Market-maker, inventory control and foreign exchange dynamics

Frank H Westerhoff

Department of Economics, University of Osnabrueck, Rolandstrasse 8, D-49069 Osnabrueck, Germany

E-mail: fwesterho@oec.uni-osnabrueck.de

Received 7 February 2003, in final form 27 June 2003
Published 22 August 2003
Online at stacks.iop.org/Quant/3/363

Abstract

This paper examines how inventory management of foreign exchange dealers may affect exchange-rate dynamics. According to empirical observations, market makers set exchange rates not only with respect to excess demand but also in recognition of their inventory. Within our model, market makers control their positions by quoting exchange rates that provoke offsetting orders of technical and fundamental traders. Our model demonstrates that such behaviour may amplify trading volume, exchange-rate volatility and deviations from fundamentals.

1. Introduction

Inventory control among foreign exchange dealers is strong relative to that found for other markets. Lyons (1998) reports that market makers prefer to end their trading day with no net position and that the half-life of an open position is significantly less than one day. On some days, it is even as low as 10 min. This is remarkably short relative to half-lives for equity dealers of roughly one week.

The chartist–fundamentalist approach offers a behavioural framework to explore interactions between heterogeneous agents. Contributions by Day and Huang (1990), Kirman (1991), Brock and Hommes (1997, 1998), Cont and Bouchaud (2000), Lux and Marchesi (2000), Chiarella and He (2001) or Farmer and Joshi (2002) are quite successful in replicating financial market dynamics. Some of these papers explicitly recognize market makers. Their behaviour is approximated by a linear price adjustment rule depending on order flow. However, these kind of rules may lead to large inventory imbalances (Farmer and Joshi 2002) which does not square with the empirical fact of aggressive inventory control.

This raises two important questions. How do market makers manage their inventory in practice, and how does this influence exchange-rate dynamics? While the first question is an empirical question, one may use the chartist–fundamentalist approach to investigate the implications of certain price adjustment rules. In Farmer *et al* (2002), the price adjustment of market makers depends linearly on order flow and inventory. Such inventory management may facilitate prices to track their fundamental values.

We interpret recent empirical microstructure evidence (e.g. Lyons 2001) somewhat differently and explore a nonlinear price adjustment rule. In our model, market makers extract information contained in order flow and inventory to determine proper exchange rates as follows. The order flow signal always has top priority. Positive excess demand drives prices up and negative excess demand drives prices down. Inventory is a second-order signal. A negative (positive) inventory reveals that dealers have set exchange rates too low (high) in the past. Clearly, the empirical evidence reveals that market makers adjust exchange rates more strongly if the second signal confirms the first signal than if the second signal contradicts the first.

Our model yields the following results. Inventory control in the above way limits the positions of market makers. If the inventory is out of equilibrium, market makers quote exchange rates that stimulate offsetting orders of chartists and fundamentalists until they are almost flat. Due to the presence of feedback traders, causality between order flow and prices runs in both directions. Excess demand causes price changes and price changes trigger new orders. Such dynamics increases trading volume. The behaviour of dealers further

1469-7688/03/050363+07$30.00

PII: S1469-7688(03)59327-7

exercises an adverse impact on market efficiency. Exchange rates fluctuate more excessively and more distantly towards their fundamentals.

The remainder of this paper is organized as follows. Section 2 presents empirical evidence on the behaviour of speculators and market makers. Section 3 contains a benchmark model of linear price adjustment. In section 4, we modify the behaviour of dealers by allowing them to manage their inventory. Section 5 offers some conclusions.

2. Description of the market participants

We regard market participants as boundedly rational in the sense of Simon (1955). Neither do they have access to all relevant information for exchange-rate determination, nor do they know the mapping from this information to prices. Instead of optimizing, agents lend themselves to a rule-governed behaviour. Fortunately, these rules are inferrable from empirical observations. Let us briefly sketch the behaviour of market participants.

Speculators seem to rely on rather simple rules to determine their orders. Survey studies such as Taylor and Allen (1992) reveal that traders strongly rely on technical and fundamental analysis to predict exchange-rate movements. Both concepts appear to be equally important.

According to market professionals (e.g. Murphy 1999), technical analysis rests on two assumptions. First, anything that may affect the price of an asset—fundamentally, psychologically, or otherwise—is actually reflected in its price. Second, the full incorporation of news into prices necessitates some time so that prices tend to move in trends. A study of price action is all that is required. Rising (falling) prices hint at bullish (bearish) fundamentals. The general nature of technical analysis is extrapolative, i.e. chartists typically trade in the direction of the current trend.

Fundamental analysis presumes that prices have an inherent tendency to converge towards their fundamental (intrinsic) values. Trading signals are derived quite simply. If the fundamental value is below the current price, then the market is overpriced and the asset should be sold. If the price is below the fundamental value, then the market is undervalued and the asset should be bought.

In our model, all orders are initiated against market makers who stand ready to absorb imbalances between buyers and sellers. The orders are immediately executed at the current price. Dealers supply excess demand from their inventory or accumulate inventory when there is an excess supply. To bound their inventory, dealers adjust prices by paying attention to special kinds of information. As pointed out by the microstructure approach, order flow and inventory convey information about the future price evolution because they mirror the behaviour of those who analyse the market.

Since this paper aims to investigate the behaviour of foreign exchange dealers, let us review in more detail how they attempt to discover proper prices and how they try to manage their inventory. Lyons (1995) identifies three channels of information relevant to the behaviour of market makers:

(1) *The news channel.* Dealers naturally adjust prices when new information arrives on the market. In the case of good news, prices go up; and in the case of bad news, prices go down. However, the calculation of equilibrium prices is a difficult task and requires time.
(2) *The order flow channel.* Market makers thus analyse order flow to learn about proper prices. On the one hand, the incoming order flow may transport superior knowledge about fundamentals. For instance, a (fundamental) analyst may have a better understanding of the mapping from news to prices. Customer order flow, i.e. transactions from firms engaged in international trade, may even pre-signal information about macroeconomic variables such as current account news. On the other hand, order flow may also reveal market sentiment. Technical traders often have an impact on short-term price movements.
(3) *The inventory control channel.* Market makers have two alternatives to rebalance their portfolios. First, they may set prices to induce trades that compensate undesired inventory imbalances. Shifting prices away from fundamentals should trigger demand from fundamentalists. Technical traders are activated through price trends. Second, a market maker may also unload his position by trading with another market maker. If a market maker sells (buys) currency, his counterpart will decrease (increase) prices.

Note that the latter two channels imply that buyer-initiated trades correlate with rising prices (and vice versa).

3. A model without inventory management

Let us try to formalize the behaviour of market makers. In this section, we first recapitulate the implications of a linear price adjustment rule depending on order flow. As shown by Farmer and Joshi (2002), under stochastic perturbations this kind of rule leads to runaway inventories. In section 4, we allow dealers to learn about proper prices from both order flow and inventory.

3.1. Set-up

Our model contains three types of agents: chartists, fundamentalists and market makers. Chartists extrapolate past price movements into the future. Orders generated from technical trading rules may be expressed as

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

where S is the log of the exchange rate and a is a positive reaction coefficient. Chartists submit buying (selling) orders if the exchange rate increases (decreases).

Fundamentalists expect the exchange rate to track its fundamental value. Demand from this group may be captured as

$$D_t^{\mathrm{F}} = b(F - S_t), \tag{2}$$

where F is the log of the fundamental value and b is a positive reaction coefficient. Fundamentalists take a long (short) position if the exchange rate is below (above) its fundamental value.

Aggregated order flow is given as a weighted sum of (1) and (2)

$$D_t = wD_t^C + (1-w)D_t^F, \tag{3}$$

where w indicates the fraction of chartists and $(1-w)$ the fraction of fundamentalists.

Market makers mediate transactions. Depending on the sign and the volume of aggregated order flow, market makers set the log exchange rate for period $t+1$ as (Farmer and Joshi 2002)

$$S_{t+1} = S_t + eD_t + X_t, \tag{4}$$

where e is a positive price adjustment coefficient. For instance, if buying orders dominate selling orders, the exchange rate goes up. The noise term X captures all remaining random elements that may affect the market maker's price setting decision.

The balancing of excess demand alters the dealers' inventory by

$$I_t = I_{t-1} - D_t. \tag{5}$$

3.2. Results

The solution for the exchange rate, obtained by combining (1)–(4), is a second-order linear difference equation. To illustrate the fact that (4) may lead to inventory imbalances, let us consider the simplest case. Assuming $a = b = 1$, $w = 0.5$ and $X = 0$, the law of motion becomes

$$S_{t+1} - S_t + 0.5eS_{t-1} = 0.5eF. \tag{6}$$

The model is stable for

$$0 < e < 2, \tag{7}$$

produces converging fluctuations for

$$0.5 < e < 2, \tag{8}$$

and has a fixed point at

$$S_t = S_{t-1} = F. \tag{9}$$

If (7) holds and if $S_1 \neq S_0 = F$ due to a pricing error of market makers (i.e. $X_1 \neq 0$), then the positions of market makers converge in the limit to

$$\lim_{t\to\infty} I_t = \frac{S_1 - F}{e}. \tag{10}$$

Any negative shock ($S_1 < S_0 = F$) induces a negative inventory and conversely.

To develop a better understanding of what is going on in the market let us consider an example with $e = 1.5$. The top panel of figure 1 displays the evolution of the exchange rate for the first 60 periods. After an initial shock ($S_1 = X_0 = -0.01$), speculators start trading. Chartists are selling since the price has declined, and fundamentalists are buying since the currency is undervalued. In the first period, orders cancel each other out so that market makers have no reason to adjust the exchange rate. In the next period, only the fundamentalists are active. Their buying orders prompt market makers to increase the exchange rates ($S_3 = -0.0025$). In period 3, both groups submit buying orders (there is an up-trend and the currency is still undervalued). Afterwards, chartists and fundamentalists trade in opposite directions ($S_4 = 0.005$). As technical demand exceeds fundamental demand, the exchange rates go up even further ($S_5 = 0.006\,875$). Note that the more the exchange rate deviates from its fundamental value, the higher the demand of the fundamentalists. If the price adjustment coefficient is not too large ($e < 2$), the demand of the fundamentalists will eventually overcompensate the demand of the chartists so that market makers reverse the exchange-rate trend. This process continues until the fixed point is reached.

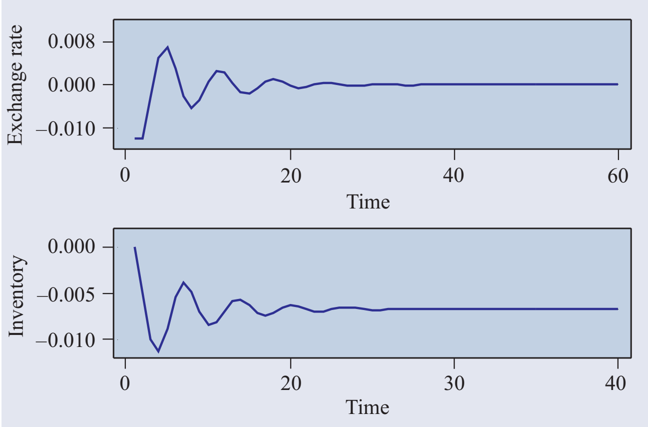

Figure 1. The top (bottom) panel shows the exchange rate (inventory) for the first 60 periods, $e = 1.5$, $F = S_0 = D_0 = 0$, $X_0 = -0.01$.

The bottom panel of figure 1 indicates that the positions of the dealers are negative after the adjustments are completed. But, as reported by Lyons (1998), market makers try to prevent lasting open positions. In the context of (4), they have only one means to limit their positions and that is to vary e. Compared to the numerical specification of figure 1, market makers are able to achieve a modest reduction of their open positions by adjusting prices more strongly. The inventory may be reduced from $I = -0.0067$ ($e = 1.5$) to -0.005 ($e \to 2$). For $e > 2$, the exchange-rate path explodes, as does the inventory.

Although dealers have one parameter to control their inventory, their positions remain out of equilibrium even if they use the optimal level of e. Indeed, (4) does not describe the behaviour of market makers appropriately.

4. A model with inventory management

4.1. Set-up

Market makers monitor the activity of other traders closely. Relative to chartists and fundamentalists, they have an additional source of information. It is the past and current flow of orders which indicates how speculators assess the market.

Within our model, current order flow is the dominating signal and is never disobeyed. Foreign exchange dealers

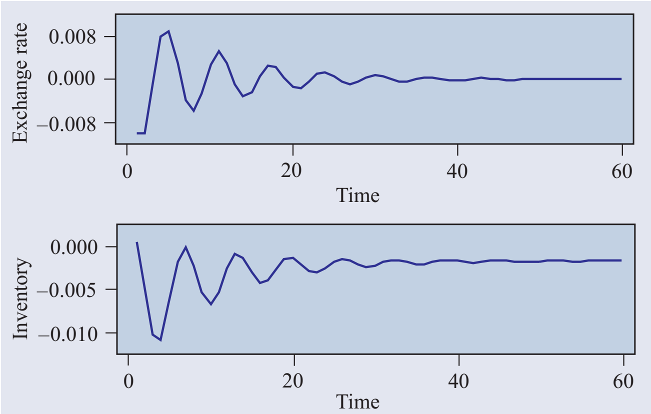

Figure 2. The top (bottom) panel shows the exchange rate (inventory) for the first 60 periods, $e = 1.5$, $r = 1.8$, $F = S_0 = D_0 = 0$, $X_0 = -0.01$.

always increase (decrease) exchange rates when there is a buying (selling) pressure. However, the degree of adjustment is not constant but depends on the positions of the market makers. For instance, a negative inventory signals that exchange rates have been too low in the past (traders have on average bought more than they have sold). To find equilibrium prices and to limit their positions, dealers alter prices more strongly if the first signal is supported by the second signal. Otherwise, the price adjustment is less pronounced.

Overall, there are four possible combinations of the two signals. The behaviour of market makers modifies to

$$S_{t+1} = \begin{cases} S_t + r|D_t|, & D_t > 0 \wedge I_t < 0 \\ S_t + e|D_t|, & D_t \geqslant 0 \wedge I_t \geqslant 0 \\ S_t - e|D_t|, & D_t \leqslant 0 \wedge I_t \leqslant 0 \\ S_t - r|D_t|, & D_t < 0 \wedge I_t > 0, \end{cases} \tag{11}$$

where the reaction coefficients fulfil $r > e > 0$. The empirical evidence on the information and inventory channel is congruent with (11). Since the nonlinearity in (11) precludes closed analysis, we proceed with a simulation analysis. Although such a procedure has its drawbacks, we would like to point out that it should be easy to replicate our findings.

4.2. Results

Figure 2 contains a simulation run for the exchange rate (top) and the market makers' inventory (bottom). We use the same specification as in figure 1, with the addition of $r = 1.8$. Simple visual inspection reveals that the exchange rates fluctuate more intensely until the fixed point is reached. Inventory control leads to a reduction in dealers' positions from $I_{60} = -0.0067$ ($e = r = 1.5$) to -0.002 ($e = 1.5, r = 1.8$).

Let us again work through the dynamics to see how the mechanism works. Without inventory control, price changes are always equal to eD_t. The parameter setting of figure 2 yields a negative inventory from period 2 onwards so that from then on the price adjustment is $r|D_t|$ for $D_t > 0$ and $-e|D_t|$ for $D_t \leqslant 0$.

The dynamics in the first two periods is identical to that of figure 1. The initial shock in period 1 triggers offsetting positions by chartists and fundamentalists so that the exchange rate remains constant. In period 2, technical analysis delivers no trading signal. But market makers are confronted with buying orders from fundamentalists, which instantly drive their positions into the negative. Since $r > e$, the exchange rate is fixed at a higher level in the inventory control regime ($S_3 = -0.001$ versus $S_3 = -0.0025$). In period 3, fundamentalists continue to purchase currency. But their demand is low because the exchange rate is relatively close to its fundamental value. Due to the strong price increase, chartists submit a large number of buying orders. Overall, dealers receive the same amount of excess demand as in the case of no inventory management. Buying pressure and negative positions prompt market makers to increase the exchange rate further ($S_4 = 0.008$ versus $S_4 = 0.005$).

Now, inventory control works for the first time. The high level of the exchange rate induces fundamentalists to sell currency aggressively. Nevertheless, there remains a low positive excess demand because chartists are still buying enthusiastically. However, the positions of market makers are less extreme than in the specification of figure 1. Again, the exchange rate is shifted upwards. In period 5, technical analysis indicates a weak buying signal, whereas fundamental analysis advises the selling of currency even more forcefully. Dealers thus partly resolve their positions. In the next period, chartists and fundamentalists trade in the same direction. In period 7, market makers are almost flat. Inventory management induces both chartists and fundamentalists to transactions which diminish the positions of market makers.

The term 'hot potato trading' usually refers to the repeated passing of inventory imbalances between market makers. When hit with an incoming order, a dealer seeks to resolve his position by trading with other dealers. Such inter-dealer transactions clearly amplify trading volume. Our model produces a different kind of hot potato trading. Note first that microstructure theory treats causality as running from order flow to prices. In our model, causality runs in both directions. Dealers respond to current and cumulative order flow by altering prices. Speculators then react to these new prices. Depending on the extent of price adjustments, the volume-amplification effect may be quite strong.

Our model thus yields alternative policy implications. Microstructure theory is sceptical about the effectiveness of transaction taxes. The high trading volume is typically explained by the dealers' desire to share risk. Imposing a transaction tax only impedes risk management. Our model allows us to be more optimistic because price movements always have an impact on speculators' demand. Clearly, it is the order flow of speculators which drives the inventory of market makers out of equilibrium. If a transaction tax hampers the activity of speculators, order flow and inventory may reach less extreme levels. As a result, foreign exchange markets are more stable.

4.3. Some Monte Carlo experiments

To explore the working of inventory management and its consequences for foreign exchange dynamics in more general

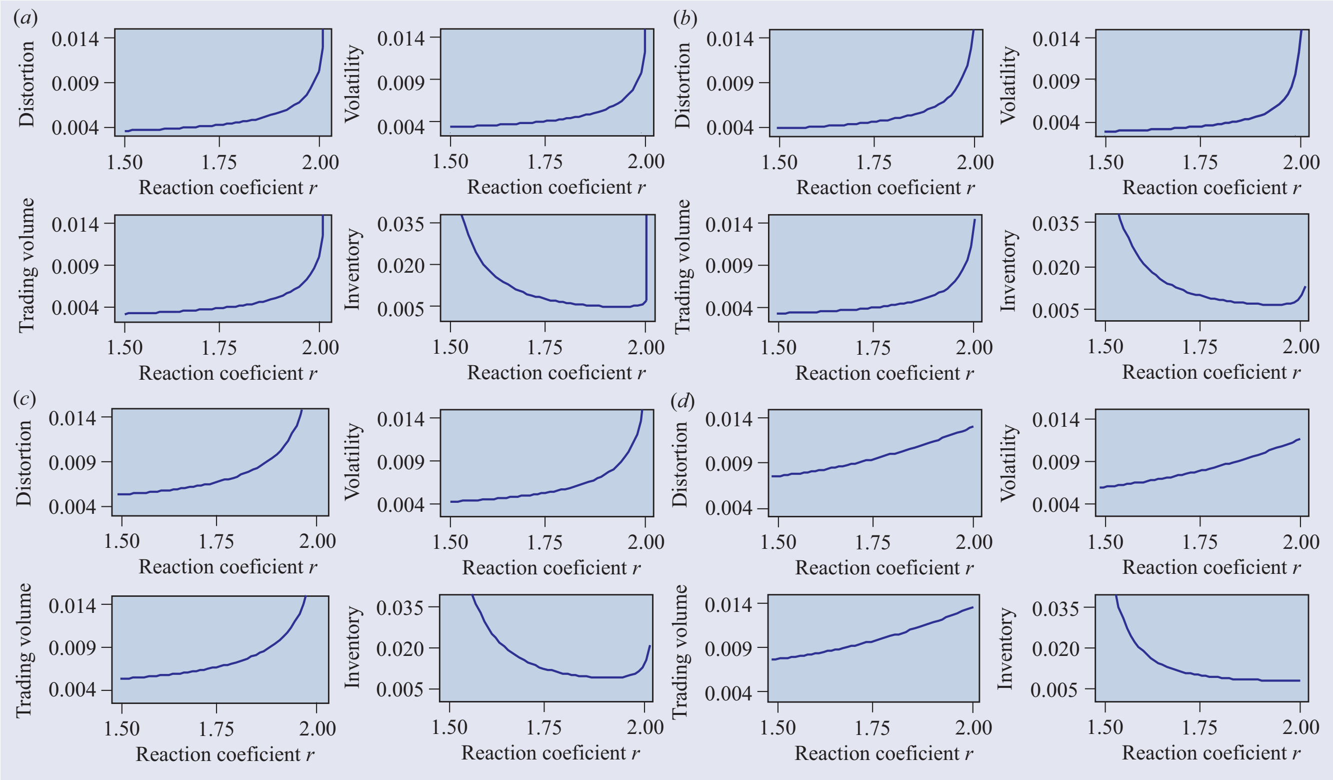

Figure 3. (*a*) The top left, top right, bottom left and bottom right panels show the impact of an increase in r on distortion, volatility, trading volume and inventory, respectively. The reaction coefficient r is increased in 51 steps from $r = 1.5$ to 2.01. The statistics are given as averages over 250 simulation runs, each containing 5000 observations. The system is perturbed at each time step with $X \sim N\ (0, 0.0025)$. (*b*) The simulation design is the same as in (*a*). The model now also includes the technical trading rule (16) with $a^1 = 1.35$, $a^2 = 0.6$ and $a^3 = 0.4$. (*c*) The simulation design is the same as in (*b*). The model now also includes the random walk of the fundamental value (17) with $News \sim N\ (0, 0.0025)$. (*d*) The simulation design is the same as in (*c*). The model now also includes the switching process (18) with $g^1 = 0.177$ and $g^2 = 8$.

terms, we carry out a few Monte Carlo experiments. Let us first introduce some statistics. We define distortions as average absolute deviations between log exchange rates and log fundamentals

$$\text{distortion} = \frac{1}{T}\sum_{t=1}^{T}|S_t - F|, \tag{12}$$

volatility as average absolute changes in log exchange rates

$$\text{volatility} = \frac{1}{T}\sum_{t=1}^{T}|S_t - S_{t-1}|, \tag{13}$$

trading volume as average absolute transactions of chartists and fundamentalists

$$\text{volume} = \frac{1}{T}\left(\sum_{t=1}^{T}|wD_t^{\mathrm{C}}| + \sum_{t=1}^{T}|(1-w)D_t^{\mathrm{F}}|\right), \tag{14}$$

and inventory as average absolute positions of market makers

$$\text{inventory} = \frac{1}{T}\sum_{t=1}^{T}|I_t|, \tag{15}$$

where T denotes the sample length.

Figure 3(*a*) shows how these measures are related to inventory control. The price adjustment coefficient r is increased in 51 steps from 1.5 to 2.01. The statistics are given as averages over 250 simulation runs, each containing $T = 5000$ observations. We add dynamic noise to the system with $X \sim N\ (0, 0.0025)$.

What are the results? Our inventory control mechanism obviously has the potential to lower the average position of dealers[1]. In numerical terms, the average absolute inventory position drops from 0.060 ($r = 1.5$) to 0.0057 ($r = 1.93$). Increasing r further yields, however, higher inventory imbalances again. For $r > 2$, the system explodes.

The behaviour of market makers may also be part of some well known empirical puzzles: (1) trading volume in foreign exchange markets is high relative to underlying trade on goods and services (the trading volume puzzle), (2) exchange-rate movements are virtually unrelated to macroeconomic fundamentals (the determination puzzle), and (3) exchange rates are excessively volatile relative to fundamentals (the excess volatility puzzle). Our simulation study indicates that

[1] Four observations are noteworthy. First, inspecting individual time series reveals that inventory control may create volatility clustering (due to regime shifts). Second, without inventory control ($e = r$) the positions of market makers are unbounded. Third, inventory imbalances deepen even more for $r < 1.5$ (not displayed). Fourth, the results are robust for different noise levels.

distortion, volatility and trading volume may increase due to inventory control.

Finally, let us check whether the results are stable. We extend our model in three steps by introducing a new technical trading rule, by enabling the fundamental value to evolve randomly and by allowing traders to switch between strategies. After these modifications, the model is basically the same as in Westerhoff (2003) from which we know that it is able to mimic actual exchange-rate fluctuations.

Let us first modify the technical trading rule. Westerhoff (2003) uses

$$D_t^{C} = a^1(a^2(S_t - S_{t-1}) + a^3(S_{t-1} - S_{t-2})), \tag{16}$$

with $a^2 = 0.6$ and $a^3 = 0.4$. For $a^1 = 1.35$, we obtain comparable statistics for the case $e = r = 1.5$. Figure 3(b) reveals that inventory control leads again to an increase in the distortion, the volatility and the trading volume. Hence, the results are not altered by the new technical trading rule.

In reality, the fundamental value is not constant but depends on the news arrival process. The evolution of the fundamental value is typically described as a random walk

$$F_t = F_{t-1} + News_t. \tag{17}$$

We assume that the innovations are given as $News \sim N(0, 0.0025)$. Visual inspection of figure 3(c) indicates the robustness of the results.

The fractions of chartist and fundamentalists have been fixed so far. However, most agents are familiar with both types of trading rules and thus switch between them. Following Hommes (2001), who argues that most traders believe that temporary speculative bubbles may arise but that these bubbles cannot last forever and that at some point a price correction towards the fundamental price will occur, the switching process may be formalized as

$$w_t = \left(1 + g^1 + g^2\sqrt{|F_t - S_t|}\right)^{-1}. \tag{18}$$

For $g^1 = 0.177$, the minimum fraction of traders who apply fundamental analysis is 15%. Put differently, 85% of the traders adjust their strategy with respect to market conditions. We set $g^2 = 8$. According to figure 3(d), the destabilizing impact of inventory management is somewhat countered by the endogenous selection of the rules. The reason is that as the distance between F and S increases, more and more traders opt for fundamental analysis. Still, the qualitative results have survived all three modifications.

5. Conclusions

The chartist–fundamentalist approach has proven to be quite successful in replicating the stylized facts of financial markets. However, the behaviour of market makers has been overly simplified so far. Fortunately, the microstructure approach offers new insights into the behaviour of market makers. Most importantly, market makers seem to adjust prices more strongly when order flow and inventory have opposite signs than when the sign is the same. Our model suggests that such behaviour limits the positions of foreign exchange dealers, but also causes markets to be less efficient: the more aggressively the inventory is controlled, the higher volatility, distortion and trading volume. All in all, our results seem to be robust.

Let us finally point out some extensions. First, the inventory control mechanism is quite simple. Market makers may adopt their price adjustment to be more flexible as the inventory evolves over time. Second, one may also try to capture inter-dealer trading, i.e. hot potato trading. Third, studying a linear price adjustment rule within the Day and Huang (1990) framework, Gu (1995) finds that to make a viable market, market makers have to churn the market. In addition to inventory control, market makers' profit maximization may therefore also destabilize the market. Note that dealer markets compete with limited order book markets. Chiarella and Iori (2002) show that the latter mechanism may also affect the price formation process. An interesting line for future research thus is to compare both order matching mechanisms regarding market efficiency in the presence of boundedly rational heterogeneous interacting agents. Should a central authority opt for a human market maker framework or a computerized limited order book? Insight from behavioural models may be useful.

Acknowledgments

The author thanks two anonymous referees and an anonymous board member for helpful comments.

References

Brock W and Hommes C 1997 A rational route to randomness *Econometrica* **65** 1059–95

Brock W and Hommes C 1998 Heterogeneous beliefs and routes to chaos in a simple asset pricing model *J. Econ. Dyn. Control* **22** 1235–74

Chiarella C and He X-Z 2001 Asset price and wealth dynamics under heterogeneous expectations *Quant. Finance* **1** 509–26

Chiarella C and Iori G 2002 A simulation analysis of the microstructure of the double auction markets *Quant. Finance* **2** 1–8

Cont R and Bouchaud J-P 2000 Herd behaviour and aggregate fluctuations in financial markets *Macroeconomics Dynamics* **4** 170–96

Day R and Huang W 1990 Bulls, bears and market sheep *J. Econ. Behav. Organ.* **14** 299–329

Farmer D, Geanakoplos J and Melby P 2002 Market making, price formation, and technical trading *Mimeo* Santa Fe Institute

Farmer D and Joshi S 2002 The price dynamics of common trading strategies *J. Econ. Behav. Organ.* **49** 149–71

Gu M 1995 Market mediating behaviour: an economic analysis of the security exchange specialists *J. Econ. Behav. Organ.* **27** 237–56

Hommes C 2001 Financial markets as nonlinear adaptive evolutionary systems *Quant. Finance* **1** 149–67

Kirman A 1991 Epidemics of opinion and speculative bubbles in financial markets *Money and Financial Markets* ed M Taylor (Oxford: Blackwell) pp 354–68

Lux T and Marchesi M 2000 Volatility clustering in financial markets: a micro-simulation of interacting agents *Int. J. Theor. Appl. Finance* **3** 675–702

Lyons R 1995 Tests of microstructural hypotheses in the foreign exchange market *J. Financial Economics* **39** 321–51

Lyons R 1998 Profits and position control: a week of FX dealing *J. Int. Money Finance* **17** 97–115

Lyons R 2001 *The Microstructure Approach to Exchange Rates* (Cambridge, MA: MIT Press)

Murphy J 1999 *Technical Analysis of Financial Markets* (New York: New York Institute of Finance)

Simon H 1955 A behavioural model of rational choice *Q. J. Economics* **9** 99–118

Taylor M and Allen H 1992 The use of technical analysis in the foreign exchange market *J. Int. Money Finance* **11** 304–14

Westerhoff F 2003 Expectations driven distortions in foreign exchange markets *J. Econ. Behav. Organ.* **51** 389–412