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Spillover Dynamics of Central Bank Interventions

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Abstract. *Central banks frequently intervene in foreign exchange markets to reduce volatility or to correct misalignments. Such operations may be successful if they drive away destabilizing speculators. However, the speculators do not simply vanish but may reappear on other foreign exchange markets. Using a model in which traders are able to switch between foreign exchange markets, we demonstrate that while a central bank indeed has several means at hand to stabilize a specific market, the variability of the other markets depends on how the interventions are implemented.*

JEL classification: *F*31, *E*58, *G*18.

Keywords: Foreign exchange markets; central bank intervention; technical and fundamental analysis.

1. INTRODUCTION

Central banks frequently intervene in foreign exchange markets. For instance, either the Federal Reserve Bank or the Deutsche Bundesbank intervened, on average, on three days out of ten from 1979 to 1994 (Saacke, 2002). Central bank interventions are motivated by the desire to check short-run trends or to correct long-term deviations from fundamental values (Neely, 2001). Although central banks seem to believe in the power of intervention operations, both the theoretical and the empirical literature remain sceptical about its usefulness (Schwartz, 2000; Sarno and Taylor, 2001; Dominguez, 2003).

One noteworthy exception is Hung (1997) who argues that central bank interventions may be successful in the presence of trend-extrapolating chartists. First, a central bank may try to destroy technical trading signals by breaking a price trend. Second, a central bank may stimulate positive feedback trading by inducing a price trend in order to guide the exchange rate closer towards its fundamental value.

Theoretical models of the exchange rate with heterogeneous traders have been pioneered by de Grauwe and Dewachter (1992, 1993) and de Grauwe *et al*. (1993): while chartists display bandwagon behaviour, fundamentalists expect the exchange rate to converge towards its fundamental value. However, the agents only correctly perceive the fundamental value on average. When the exchange rate is equal to its fundamental value, half the fundamentalists view the exchange rate as undervalued and half as overvalued. Consequently, the net impact of fundamentalists is zero. But as the distortion in the market becomes larger, the influence of fundamentalists increases. Due to this non-linear weighting scheme, the model generates interesting dynamics. Overall, the chartist–fundamentalist approach has proven to be quite successful in replicating the stylized facts of financial markets (e.g. Kirman, 1991; Brock and Hommes, 1998; Lux and Marchesi, 2000; Farmer and Joshi, 2002).

Our aim is to develop a model in the spirit of the chartist–fundamentalist approach that allows the investigation of the effectiveness of central bank interventions. We consider a limited number of linked foreign exchange markets. Fundamentalists are regarded as experts who specialize in one market and thus remain in that market. Since chartists use rather flexible extrapolative trading rules, they may easily wander between markets. To be precise, chartists trade forcefully in those markets which display price trends but which are not too misaligned. The interaction between the traders endogenously causes complex exchange rate dynamics.

We study the behaviour of a single central bank. In agreement with empirical observations (Neely, 2001), the central bank either counters the orders of chartists or trades like a fundamentalist. Both strategies have the power to stabilize the market in which the interventions take place. However, the intervention market appears to be more attractive for the chartists and thus shows on average a higher number of chartists. As a result, volatility and distortion also decline in the other markets.

Central banks sometimes attempt to manipulate the exchange rate level in order to boost the domestic economy. Our model reveals that central bank interventions may indeed shift the level of the exchange rate. As a by-product, the volatility in that market declines. Since chartists leave the distorted intervention market, the remaining markets face a higher concentration of chartists. Hence, a ‘beggar-my-neighbour’ policy is likely to destabilize related foreign exchange markets.

The remainder of the paper is organized as follows. Section 2 presents our model. In Section 3, we explore the effectiveness of several central bank intervention rules. The final section concludes the paper.

2. THE MODEL

2.1. Motivation

Traders are assumed to be boundedly rational in the sense of Simon (1955). Neither do they have access to all relevant information for price determination, nor do they know the mapping from this information to prices. But how do agents trade in financial markets? Smith (1991) concludes from a series of asset-pricing experiments that agents lend themselves to a rule-governed behaviour. In fact, Taylor and Allen (1992) report that professional traders apply both technical and fundamental analysis to determine their orders. Our model is based on these observations.

We consider a fixed number of foreign exchange markets.[1] Fundamental analysis is time-consuming and requires intensive research. Fundamentalists thus do not monitor all markets. For simplicity, we assume that a fundamentalist concentrates on one market only. Moreover, fundamentalists are uniformly distributed across markets. Technical analysis derives trading signals out of past price movements and is rather easy to conduct (Murphy, 1999). The attention of a chartist is obviously not restricted to a certain market. To limit the risk of being caught in a bursting bubble, chartists prefer markets which are not too distorted. The behaviour of fundamentalists tends to stabilize markets whereas the activity of chartists is typically destabilizing. If a market attracts an increasing number of chartists, the exchange rate is likely to be driven away from fundamental values (and vice versa).[2]

Since interventions are sterilized and performed secretly, the monetary base is constant and traders do not have the opportunity to act strategically against the central bank. We study the effectiveness of the two most common intervention strategies (Neely, 2001). First, the ‘leaning into the wind’ rule aims at reducing positive feedback pressure. For instance, if the price of a currency goes up, the central bank takes a short position. Second, ‘targeting long-run fundamentals’ means that the central bank always trades in the direction of the fundamental exchange rate. If the exchange rate is below (above) its fundamental value, the central bank submits buying (selling) orders. The goal of our paper is to examine the consequences of such intervention rules within a system of linked foreign exchange markets.

2.2. Set-up

Exchange rates are determined on $k = 1, 2, \ldots, K$ order-driven markets in which four types of agents are active: market-makers, fundamentalists, chartists and central banks. All orders are initiated against market-makers who stand ready to absorb imbalances between buyers and sellers. Following Farmer and Joshi (2002), market-makers quote the exchange rate S in market k at time t as

1. This model is a simplified version, adopted to foreign exchange markets, of a multi-asset market framework discussed in Westerhoff (2004). There it is demonstrated that the model has the potential to match the basic stylized facts of financial markets.
2. Such changes in the composition of chartists and fundamentalists in a market introduce a non-linearity which is somehow related to the non-linearity explored in de Grauwe *et al.* (1993): the system (i.e. the market) is unstable only in the neighbourhood of the fixed point (i.e. the fundamental value).

$$S_{t+1}^k = S_t^k + a^{M,k}(D_t^{F,k} + W_t^k D_t^{C,k} + D_t^{B,k}) \tag{1}$$

where $a^{M,k}$ is the reaction coefficient of the market-makers, and $D^{F,k}$, $D^{C,k}$ and $D^{B,k}$ are the orders of fundamentalists, chartists and central banks, respectively. The fraction of chartists currently active in market k is denoted by W^k. According to (1), excess buying drives exchange rates up, whereas excess selling drives them down.

The fundamental values F^k of the K exchange rates are constant and known by all agents. Fundamentalists bet on mean reversion. Their orders may be expressed as

$$D_t^F = a^{F,k}(F^k - S_t^k) \tag{2}$$

where $a^{F,k}$ is a positive reaction coefficient. The demand of chartists is given as

$$D_t^C = a^{C,k}(S_t^k - S_{t-1}^k) \tag{3}$$

Since $a^{C,k} > 0$, chartists submit buying (selling) orders if the exchange rate rises (declines). Note that (2) and (3) are in harmony with mean–variance preferences and regressive and adaptive expectation formation, respectively (Hommes, 2001).

According to market professionals (Murphy, 1999), the philosophy of technical analysis is to ride on a bubble. But, as is well known, eventually every bubble bursts. Chartists identify the risk of being caught in a bursting bubble as

$$A_t^k = \log \frac{1}{1 + f^k(F^k - S_t^k)^2} \tag{4}$$

The bell-shaped form of (4) is bounded between $-\infty$ and 0 ($f^k > 0$). For $F^k = S^k$, the attractiveness of market k reaches its maximum value 0. The larger the distance between F^k and S^k, the lower the fitness of that market. The probability that a chartist enters market k is derived by a discrete choice model (Manski and McFadden, 1981):

$$W_t^k = \frac{\exp(g^k A_t^k)}{\sum_{k=1}^{K} \exp(g^k A_t^k)} \tag{5}$$

The higher the attractiveness of market k, the more chartists will enter that market. The parameter g^k indicates how sensitive the mass of traders is to selecting the most attractive market. For $g^k = 0$, the chartists do not observe any differences in the fitness of the markets and are thus split evenly across markets. If g^k tends to infinity, all chartists enter the market with the highest fitness.

Our focus is on one central bank operating in market 1. The intervention volume of the central bank is given as

$$D_t^1 = \begin{cases} a^{L,1}(S_{t-1}^1 - S_t^1) & LAW \text{ on} \\ a^{T,1}(F^1 - S_{t-1}^1) & TARGET \text{ on} \\ 0 & \text{intervention off} \end{cases} \quad (6)$$

The parameters of the 'leaning against the wind' rule (*LAW*) and the 'targeting long-run fundamentals' rule (*TARGET*) are both positive ($D_t^2 = D_t^3 = \cdots = D_t^K = 0$).

All k markets involve the same key currency (say USD). The laws of motion of the K exchange rates are obtained by combining (1) to (6). Implicitly, our model fixes several cross-rates. Four types of markets exist: (A) market $k = 1$ comprises speculators and a central bank; (B) markets $k = 2$ to K include speculators but no central bank; (C) cross-markets directly related to market 1 (e.g. S_t^2/S_t^1); and (D) cross-markets not directly related to market 1 (e.g. S_t^2/S_t^3).

2.3. Calibration

Since the model precludes closed analysis we proceed with a numerical analysis. Although such a procedure may face some drawbacks, we would like to point out that it should be rather simple to replicate our results and check their robustness.

We use the following parameter setting for $K = 5$ symmetric markets: $a^{M,k} = 1, a^{F,k} = 0.2, a^{C,k} = 5, f^k = 500{,}000, g^k = 1.2$. The reaction coefficients of the central bank are given as $a^{L,1} = 0.2, a^{T,1} = 0.4$. The initial conditions are $F^k = 1$ and $S_0^k = 1$. In period 1, the system is disturbed as $S_1^k = 1 + 0.01k$.

3. SIMULATION ANALYSIS

3.1. Examples of unbiased interventions

Figure 1 displays the impact of the *LAW* strategy on the four types of markets for 10,000 periods (first panel S_t^1; second panel S_t^2; third panel S_t^2/S_t^1; and fourth panel S_t^2/S_t^3). The rule is switched on in $t = 5{,}000$. Without interventions, the exchange rates fluctuate in a complex manner around their fundamental values. Remember that the process is completely endogenous. The dynamics live from the fact that markets which are close to fundamentals attract destabilizing speculators and that distorted markets repel them.

Visual inspection reveals that *LAW* interventions stabilize all types of markets. The reason is that this rule destroys or at least weakens the trading signals of chartists. Since the intervention market is less distorted, it draws in chartists from type B markets so that markets of type B also benefit from intervention operations. Of course, the stabilization transfers itself to the cross-rates.

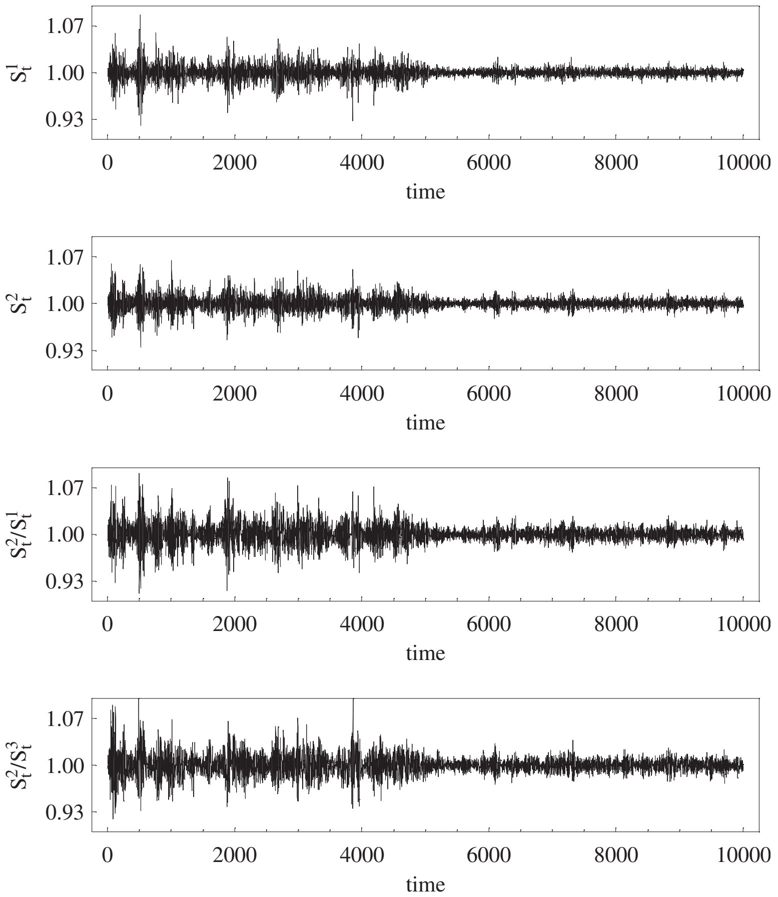

Figure 1 Unbiased *LAW* interventions and the evolution of the exchange rate

Notes: The dynamics are displayed for 10,000 observations. Interventions start in period 5,000. The first, second, third and fourth panels show a type A market, a type B market, a type C market and a type D market, respectively. Parameter setting as in Section 2.3.

Figure 2 shows the outcome for the *TARGET* rule. Interventions recommence in period 5,000 and calm down all types of markets. *TARGET* interventions work like an increase in the power of fundamentalists. If more demand is based on mean reversion, exchange rates are indeed driven closer towards fundamentals. As in the previous case, more chartists enter the intervention market so that all markets profit from this policy.

3.2. Examples of biased interventions

So far the central bank has tried to limit misalignments. But central banks sometimes attempt to shift the level of the exchange rate away from

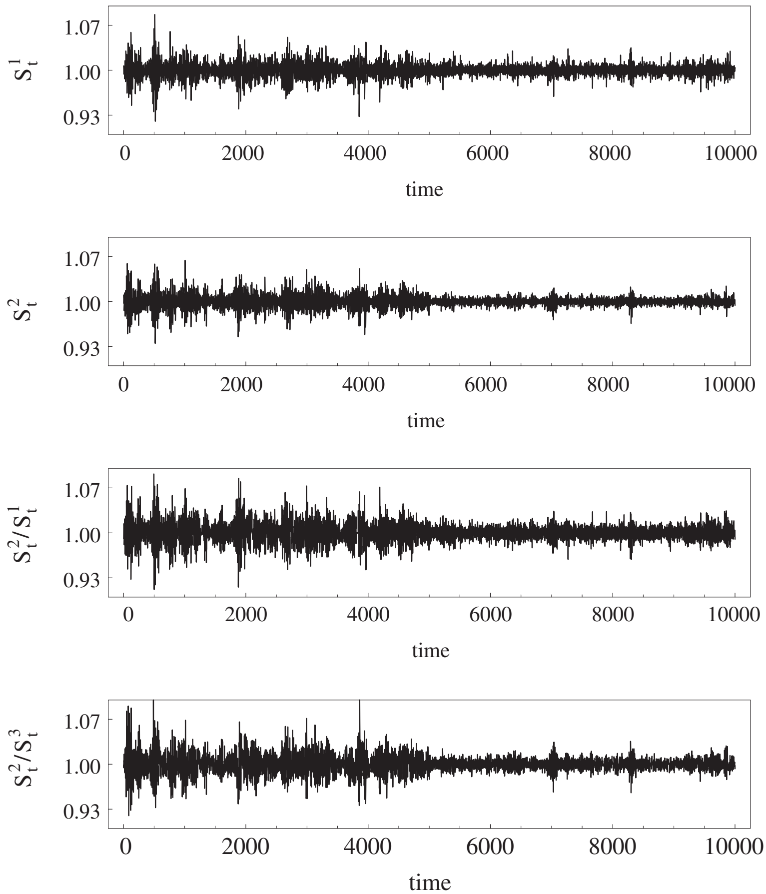

Figure 2 Unbiased *TARGET* interventions and the evolution of the exchange rate

Notes: The dynamics are displayed for 10,000 observations. Interventions start in period 5,000. The first, second, third and fourth panels show a type A market, a type B market, a type C market and a type D market, respectively. Parameter setting as in Section 2.3.

fundamentals. The central bank may then intervene as

$$D_t^1 = \begin{cases} a^{L,1}(c^{L,1} + S_{t-1}^1 - S_t^1) & \text{biased } LAW \text{ on} \\ a^{T,1}(c^{T,1} + F^1 - S_{t-1}^1) & \text{biased } TARGET \text{ on} \\ 0 & \text{intervention off} \end{cases} \tag{7}$$

With positive (negative) constant feedback coefficients $c^{L,1}$ or $c^{T,1}$, the central bank aims at increasing (decreasing) the level of the exchange rate.

Figures 3 and 4 illustrate the impact of such biased interventions on the dynamics. The policy is activated in period 5,000 with positive constant feedback. Both rules in fact achieve the raising of the exchange rate above its

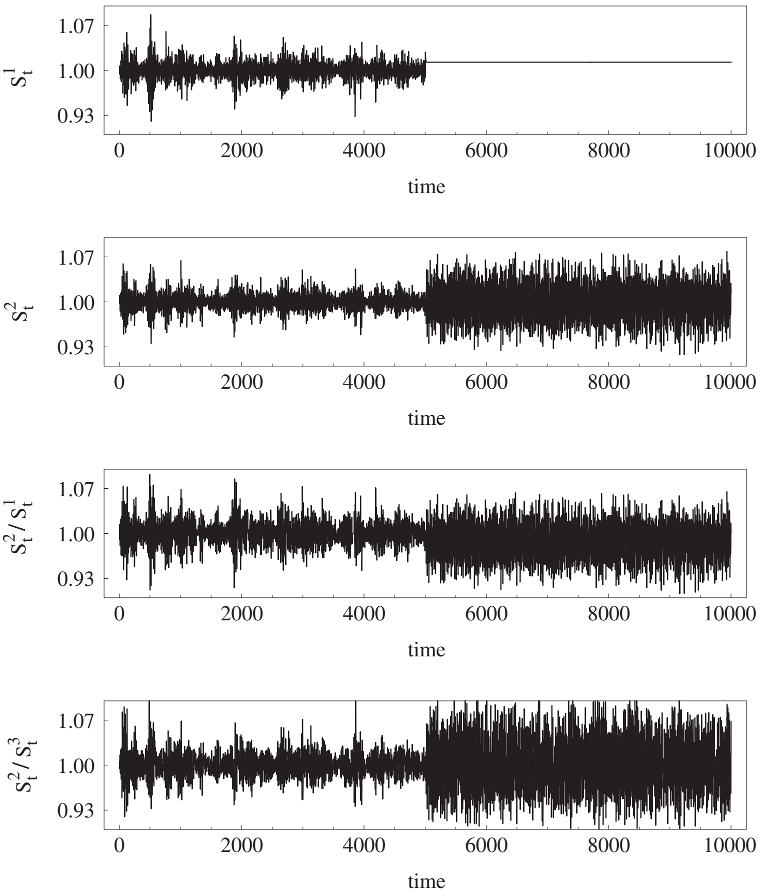

Figure 3 Biased *LAW* interventions and the evolution of the exchange rate

Notes: The dynamics are displayed for 10,000 observations. Interventions start in period 5,000. The first, second, third and fourth panels show a type A market, a type B market, a type C market and a type D market, respectively. Parameter setting as in Section 2.3, but $a^{L,1} = 0.2$, $c^{L,1} = 0.0125$.

fundamental value. Moreover, exchange rate fluctuations are completely eliminated in the intervention market.[3] Since the intervention market is now very unattractive for the chartists, they wander to markets of type B.

3. Wieland (2002) proves that non-linear dynamical systems may be stabilized by adding a constant feedback term to the system equations. Note that a constant feedback coefficient, e.g. $c^{L,1}$ or $c^{T,1}$, shifts the map upwards or downwards along the ordinate. A stable fixed point is obtained by selecting a constant feedback coefficient such that a point on the graph with a modulus smaller than 1 intersects the 45°-line. As visible from Figures 5 to 7, the latter conditions are fulfilled for a finite interval of numerical values $c^{L,1}$ and $c^{T,1}$ (due to (7), an increase in $a^{L,1}$ and $a^{L,2}$ yields an increase in the feedback terms too). Even if the system is perturbed with noise, the so-called constant feedback method is still able to eliminate most of the endogenous fluctuations.

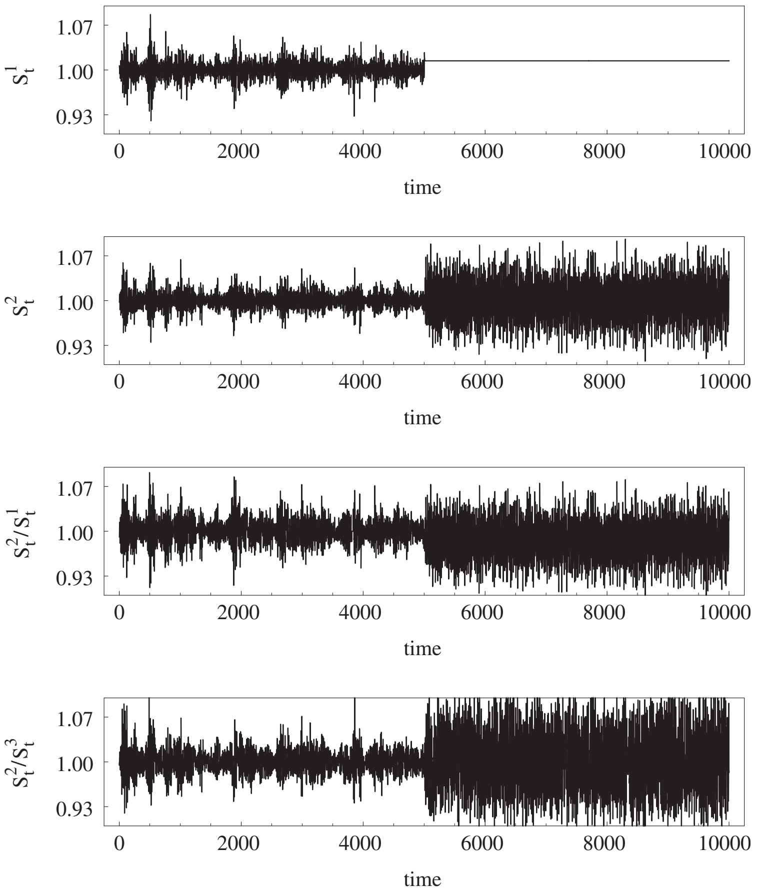

Figure 4 Biased *TARGET* interventions and the evolution of the exchange rate

Notes: The dynamics are displayed for 10,000 observations. Interventions start in period 5,000. The first, second, third and fourth panels show a type A market, a type B market, a type C market and a type D market, respectively. Parameter setting as in Section 2.3, but $a^{T,1} = 0.08$, $c^{T,1} = 0.05$.

Exchange rate fluctuations naturally increase in these markets, but also in the related type C and D cross-markets.

3.3. A Monte Carlo analysis

Let us generalize our analysis. To compare the efficiency of the rules, we define volatility as the average absolute relative change in exchange rates

$$V = \frac{1}{T-1}\sum_{t=1}^{T} |S_t - S_{t-1}|/S_{t-1} \tag{8}$$

and distortions as the average absolute relative distance between exchange rates and fundamentals

$$D = \frac{1}{T-1}\sum_{t=2}^{T} |S_t - F^*|/F^* \tag{9}$$

where T denotes the sample size and F^* stands for the central bank's desired exchange rate level.

Figure 5 presents how volatility and distortion react to an increase in the intervention level. The first, second, third and fourth line of panels show the outcome for the unbiased *LAW* rule, for the unbiased *TARGET* rule, for the biased *LAW* rule and the biased *TARGET* rule, respectively. The intervention level is increased in 25 steps as indicated on the axis. For each intervention level, volatility and distortion are computed as averages over 20 simulation runs with 5,000 observations each. The panels contain four lines representing the four types of markets (solid line: type A market; triangles: type B market; rectangles: type C market; circles: type D market). In the case of unbiased interventions, the distortion is calculated with $F^* = 1$. In the case of biased interventions, the central bank aims at stabilizing the exchange rate in the intervention markets at $F^* = 1.02$.

What are the results of this Monte Carlo analysis? The unbiased *LAW* strategy strongly reduces both volatility and distortion in all types of markets. Unbiased *TARGET* interventions also decrease distortions in all types of markets. However, they do not reduce volatility in the intervention market. By driving the exchange rate closer towards fundamentals, orders of chartists are enforced that offset the effect on volatility. Nevertheless, in markets of type B, volatility is reduced. This is also the case for cross-rates unrelated to market 1 (type D markets).

Both the biased *LAW* rule and the biased *TARGET* rule have the potential to manipulate the level of the exchange rate in the intervention market. Since volatility in that market is strongly reduced, the exchange rate for $a^{L,1} \approx 0.11$ or $a^{T,1} \approx 0.09$ is indeed raised to $F^* = 1.02$. If interventions are carried out more forcefully, the exchange rate is driven even higher. But such a 'beggar-my-neighbour' policy has its price: it destabilizes all other markets.

3.4. A sensitivity analysis

So far, we have used one parameter setting to characterize the behaviour of the traders. Note that the parameter setting of Figure 5 produces a volatility of around 0.57 in markets of types A and B and of around 0.85 in markets of types C and D (no intervention). However, the volatility of daily *DEM/USD* (*DEM/JPY*) exchange rates was $V = 0.5$ ($V = 0.44$) in the period 1974 to 1998. This raises the question whether our results also hold in a low volatility regime.

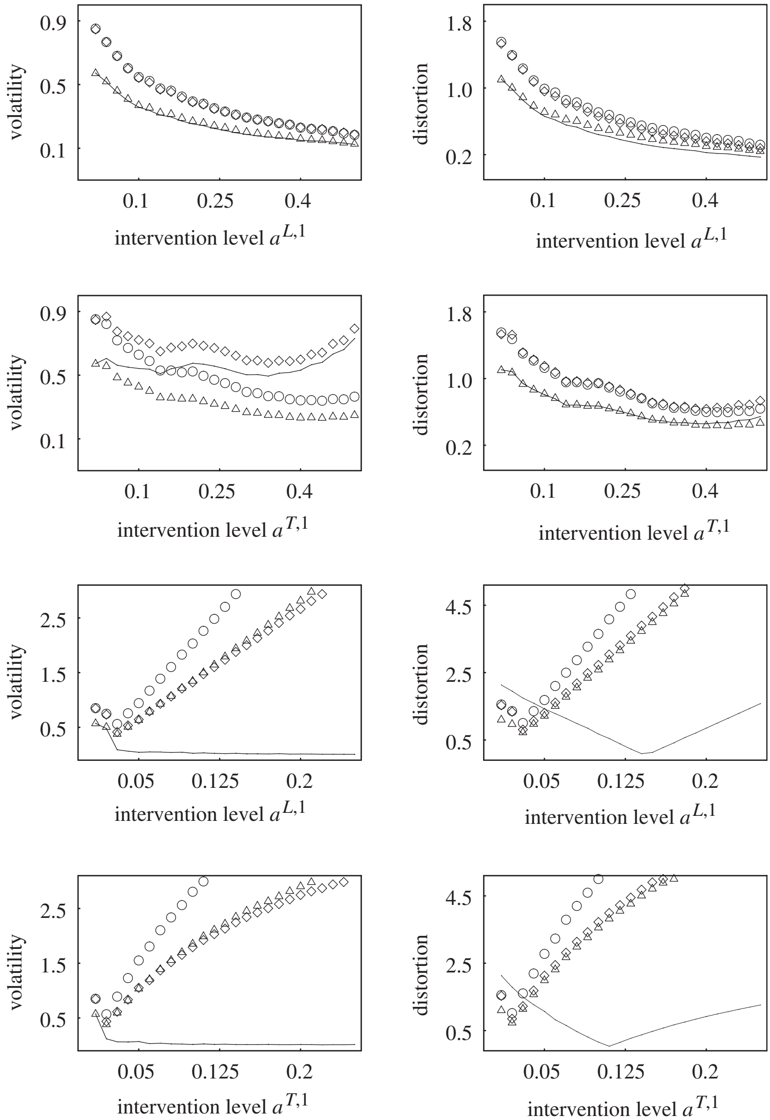

Figure 5 A Monte Carlo analysis

Notes: The first, second, third and fourth line of panels show unbiased *LAW* interventions, unbiased *TARGET* interventions, biased *LAW* interventions and biased *TARGET* interventions, respectively. Volatility and distortion are computed from 20 simulation runs, each containing 5,000 observations ($F^* = 1.02$ in the biased intervention market, else $F^* = 1$). The solid lines, triangles, rectangles and circles indicate market types A, B, C and D, respectively. The intervention level is increased in 25 steps as indicated on the axis ($c^{L,1} = 0.03$ and $c^{T,1} = 0.06$). The remaining parameters are as in Section 2.3.

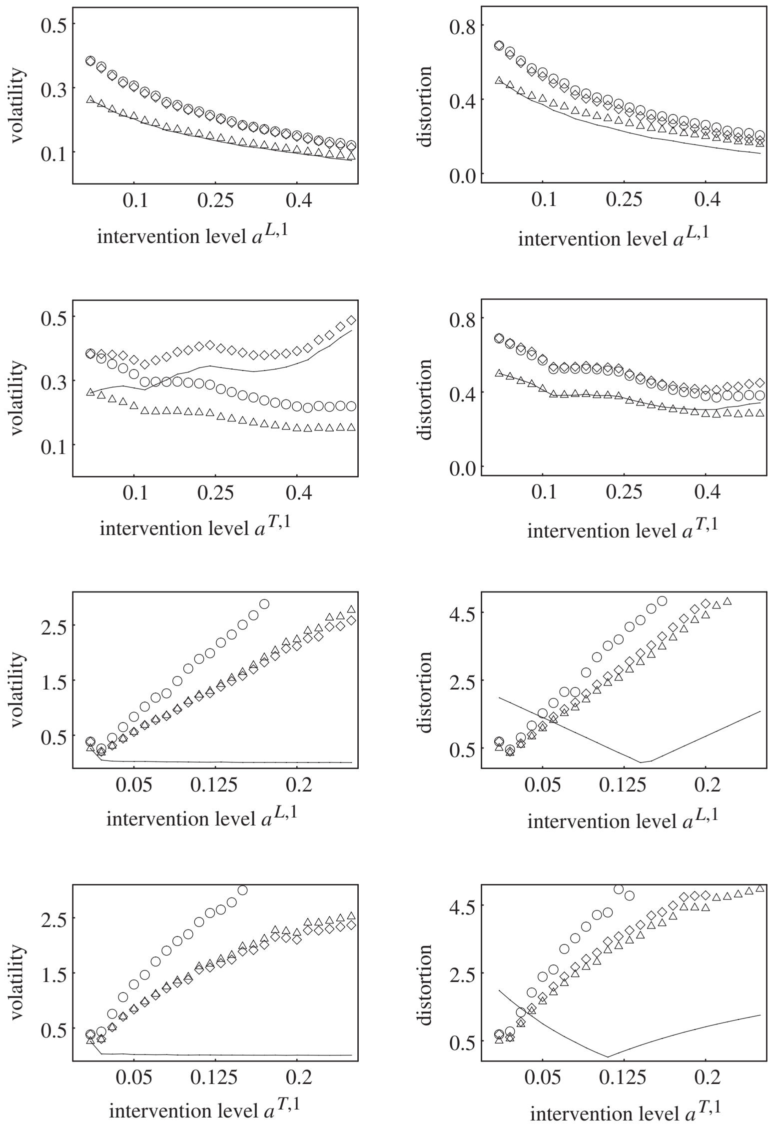

Figure 6 Sensitivity analysis 1: less aggressive chartists

Note: The same simulation design as in Figure 5, but $a^{C,k} = 4.8$.

Figure 6 presents a Monte Carlo study with $a^{C,k} = 4.8$ instead of $a^{C,k} = 5$. Without central bank interventions, we observe a volatility of around 0.26 in type A and B markets and of around 0.38 in type C and D markets. As can be seen, our results are quite stable. Unbiased 'leaning into the wind' interventions reduce both the volatility and the distortion in all types of

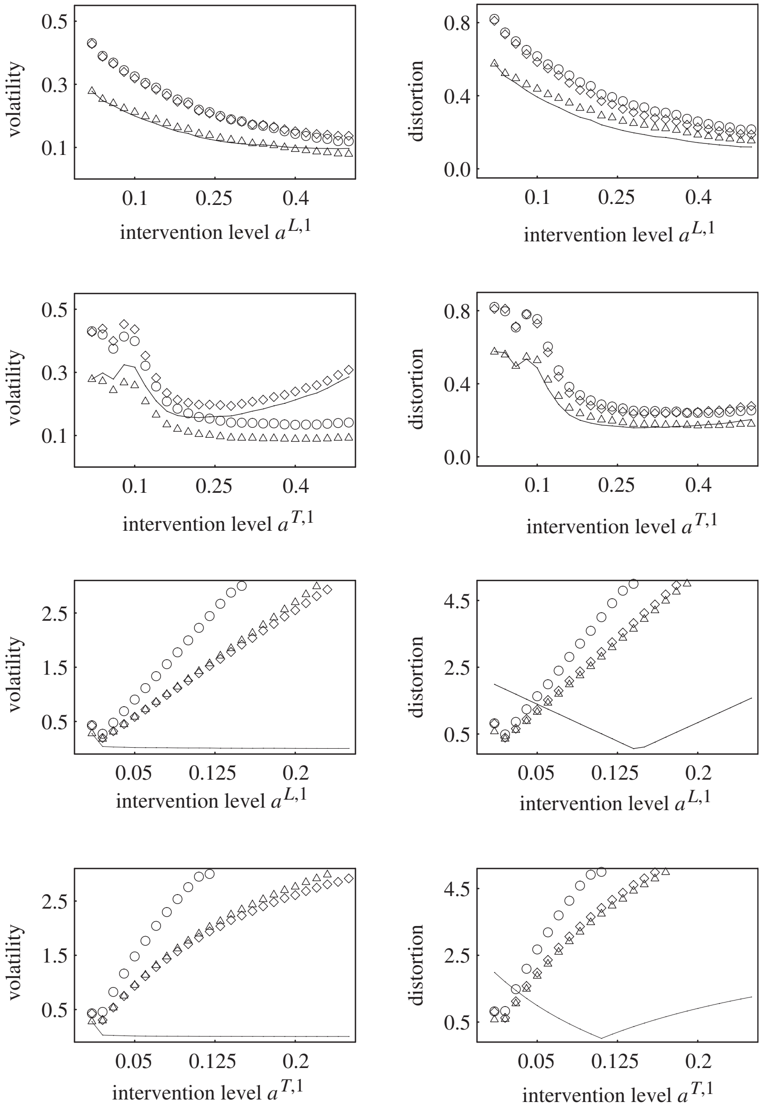

Figure 7 Sensitivity analysis 2: more rational chartists

Note: The same simulation design as in Figure 5, but $g^k = 2.4$.

markets. Unbiased target interventions lower the distortion in all types of markets. Biased interventions successfully increase the level of the exchange rate and simultaneously limit the volatility in the intervention market. As in the previous setting, such a 'beggar-my-neighbour' policy destabilizes all other markets.

The estimates displayed in Figure 7 are computed assuming $g^k = 2.4$ instead of $g^k = 1.2$. An increase in the rationality of the traders also decreases the volatility. In the case of no intervention, the volatility in type A and B markets is calculated as 0.28 and in type C and D markets as 0.43. Since the chartists now switch more quickly across markets, the exchange rate fluctuations become more stable. To be precise, periods of extreme volatility (outbursts such as those visible in Figure 1), become less frequent.

Nevertheless, Figure 7 reveals that central bank interventions are still able to reduce the volatility in the intervention markets. The other markets are either stabilized or destabilized, depending on whether the interventions are unbiased or biased.[4] In the case of unbiased target interventions, it seems that to lower volatility and distortion the central bank has to intervene forcefully enough. Put differently, weak interventions may not always suffice to stabilize the markets.

4. CONCLUSIONS

Central banks rely on heuristic intervention methods to stabilize foreign exchange markets (Neely, 2001). Inspired by the chartist–fundamentalist approach (Kirman, 1991; de Grauwe *et al.*, 1993; Brock and Hommes, 1998; Lux and Marchesi, 2000; Farmer and Joshi, 2002), we provide a first multi-foreign exchange market framework that may help evaluate such operations. Simulation analysis reveals that central bank interventions may succeed in calming down markets. However, one important message of this paper is that the market in which interventions take place either attracts more or drives away some destabilizing speculators. In the latter case, the performance of other markets is worsened.

Our results are, of course, preliminary and should be treated with caution. Many factors influence the power of central bank interventions. For instance, fundamentalists may also have some kind of flexibility in selecting their markets. Nevertheless, we firmly believe that models based on heterogeneous interacting agents offer novel insights into the working of certain policy tools. We hope that our paper encourages further research in this direction.

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4. We have, of course, carried out more simulations, e.g. with parameter settings which generate a volatility higher than the one of Figure 5. Our findings seem to be robust.

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