and shocks to the liquidity traders.

Figure 3: Simulated nominal (solid line) and fundamental (dots) exchange rate from the free float model



The misalignment from  $t=750$  on is clearly visible. While the fundamental rate deteriorates continuously, the liquidity traders and chartists stabilize the nominal exchange rate. Table 1 gives some statistics on the characteristics of the simulation studies with 100,000 runs. As the properties of the estimators' distributions are unknown, we present the median and the interquartile range to indicate location and scale of the estimates.

The nominal exchange rate process generated with our free float model replicates the stylized characteristics of empirical exchange rate data: excess volatility, leptokurtosis, volatility clustering, and persistent misalignments. Firstly, the nominal variance is twice the variance of the fundamentals showing excess volatility. Secondly, the median excess kurtosis of the simulated series is 11. Thirdly, the null hypothesis of homoskedasticity is rejected as for 99.7% of the simulated time series, the estimated ARCH coefficient in a GARCH(1,1) estimation is highly significant. Finally, the median of the misalignment periods within a run is 479, i.e. nearly half of the time the nominal exchange rate heavily deviates from the fundamentals. We define fundamental and nominal exchange rate to be misaligned if the difference is larger than 100 times the variance of the fundamentals' innovations.<sup>17</sup>

Table 3: Summary statistics for the floating scenario.

	Variance of daily nominal returns <sup>18</sup>	Excess kurtosis of daily returns	Number of simulations with p-value of ARCH coefficient <1%	Duration of misalignments period
Example time series	0.020	14	0	503
Median from 100' simulated time series	0.022 (0.020,0.025)	11 (9, 14)	99,7%	479 (426, 528)

Note: The numbers in brackets give the first and third quartile of the statistics.

### 3.2.1 Target Zone

<sup>17</sup> That is 10 times the standard deviation. If the fundamentals are normally distributed, we should observe such a deviation only once in over a trillion years.

<sup>18</sup> The variance of the fundamentals  $\sigma_{fund}^2$  is 0.01.



We now introduce the target zone regime according to equation (23) and (24) into the simulation. The symmetric target zone is normalized to an upper bound of 1, which is reached for an inventory of  $\bar{p} = 2$ , i.e. the width of the band equals twenty times the standard deviation of the fundamentals' innovations.<sup>19</sup> All other parameters remain unchanged.

Figure 4 illustrates the target zone regime under the identical set of innovations to the fundamental inventory process<sup>20</sup> and shocks to the liquidity traders which was used for the example in figure 3 and table 1. The top graph in figure 4 compares the fundamental to the nominal inventory.

We again calculate the summary statistics for the benchmark example and the average of 100,000 simulations in table 2. In addition, we look at the first intervention time of the central bank.<sup>21</sup> The simulated target zone exchange rate process replicates the characteristics of real data series. It is less volatile, less leptokurtotic, and shows a lower degree of disconnection from the fundamentals than the free floating regime. The series are heteroskedastic and show a hump shaped distribution within the band.

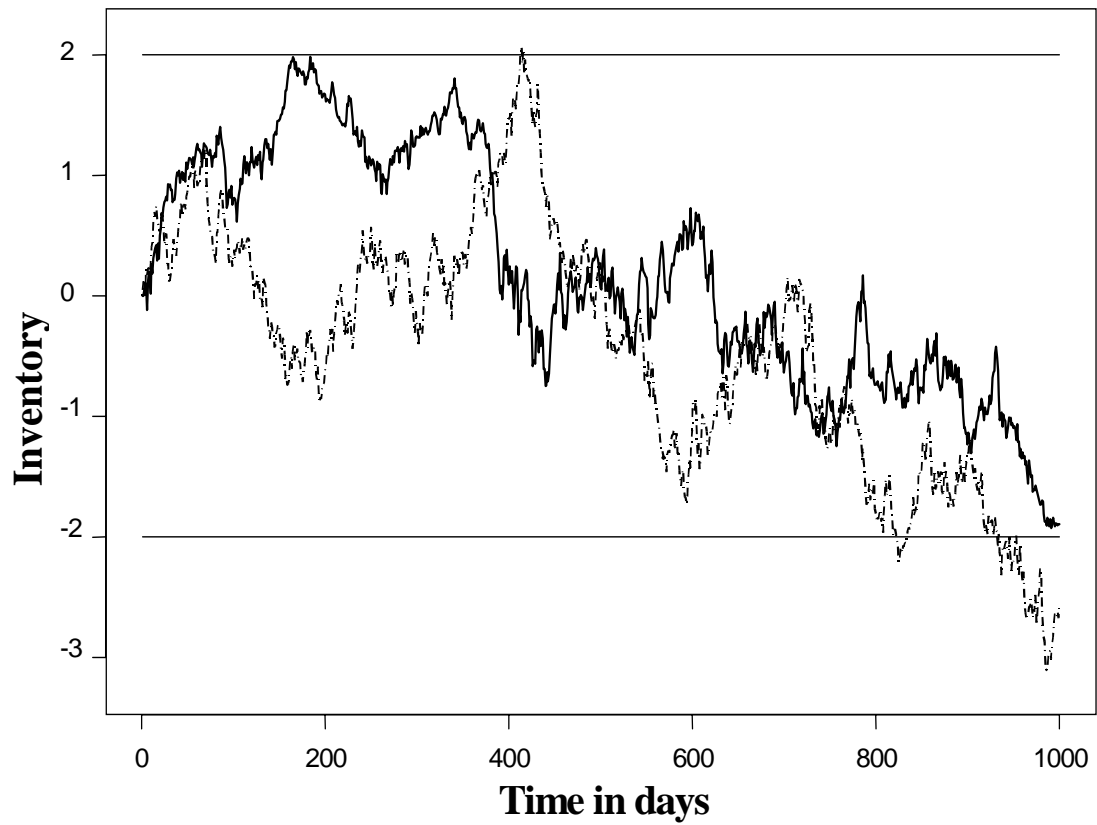
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<sup>19</sup> That is even bigger than 100 times the variance.

<sup>20</sup> In the floating regime the inventory may be identified by the nominal exchange rate.

<sup>21</sup> If the central bank does not intervene in a run, this time is set to 1000.

Figure 4: Simulated nominal (solid line) and fundamental (dots) inventory from the target zone model



The best known phenomenon of managed exchange rates is the reduction of the nominal exchange rate volatility. While in traditional economic models this volatility is transferred to other macroeconomic variables, empirical analyses reject this view. Flood and Rose (1995) analyze this volatility disconnect puzzle, i.e. real and nominal volatility are disconnected. They show in an extensive panel study that the nominal volatility of exchange rates declines for managing countries while the volatility of the fundamentals remains unchanged. More recent approaches using heterogeneous agents setups suggest theoretical explanations for multiple levels of nominal volatility for a given fundamental volatility. For example, the model of Jeanne and Rose (2002) shows multiple equilibria. They interpret the low volatility solution as a credible management regime and the high volatility solution as free float. In Bauer and Herz (2005), the nominal volatility depends on the credibility and degree of the central banks commitment to stabilize the exchange rate. A credible commitment prevents trend reinforcing herd effects. Traders build their expectations in the spirit of Krugman's (1991) approach, i.e. with a certain proactive obedience, by incorporating the expected reaction of the exchange rate to central bank interventions. This creates self fulfilling expectations and de facto discharges the central bank from its obligation to actually intervene with the exception of very large exogenous shocks. If the central bank fails to communicate a credible commitment, technical trading reinforces nominal trends and thus either increases nominal volatility or frequently calls for interventions.

Our model displays these stylized facts. While in the free floating regime, the nominal variance is excessively higher than the variance of the fundamental process, in the managed regime the converse holds true. The nominal volatility is disconnected from the fundamental volatility. For the same fundamental process and the – but for the traders' expectation building – same model setup, the nominal variance is on average

twice as high as the fundamental variance in the free floating regime and less than one third of the fundamental variance in the target zone regime.

Another puzzle of exchange rates is the high frequency of large changes. The distributions of exchange rate returns deviates from the normal distribution by fat tails albeit the underlying fundamental don't. Empirical findings like (e.g. De Vries (2001), Lux (1998), or Lux and Marchesi (2000)) document the leptokurtosis. The exchange rate processes simulated by our model show an average excess kurtosis of 11 in the free float and 2.5 in the target zone regime. The target zone value is less than for the floating regimes, but still indicates significantly heavy tailed distributions.

Nominal exchange rates are also characterized by clustered volatilities which cannot be traced back to specific features of the fundamental or news process (see. e.g. Lux and Marchesi (2000), Andersen et al.(2001) or De Vries (2001)). Commonly these time series property is associated with ARCH and GARCH processes introduced by Engle (1982) and Bollerslev (1986). Our model replicates this feature, too. For 95% of the simulated time series the estimated ARCH coefficient in a GARCH(1,1) estimation is highly significant, while the fundamental process in each simulation is a random walk with normally distributed innovations.

Another empirical observation is the “disconnect puzzle”, i.e. the exchange rate appears to be misaligned or disconnected from its underlying fundamentals (compare e.g. Meese and Rogoff (1983), Obstfeld and Rogoff (2000), Lyons (2001)). Goodhart and Figluoli (1991) and Faust et al. (2002)) show that exchange rates move independently from news in the fundamentals. For our simulation, we call fundamental and nominal exchange rate to be misaligned if the difference is larger than 100 times the variance of the fundamentals' innovations, i.e. half the width of the band. The median duration of the misalignment periods within a run in the target zone regime is 503 days.

Table 4: Summary statistics for the target zone scenario.

	Variance of daily returns	Excess kurtosis	p-value of ARCH coefficient <1%	Duration of misalignment periods	Average time of first Central Bank intervention
Example time series	0.0033	1.8	0	419	1000
Median from 100' simulated time series	0.0028 (0.0021, 0.0034)	2.5 (1.8, 3.8)	95,4%	503 (388, 625)	950 (600, 1000)

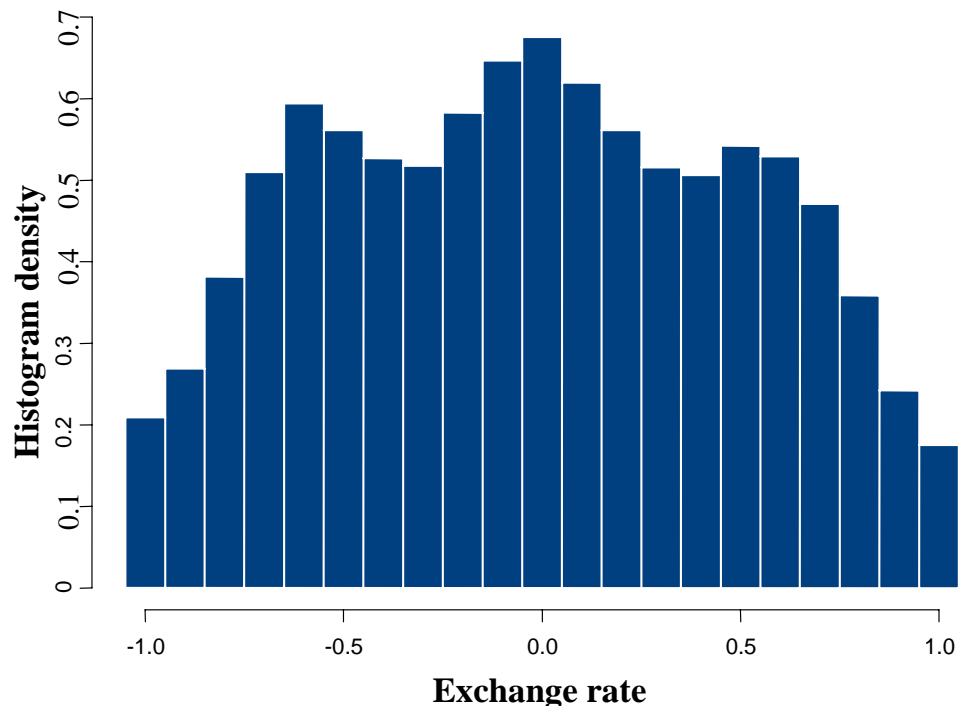
Note: The numbers in brackets give the first and third quartile of the statistics.

The most important empirical failure of the basic Krugman (1991) model, is its implication of a U-shaped distribution of the exchange rate within the band. The sensitivity of the nominal exchange rate with respect to movements of the fundamentals decreases with the deviation from the central parity. Thus for a random walk fundamental process, the model predicts the exchange rate to remain longer at the border of the band than in the interior. Empirical evidence strongly rejects the U-shaped distribution hypothesis. On the contrary, empirical studies (see e.g. Flood, Rose and Mathieson (1991), Bertola and Caballero (1992) or Lindberg and Söderlind (1994)) suggest a hump shaped distribution centered around the central parity.

In the Krugman model, the exchange rate evolves directly from the fundamental process. Thus – even for extensions like Garber and Svenson (1995), who include intramarginal interventions, and Werner (1995), who endogenizes the probability of realignments, – only the assumption of a mean reverting fundamental process yields the type of hump-shaped distribution compatible with empirical results.

Our approach with a heterogeneous trader structure overcomes this obstacle. Figure 5 shows a histogram of the exchange rate of the 100,000 runs. It displays the characteristic hump shape (see Sarno and Taylor 2002, pg. 184 ff.). Albeit the fundamental process is a random walk, the exchange rate process remains in the middle of the band longer than in the free floating model.

Figure 5: Histogram of the nominal exchange rate in the target zone model



### 3.2.3 Sensitivity analysis and potential extensions

In this section, we relate the behavior of the simulations to different values of important parameters assumptions of the model.

An increase of the variance of the fundamental process naturally increases the variability of the nominal exchange rate. In addition, the fundamental process leaves the area supporting the target zone faster, more likely and thus central bank interventions become more frequent and more intensive. Reducing this volatility source reverses these effects. In the border case of completely stable fundamentals  $\hat{s}_{lr} \equiv 0$ , the exchange rate remains within the interior of the band without central bank interventions.

If the second source of exogenous shocks (the shocks to the liquidity traders) is intensified, i.e.  $\sigma_{CA}$  increases, the exchange rate becomes more volatile within the band and the distribution of the exchange rate tends to a uniform distribution within the band.

Applying a stationary AR(1) process to the fundamental generating process instead of a random walk reduces the variance and excess kurtosis of the simulated time series. The duration of misalignments as well as the necessity for central bank interventions decrease.

### 3.2.4 Extensions

Finally, we outline extensions of the model, which are subject to future research.

Firstly, the extensions of Garber and Svenson (1995) – which includes intramarginal interventions into the Krugman model – and Werner (1995) – which endogenizes the probability of realignments – can be transferred straightforwardly into our heterogeneous agent setting. The incorporation of intramarginal interventions should strengthen the simulation results. An endogenous probability, i.e. an exchange rate close to the border of the band implies a high perceived probability for a realignment, should create a potential for self-fulfilling crises. A swing of the exchange rate might trigger a self-fulfilling credibility crises of the exchange rate. Thus comparisons of simulations

with and without endogenous realignment probability with the same set of stochastic shocks and under the same fundamental process, the self-fulfilling decrease of credibility can lead to a currency crisis which would not occur if the credibility remains exogenous.

Secondly, we would like to better incorporate the effects of central bank interventions on the course of the fundamentals. At present, marginal interventions merely absorb the excess inventory necessary to keep the exchange rate within the band. Unsterilized interventions, however, might create some change in the drift of fundamentals. Furtherly, the magnitude of marginal interventions is typically arranged to induce a step into the interior of the band and we would like to adept this feature also.



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