Can the interaction between a single long-term attractor and heterogeneous trading explain exchange rate behaviour? A nonlinear econometric investigation

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Can the interaction between a single long-term attractor and heterogeneous trading explain exchange rate behaviour? A nonlinear econometric investigation.

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Abstract

Over the last 15 years, exchange rate movements have been smoother and slower than expected, given the entity of the sharp shifts in the fundamental variables brought about by the international financial crisis. Since the beginning of the '90s researchers have explored different approaches in order to understand high frequency exchange rate dynamics. Among them the model that assumes heterogeneous trading strategies, where 'fundamentalists' coexist with 'chartists' in nonlinear transitional specifications, plays an increasingly relevant if puzzling role.

We study the US dollar, the British pound and the Japanese yen vs the euro over the period 2002 to 2016 using weekly data. The most important contribution of this paper is that we find empirical evidence that both types of agent react to the same transition variable, viz. the absolute distance of the actual exchange rate to its relative PPP value. The spot foreign currency demand of fundamentalists is driven by the size of the misalignment both directly and through a transition function, which models the adoption of fundamental strategies by newcomers. The number of chartists also varies according to the absolute distance of the exchange rate change from its fundamental value. Evidence supports the existence of stabilizing and destabilizing behaviour not only by chartists but also by fundamentalists.

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1. Introduction

Modeling exchange rate dynamics has never been an easy task. Most fundamental models failed both to explain and to predict exchange rate movements in a consistent way over time and across currencies. A possible explanation is that there are important non linearities in the data, due to an endogenous price movement which results from the interaction of heterogeneous bounded-rational strategies based both on technical and fundamental analysis.[1] The heterogeneity of these strategies could be longitudinal, i.e vary across agents and over time, and produce in this way effects that could properly match the actual exchange rate dynamics.

In a seminal work Frankel and Froot (1986) introduce a chartists fundamentalists approach in a foreign exchange model. They explain the movements of the US dollar in the eighties as the outcome of the interaction between fundamentalists' long term trading strategies and chartists' short term behaviour.

Brock and Hommes (1997, 1998) and Westerhoff (2004), among many others, assume that different groups of agents condition their behaviour on differing types of information and beliefs. Westerhoff and Reitz (2005) analyse how deviations from a "believed" fundamental value weaken fundamentalists' beliefs changing the number of agents in the market, with consequences on stability. In their paper chartists were only of the trend follower type.

Switching mechanisms are modelled according to past performances (Boswijk et al 2007), fundamental prices (Manzan and Westerhoff, 2007), accuracy of past forecasts (de Jong et al., 2010, Prat and Unctum, 2015) and business cycle indexes (Lof, 2012). Alternatively, they are attributed to changes in expectations

[1] See, among many others, De Grauwe and Vansteenkiste (2007), Menkhoff et al. (2009), de Jong et al. 2010, ter Ellen et al. (2013), Chia et al. (2014) and Flaschel et al. (2015).

based on some unobserved factors in financial markets, governed by a Markov process (Chiarella et al., 2012).

This paper extends the previous literature adding several features.

- Because of its dimension, depth and liquidity, and of its geographical extension, the foreign exchange market is a privileged field of analysis for heterogeneous agents models. Most empirical studies, however, impose too many ex-ante restrictions and are vulnerable to a data snooping criticism. We include almost no a-priori restrictions in our analysis and the selected specification is data driven.
- In our research we allow for a differing behaviour among traders of the same category, be they chartists or fundamentalists. Some alter their reaction over time and account for the regime shifting component and others are impervious to changes and maintain their presence in the market irrespectively of the changes of the transition variable. We introduce in this way a second classification, between resilient and regime shifting market agents.
- Both fundamentalists and chartists may change their reaction over time and over regimes. Wan and Kao (2012) introduce contrarian noise trading behaviour in their analysis without relating it, however, as we do in our paper to misalignements with respect to a chosen anchor value. Furthermore, we assume that fundamentalists too may behave as contrarians and have a destabilizing reaction to market disequilibrium. In periods of extreme financial and exchange rate turmoil a homogeneous stabilizing fundamentalist market reaction cannot be imposed a-priori and has to be tested empirically.

Indeed, the empirical analysis shows that, in the same time period, pricing efficiency is not homogeneous across exchange rates. The US dollar euro exchange rate seems to be priced in a more efficient way than the Japanese yen euro or the British pound euro rates.

The paper is organised as follows. In Section 2 we introduce the model, the characteristics of trading agents as well as the effects brought about by the simultaneous implementation of different strategies. We present the data and the non-linear transition econometric model in Section 3. The empirical results are set forth in Section 4. Section 5 concludes the paper.

2. The econometric model: trading strategies and their impact on the exchange rate

In this section we discuss how changes in the trading behaviour of heterogenous agents affect exchange rate determination. The usual distinction applies, if trading strategies depend only on the past history of the exchange rate the agents are defined "chartists", if they depend on external information used to assess a long term fundamental value the agents are called "fundamentalists". Chartists can be further classified as trend followers or contrarians according to whether they trade following the trend or they do the reverse. The final effect on the exchange rate will depend on the interaction between different types of agents and will vary over time since agents can decide to enter or exit the market according to a transition function geared to the gap between the spot exchange rate and its long-term equilibrium value.

Given the high degree of uncertainty and disagreement which characterizes the foreign exchange markets (Ellen ter et al. 2016), most agents will review periodically their arbitraging performance and their beliefs. When substantial losses occur they may lose credibility (with their principals) or run out of liquidity. Short-terminism applies as agents with a poor performance may have to leave the market, without having the time to recoup an eventual shortfall. Indeed, traders' confidence is likely to decline if the exchange rate deviates from the value expected according to the adopted rule. This phenomenon is modeled introducing a confidence function (the transition function) that accounts for the shifts in the number of each type of active trader in the market. In our model, two LSTAR transition functions, g^F and g^C, apply respectively to fundamentalists and to chartists.

a. Fundamentalists

The fundamentalists' trading strategy assumes that the actual exchange rate will revert towards its fundamental value. Their foreign currency demand function reads as follows:

$$D_t^F = a_1 g_t^F(\Delta f_t - \Delta s_t) + a_2 (\Delta f_t - \Delta s_t) \qquad (1)$$

where f_t and s_t denote, respectively, the logs of the fundamental and spot exchange rates, quoted as number of units of domestic currency per euro. There is a lack of consensus on the true drivers of the equilibrium exchange rate (Sarno and Taylor, 2002). Nonetheless as anchor value of the exchange rate in the long-run most models use either the purchasing power parity (PPP) or the uncovered interest rate parity (UIP).

In this paper f_t is the equilibrium value of the spot exchange rate according to the relative PPP hypothesis.[2] In equation (1) we assume that fundamentalists react to deviations from the relative PPP, buying foreign currency if the rate of change of the spot exchange rate Δs_t is lower than Δf_t and selling foreign currency if the

[2] We also tried the UIP anchor and obtained poor empirical results.

reverse is true, which implies that both a_1 and a_2 will be positive.[3] In equation (1) we draw a distinction between fundamentalists that are always active on the market (resilient) and those that enter or exit the market according to their beliefs (regime shifting). The inclusion of g^F, which denotes a LSTAR transition function, is justified, as pointed out by Wan and Kao (2009), by the impact on speculators confidence of past performances i.e. by the entity of the deviations of past values of the exchange rate changes from their fundamental value. Following Westerhoff and Reitz (2005) we model the confidence/transition function as follows:

$$g_{t,d}^F = \frac{1}{1 + e^{-\gamma^F \frac{|\Delta f_{t-d} - \Delta s_{t-d}|}{\widehat{\sigma_{\Delta s_{t-d}}}}}} \qquad (2)$$

Where d, the delay parameter, is the number of lags with which the transition variable $|\Delta f_t - \Delta s_t|$ enters the LSTAR function and reflects frictions in the price setting mechanism. We impose no ex-ante hypothesis on the sign of γ^F. Hence the number of fundamentalists entering the market, differently from the standard approach, may vary from 0 to 1. If $\gamma^F > 0$ fundamentalists believe in the mean reversion property of the real exchange rate i.e. that deviations from the relative PPP are only temporary. When $\gamma^F < 0$, they no longer believe that the relative PPP is an attractor and leave the market (Kao et al 2015).[4] The speed of agents' reaction and the heterogeneity of beliefs is quantified by the absolute value of γ^F.

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[3] Fundamentalists may however believe that the persistence of the misalignment will last for some time, in which case a_1 and a_2 will be negative (i.e. they persist to buy/sell foreign currency if Δs_t larger/smaller than Δf_t). This is a symptom of the failure of the price signaling process that may occur in periods of turbulence. Reitz and Taylor (2008) label this loss of confidence in fundamentals a "coordination failure" since a single agent will be afraid to trade against the market even if fundamentals would suggest to do so.

[4] Shleifer and Vishny (1997) were the first to point out that fundamentalists, if trades based on their own forecasts turn out to be persistently incorrect, will be wary to enter the market.

Finally, the transition variable $|\Delta f_t - \Delta s_t|$ is normalised using the conditional standard deviation of the exchange rate change Δs_{t-d}.

b. Chartists

Chartists focus on past exchange rate movements only. Their foreign currency demand function reads as

$$D_t^C = b_1 g_t^C \Delta s_t + b_2 \Delta s_t \qquad (3)$$

Chartists are partitioned in two fractions: one, resilient, is always trading while the other, regime shifting, enters or exits the market according the LSTAR transition function g^C. The properties of the latter are analogous to those of the fundamentalist equation (2) and reflect the reaction of chartists to the size of real exchange rate misalignment.

$$g_{t,d}^C = \frac{1}{1 + e^{-\gamma^C \frac{|\Delta f_{t-d} - \Delta s_{t-d}|}{\widehat{\sigma_{\Delta s_{t-d}}}}}} \qquad (4)$$

Here too, no restrictions are set on the sign of γ^C and consequently shifts in the transition variable may bring about either an increase or a decrease in the number of active chartists. Chartists will behave as trend followers when b_1 and b_2 are positive or as contrarians when b_1 and b_2 are negative. As it is well known, exchange rate may overshoot. In this case contrarians are stabilizers since they bring about price reversals by betting against the current trend.

c. Combining trading behaviours and the role of the transition function

Exchange rates are set in an order driven market where trading positions are revised every period. Hence exchange rate changes from t to t+1 are a function of the excess demands of fundamentalists and chartists and are parameterized by the following log-linear function

$$s_{t+1} = s_t + \theta(D_t^F + D_t^C) + u_{t+1} \qquad (5)$$

u_{t+1} accounts for the remaining determinants of exchange rate dynamics. Inserting equations (1) to (4) into equation (5) we obtain

$$\Delta s_{t+1} = e_0 + e_1 g_{t-d_f}^F (\Delta f_t - \Delta s_t) \quad + e_2(\Delta f_t - \Delta s_t) \quad + e_3 g_{t-d_C}^C \Delta s_t + e_4 \Delta s_t + \varepsilon_{t+1} \qquad (6)$$

Where $e_1 = \theta a_1$, $e_2 = \theta a_2$, $e_3 = \theta b_1$, and $e_4 = \theta b_2$. Exchange rate movements reflect the interactions of the orders of heterogeneous traders.

3. Data and model specification

a. Data description

Our weekly exchange rate data span the 3 January 2002 – 4 August 2016 time-period and are taken from Bloomberg. The descriptive statistics are set out in Table 1. We recall here, for the sake of clarity, that the currencies we study - US dollar, GB pound, Japanese yen – are defined as the number of units of domestic currency per units of foreign currency (i.e. euro). The endogenous variable Δs_t is the first difference of the log of the exchange rate since as expected exchange rates are not stationary in levels, see Figure 1.

<INSERT FIGURE 1 ABOUT HERE>

$\Delta(f_t - s_t)$ measures the weekly deviations from the relative purchasing power parity, where the price indexes are monthly CPI from the OECD Database.

VIX is the market expectation of near term volatility conveyed by the S&P100 stock index option prices from the CBOE database, which provides also the Skew Index, a measure of a potential tail risk-return of two or three standard deviations below the mean in the S&P500 index over the next 30 days. All the time series are stationary but neither normal nor conditionally homoskedastic. The VIX and Skew indexes, which provide proxies for shifts in the sentiment of investors, are used at first as tentative transition variables in the switching function and subsequently to date changes in the number of agents entering the markets.

<INSERT TABLE 1 ABOUT HERE>

b. Model specification

Since exchange rates changes are conditionally heteroskedastic when sampled with a weekly frequency, a GARCH (1,1) is used to model the variances $\sigma_{\Delta s_{t-d}}$ that enter equations (2) and (4). Equation (7) - the empirical version of equation (6) - parameterizes the corresponding conditional mean:

$$\Delta s_t = e_0 + e_1 g^F_{t-1-d_F} (\Delta f_{t-1} - \Delta s_{t-1}) + e_2(\Delta f_{t-1} - \Delta s_{t-1}) + e_3 g^C_{t-1-d_C} \Delta s_{t-1} + e_4 \Delta s_{t-1} + \epsilon_t \qquad (7)$$

Where

$$g^F_{t-1-d_F} = \frac{1}{1+e^{-\gamma^F \frac{\left|\Delta f_{t-1-d_F} - \Delta s_{t-1-d_F}\right|}{h_{t-1-d_F}}}} \qquad (8)$$

$$g^C_{t-1-d_C} = \frac{1}{1+e^{-\gamma^C \frac{\left|\Delta f_{t-1-d_C} - \Delta s_{t-1-d_C}\right|}{h_{t-1-d_C}}}} \qquad (9)$$

and the GARCH (1,1) parameterization is

$$h^2_t = \omega + \alpha\epsilon^2_{t-1} + \beta h^2_{t-1} \quad (10)$$

$$\nu_t|\Omega_{t-1} \sim N(0,1)$$

ν_t being the standardized residual of equation (7).

In this paper a regime shifting fraction of the economic agents – be they fundamentalists or chartists - has beliefs on the long term reliability of the anchor (i.e. the relative PPP) which are affected by the size of the misalignment according to a logistic reaction function (equations (8) and (9)) controlled by the sign and the absolute value of γ. More precisely, the sign of γ indicates whether they believe or not in the economic significance of the long run equilibrium and its absolute value defines the homogeneity of their reaction.

A-priori we would expect the fundamentalists to stabilize the exchange rate, and the sign of e_1 and e_2 to be positive. We found, however, some exceptions with destabilizing fundamentalists and negative e_1 and e_2 parameters. Coefficients with opposite signs are also frequent in the case of chartists. We label them trend followers if e_3 and e_4 are positive, and contrarians if e_3 and e_4 are negative. Equation (7), moreover, does not rule out the possibility of having simultaneously stabilizing and destabilizing behaviours within the same category of agents (i.e. e_1 and e_2 (e_3 and e_4) of opposite signs).

As for the transition function, if the misalignment is very large and $\gamma^F > 0$, then $g^F = 1$ and both resilient and market sensitive speculators will be active in the market. If $\gamma^F < 0$, the confidence of fundamentalists on current pricing decreases as the deviation rises. In this case - for very large misalignments - g^F could collapse to zero, leaving only resilient fundamentalists on the market. The same reasoning holds for chartists.

This specification generalises the standard approach set out by Westerhoff and Reitz (2005) where γ is assumed a-priori to be positive, which implies that fifty percent of the speculators at least are always trading on the market and no distinction is drawn between market sensitive and resilient speculators

4. Estimation results

a. Model estimation

Table 2 presents maximum likelihood estimates of the logistic smooth transition regime switching GARCH system set out in equations (7) to (10). The adopted parameterization is justified by the strategy set out by Teräsvirta (1994.a). At first, the lag of the autoregressive exchange rate log difference is selected using the Akaike Information Criterion: a one-week lag provides the best fit.[5] A test of linearity against the non-linear parameterization of equation (7) is performed following the procedure of Luukkonen at al. (1988), as modified by Wan and Kao (2009). The transition functions (8) and (9) are replaced in equation (7) by a third order Taylor series approximation. The following auxiliary equation is estimated

[5] As suggested by Teräsvirta (1994.a, p. 211), using the SBIC order selection criterion in this context may lead "to too parsimonious a model in the sense that the estimated residuals of the selected model are not free from serial correlation".

$$\Delta s_t = \pi_0 + \pi_1(\Delta f_{t-1} - \Delta s_{t-1}) + \pi_2(\Delta f_{t-1} - \Delta s_{t-1})w_{t-1-d_F} + \pi_3(\Delta f_{t-1} - \Delta s_{t-1})w_{t-1-d_F}^2 +$$

(11)

$$\pi_4(\Delta f_{t-1} - \Delta s_{t-1})w_{t-1-d_F}^3 + \mu_1\Delta s_{t-1} + \mu_2\Delta s_{t-1}w_{t-1-d_C} + \mu_3\Delta s_{t-1}w_{t-1-d_C}^2 + \mu_4\Delta s_{t-1}w_{t-1-d_C}^3 + \epsilon_t$$

where, $w_{t-k} = |\Delta f_{t-1-k} - \Delta s_{t-1-k}|$, $k = d_F, d_C$.

We test linearity against STAR modeling - for various values of d_F and d_C - performing LM tests of the null hypothesis H_0: $\pi_2 = \pi_3 = \pi_4 = \mu_2 = \mu_3 = \mu_4 = 0$. For the values of the delay parameters of the first row of Table 3, the T.N.T. statistics uniformly reject H_0. Our non linear parameterization is thus justified by the data and the time-varying fractions of chartists and fundamentalists in equation (7) are parameterized using equations (8) and (9).[6]

<INSERT TABLE 2 ABOUT HERE>

The overall quality of fit of the estimates, set out in Table 2, is satisfactory. The parameters of both the conditional mean and conditional variance relationships are significantly different from zero and have meaningful signs. The usual misspecification tests suggest that the standardized residuals ν_t are well behaved and that the serial correlation and heteroskedasticity of the original return time series are captured by the model ($E(\nu_t) = 0, E(\nu_t^2) = 1$, and both ν_t and ν_t^2 are serially uncorrelated).

According to the sign of the coefficients, resilient fundamentalists behave similarly for all three exchange rates as the corresponding coefficient e_2 estimates are

[6] The Taylor procedure allows us to reject the alternative ESTAR parameterization of the transition function. For the sake of parsimony these tests are not reported here.

always negative. This destabilizing behaviour is systematically dampened by the regime shifting fundamentalists whose presence in the market grows with the size of the disequilibrium ($e_1 > 0$). The absolute value of γ^F is ten times larger in the case of the US dollar than for the pound and the yen; this indicates a much smaller uncertainty about the long run value of the US dollar (i.e. about the corresponding relative PPP). Further the positive sign of γ^F indicates that fundamentalists believe in the economic value of this long run attractor as measured by the market.

As for the chartists, we obtain fuzzier results. In the case of the dollar and the pound, resilient chartists are contrarians and play a stabilizing role whereas regime shifting chartists are trend followers and destabilize the market. For the yen, the opposite is the case. Here too, the absolute value of γ^C is much larger in the case of the US dollar than in the case of the pound. Its positive sign reflects the credibility of the relative PPP measure. As for the yen, the results are completely different and reflect a much greater uncertainty: the absolute value of γ^C is very low and the corresponding sign is negative. Hence greater misalignments bring about a reduction in the number of chartists, who no longer believe in the economic significance of the relative PPP derived from market prices.[7]

<INSERT TABLE 3 ABOUT HERE>

In Table 3, besides the non-linearity test of Teräsvirta (1994.b) discussed above, we find the test of Eitrheim and Teräsvirta (1996). It is used to assess the presence of non-linearity in the estimated standardized residual of equation (7).

[7] In testing the proper empirical model, we also try the case with no resilient speculators on the market. Overall, according to the LR test, this kind of parameterization is either strongly rejected (for the US dollar and the British pound) or turns out to be without any reasonable meaning (for the Japanese yen).

The R.N.T. statistics of the second row are never significant and fail to reject the null of no residual post estimation non-linearity.

b. Stability and dynamic interactions of trading behaviours

In order to assess the overall impact on exchange rate movements of the different categories of agents we compute weighted sums of the corresponding estimated coefficients of equation (7). That is to say we calculate the sums $(e_1\overline{g^F} + e_2)$ and $(e_3\overline{g^C} + e_4)$ where $\overline{g^F}$ and $\overline{g^C}$ are the average values of the transition function time series over the corresponding time periods. We report them in Table 4.

<INSERT TABLE 4 ABOUT HERE>

For the US dollar, fundamentalists play a stabilizing role throughout whereas chartists are always destabilizers. The opposite holds true for the GB pound and the Japanese yen: in both cases the composite aggregates of chartists (resilient and market sensitive) tend to stabilize the exchange rate and of fundamentalists to destabilize it.[8]

These results provide further support for the hypothesis of a greater efficiency of the US dollar currency market. At the same time the role of chartists, especially for the pound and the yen, displays an increasing sophistication and justifies our hypothesis of relating their temporary presence to an assessment of the long-term market disequilibrium.

<INSERT FIGURE 2 ABOUT HERE>

[8] Frenkel et al. (2009) find that contrarian beliefs are predominant in the yen market whilst the reverse is true for the dollar exchange rate.

Figure 2 depicts the impact over time of resilient and regime shifting speculators. It provides additional insights into their destabilizing or stabilizing behaviour, which is strongly affected by the size of the deviations from the relative PPP. In the case of US dollar, both for chartists and fundamentalists, large deviations from the long term equilibrium bring about switches in the sign of the coefficients: fundamentalists become stabilizers whereas for small misalignements they are destabilizing contrarians and, on the other hand, chartists become trend followers while, for small deviations, they behave as contrarians. As for the UK pound, switches in sign occur only for chartists that become trend followers when the deviations from the relative PPP are large. For the Japanese yen too, chartists modify their behaviour in the case of large misalignments and become trend followers.

<INSERT TABLE 5 ABOUT HERE>

A more accurate analysis of the dynamics of the interaction between chartists and fundamentalists is therefore called for.[9] Taking into account the combinations of positive and negative values of the explicative variables, which reflect the trading strategies of chartists and fundamentalists, any shock to the system is absorbed in a stable framework in the case of the US dollar, and in a saddle point equilibrium path in the case of the pound and the yen (see Table 5). The latter would require - whenever out of the saddle path as in cases (1) and (4) - an exchange rate policy intervention.

[9] The results of Table 5 are based on the average impacts set out in Table 4 and are obtained from the ML estimation of the transition functions.

c. Further investigations

As final investigation of the informative content of our estimates we analyze, in Table 6, the correlation between proxies of market uncertainty, such as the VIX and the Skew indexes, and the time series that measure the portion of agents active in the foreign exchange rate markets according to the estimates of equations (8) and (9).

In the case of the US dollar traders are not sensitive to an increase in uncertainty (i.e. to a rise in the VIX index) whereas in both the pound and the yen markets both fundamentalists and chartists seem to react significantly to it. As expected, in the case of Japan, the number of chartists declines as uncertainty rises. Interestingly the correlation with the skew index (that is with an increasing likelihood of extreme events) is showing a strong negative relation only with the chartists in the US dollar market, as if their confidence in the model were to decrease only in extremes cases.

<INSERT TABLE 6 ABOUT HERE>

As final test of the quality of the fit we compute in sample RMSE and MAE statistics (Table 7) associated with three differing parameterizations of the exchange rate returns: the nonlinear model (equations (7) to (10)), a linear version of equation (7), and the standard random walk model. We find that the LSTAR specification outperforms the remaining ones, and provides always the smaller statistics.

<INSERT TABLE 7 ABOUT HERE>

5. Conclusions

This paper provides two innovative results. Strong empirical evidence is found that resilient and market sensitive regime shifting speculators behave differently: the former tend to destabilize the exchange rates whilst the latter tend to stabilize it (in the case of chartists the opposite is true, with the exception of the Japanese yen). Moreover, regime shifting speculators, be they chartists or fundamentalists, react to the same transition variable, viz. to the absolute distance of the actual exchange rate to its relative PPP value. Contrary to common beliefs, a real indicator such as the real exchange rate misalignment affects the spot exchange rate movements also in the short term. Indeed, the long-term disequilibrium affects the short term demand of fundamentalists both directly and through a transition function, which models the adoption of fundamental strategies by new comers. In the same way the number of chartists, who react to the past exchange rate dynamics, varies according to the absolute distance of the exchange rate from its fundamental value. An accurate analysis of the overall impact of chartists detects the presence of contrarian trading in the British pound and the Japanese yen markets, and of trend following in the US dollar market. In the case of fundamentalists too the standard reactions seem to be reversed: to a stabilizing behavior in the US dollar market corresponds a destabilizing one in the remaining markets. Moreover, the confidence of the market participants in the long-term value of the exchange rate is highly heterogeneous and varies from a high degree in the case of the US dollar to a lower one in the case of the Japanese yen leaving in a middle rank the pound.

Finally, analyzing the stability characteristics of the systems we find that a shock is fully absorbed in the US market where the system shows a stable equilibrium and fails to do so in the case of the remaining markets where the systems return to the equilibrium only under given circumstances.

We conclude this paper noting that a clear-cut distinction between stabilizing fundamentalist speculators, who react to price misalignments, and destabilizing chartist trend followers does not seem to hold. Whether this phenomenon is due to the extremely turbulent time period over which we perform our research or to technological/institutional innovations that have altered the behaviour of chartists and fundamentalists lies outside the scope of this paper and constitutes the topic of further research.

TABLE 1. Descriptive Statistics

	Δs_{USD}	Δs_{GBP}	Δs_{YEN}	$\Delta(f_t - s_t)_{USD}$	$\Delta(f_t - s_t)_{GBP}$	$\Delta(f_t - s_t)_{YEN}$	VIX	SKEW Index
Mean	0.029	0.043	-0.005	-0.000	-0.000	-0.000	19.937	120.603
Std.Dev.	1.149	0.942	1.361	0.012	0.010	0.014	9.063	6.398
Skew.	-0.061	0.372	-0.610	0.039	-0.795	0.592	2.334	0.594
Kurt.	4.745	5.625	6.841	4.567	7.989	6.538	10.849	3.301
JB	97.221 [0.000]	236.419 [0.000]	515.800 [0.000]	78.152 [0.000]	870.655 [0.000]	442.128 [0.000]	2648.031 [0.000]	47.711 [0.000]
ARCH(1)	6.818 [0.009]	104.680 [0.000]	16.217 [0.000]	9.940 [0.002]	107.090 [0.000]	17.088 [0.000]	633.010 [0.000]	590.140 [0.000]
ARCH(5)	26.638 [0.000]	317.950 [0.000]	125.915 [0.000]	28.690 [0.000]	239.420 [0.000]	121.080 [0.000]	2634.100 [0.000]	2240.300 [0.000]
ADF(n)	-21.772 [0.000]	19.424 [0.000]	-22.639 [0.000]	-21.954 [0.000]	-18.232 [0.000]	-22.466 [0.000]	-4.042 *c* [0.001]	-4.822 *c,t* [0.000]

Notes. Probability values in square brackets; Skew: Skewness; Kurt: Excess Kurtosis; JB: Jarque-Bera normality test; ARCH(n): Ljung-Box test statistic for n-th order serial correlation of the squared time series; ADF(n): Augmented Dickey Fuller unit root test statistic, with nth order autoregressive component (n=1 for Δs_t, n=0 for $f_t - s_t$, n=2 in the case of VIX and n=7 in the S.I. ADF test). In the case of the VIX index, which seems to be affected by a relevant regime shift, the breakpoint unit root test of Vogelsang and Perron (1998) provided qualitatively analogous results. The data have a weekly frequency over the sample period 3 January 2002 - 4 August 2016.

TABLE 2. Model estimates: equations (7) to (10)

	US dollars per euro $[d_F = 7, d_C = 0]$	GB pounds per euro $[d_F = 4, d_C = 0]$	JP yens per euro $[d_F = 1, d_C = 1]$
e_0	0.0281 (0.8422)	0.0149 (0.5815)	0.0304 (0.7935)
e_1	109.1408 (3.8650)	26.2579 (2.1964)	150.7238 (1.8218)
e_2	-99.4553 (-2.9108)	-39.5982 (-3.8766)	-155.9194 (-2.6881)
e_3	2.2708 (24.5202)	0.8969 (2.7884)	-55.3928 (-11.1127)
e_4	-1.9760 (-17.5894)	-0.8205 (-2.8921)	27.1415 (12.1159)
γ^F	1394.8754 (4.1447)	129.0167 (1.9400)	112.6703 (3.0325)
γ^C	552.9423 (5.0361)	120.2641 (3.4354)	-1.9367 (-1.7069)
ω	0.0244 (2.0914)	0.0196 (2.2153)	0.0493 (2.4148)
α	0.0696 (4.9860)	0.0847 (4.4577)	0.1117 (3.4046)
β	0.9114 (69.9868)	0.8934 (36.1779)	0.8648 (31.1214)
LLF	-1126.2732	-951.5951	-1237.0837
	$\nu_t = \epsilon_t / \sqrt{h_t}$	$\nu_t = \epsilon_t / \sqrt{h_t}$	$\nu_t = \epsilon_t / \sqrt{h_t}$
AR(1)	0.345 [0.5571]	0.201 [0.6542]	0.998 [0.3179]
AR(2)	0.558 [0.7566]	3.339 [0.1883]	3.924 [0.1406]
AR(5)	3.158 [0.6757]	4.989 [0.4173]	9.187 [0.1018]
ARCH(1)	0.9279 [0.3354]	0.4875 [0.4850]	0.0898 [0.7644]
ARCH(2)	6.0163 [0.0493]	0.4796 [0.7867]	0.1356 [0.9344]
ARCH(5)	7.9417 [0.1595]	7.4569 [0.1888]	9.1079 [0.1048]
JB	9.5631 [0.0083]	30.8906 [0.0000]	47.7924 [0.0000]
E$[\nu_t]$	-0.0104	0.0132	-0.0230
E$[\nu_t^2]$	0.9666	0.9604	0.9853
Sk.	-0.2063	0.2217	-0.2625
Kurt.	0.3341	0.8391	1.0637

Notes: The conditional normality of the standardised residuals is rejected, and the t-ratios reported on this table are based on the quasi-maximum likelihood estimation procedure of Bollerslev and Wooldridge (1992).

TABLE 3. Tests of non-linearity

Tests	US dollars per euro	GB pounds per euro	JP yens per euro
Delay parameters	$[d_F = 7, d_C = 0]$	$[d_F = 4, d_C = 0]$	$[d_F = 1, d_C = 1]$
T.N.T.	2.1234 [0.0485]	3.5176 [0.0019]	2.7115 [0.0130]
R.N.T.	1.3676 [0.2158]	1.6320 [0.1231]	0.5790 [0.7472]

Notes. T.N.T.: Teräsvirta (1994.b) test of nonlinearity; R.N.T.: Eitrheim and Teräsvirta (1996) test of no remaining nonlinearity.

TABLE 4. Stabilizing vs destabilizing impact of fundamentalists and chartists

	Fundamentalists	Chartists*
US dollar	2.7278 stab	4.0520 dest
GB pound	-10.4739 dest	-9.6328 stab
JP yen	-25.8927 dest	-16.8979 stab

Note: *The coefficients have been multiplied by 100 to allow comparison with the coefficients of the fundamentalists. Subsample estimations (before and after the Lehman crisis) do not contradict the full sample results.

TABLE 5. Dynamic interaction between fundamentalists and chartists

US dollars per euro

	$\Delta s_{t-1} > 0$		$\Delta s_{t-1} < 0$	
	(1)	(2)	(3)	(4)
	$(\Delta f - \Delta s)_{t-1} > 0$	$(\Delta f - \Delta s)_{t-1} < 0$	$(\Delta f - \Delta s)_{t-1} > 0$	$(\Delta f - \Delta s)_{t-1} < 0$
Chartists	Sell \$ $\Delta s_t > 0$	Sell \$ $\Delta s_t > 0$	Buy \$ $\Delta s_t < 0$	Buy \$ $\Delta s_t < 0$
Fundamentalists	Sell \$ $\Delta s_t > 0$	Buy \$ $\Delta s_t < 0$	Sell \$ $\Delta s_t > 0$	Buy \$ $\Delta s_t < 0$
Spot exchange rate impact	Rapid depreciation $\Delta s_t >> 0$. The system switches to (2) when $\Delta s_t > \Delta f$	Fundamentalists take long positions dampening the depreciation pressure due to chartists' sales	Fundamentalists take short positions dampening the appreciation pressure due to chartists' purchases.	Rapid appreciation $\Delta s_t << 0$. The system switches to (3) when $\Delta s_t < \Delta f$

GB pounds per euro and JP yens per euro

	$\Delta s_{t-1} > 0$		$\Delta s_{t-1} < 0$	
	(1)	(2)	(3)	(4)
	$(\Delta f - \Delta s)_{t-1} > 0$	$(\Delta f - \Delta s)_{t-1} < 0$	$(\Delta f - \Delta s)_{t-1} > 0$	$(\Delta f - \Delta s)_{t-1} < 0$
Chartists	Buy £, ¥ $\Delta s_t < 0$	Buy £, ¥ $\Delta s_t < 0$	Sell £, ¥ $\Delta s_t > 0$	Sell £, ¥ $\Delta s_t > 0$
Fundamentalists	Buy £, ¥ $\Delta s_t < 0$	Sell £, ¥ $\Delta s_t > 0$	Buy £, ¥ $\Delta s_t < 0$	Sell £, ¥ $\Delta s_t > 0$
Spot exchange rate impact	Rapid appreciation $\Delta s_t << 0$. The system is unstable as $\Delta s_t << \Delta f$	Fundamentalists take short positions dampening the appreciation pressure due to chartists' purchases.	Fundamentalists take long positions dampening the depreciation pressure due to chartists' purchases.	Rapid depreciation $\Delta s_t >> 0$. The system is unstable as $\Delta s_t >> \Delta f$

Table 6. Correlation Analysis between VIX and Skew index and the number of active agents in the markets

VIX index

	US dollar	GB pound	JP yen
Chartists	0.0270 (0.7460)	0.0754** (2.0858)	-0.0954*** (-2.6439)
Fundamentalists	-0.1014 (-0.4117)	0.1060*** (2.9394)	0.0631* (1.7423)

Skew Index

	US dollar	GB pound	JP yen
Chartists	-0.1105*** (-3.066)	0.0030 (0.0851)	-0.0249 (-0.6872)
Fundamentalists	0.0026 (0.0716)	-0.0032 (-0.0089)	0.0113 (0.3138))

Notes: Student-t ratios in parentheses; *, **, and *** denote, respectively the 10, 5, and 1 percentage levels of significance.

Table 7. Relative in sample forecasting accuracy

RMSE

	US dollar	GB pound	JP yen
LSTAR	1.101686	0.915406	1.321510
LINEAR	1.110677	0.921791	1.322960
RANDOM WALK	1.144570	2.054049	1.355349

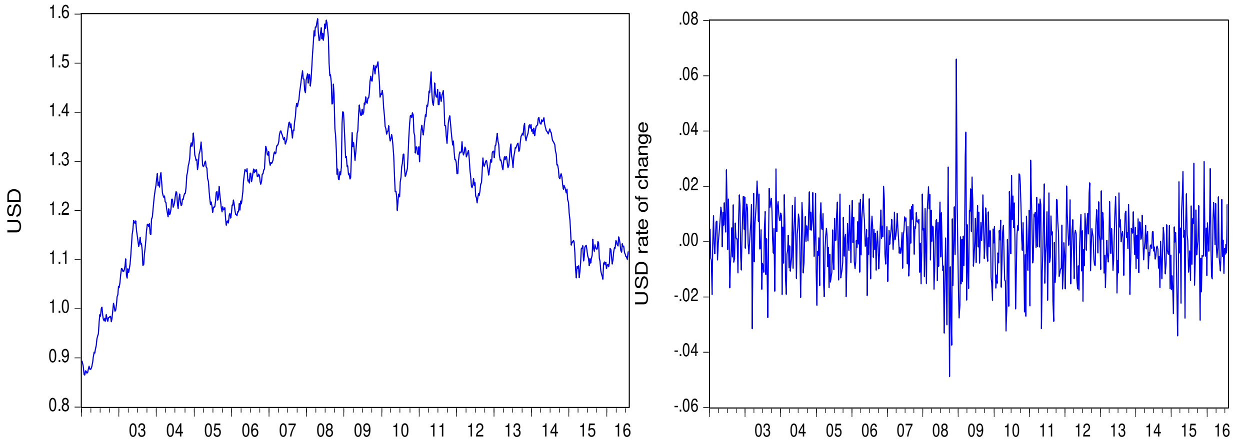
MAE

	US dollar	GB pound	JP yen
LSTAR	0.848967	0.614221	0.960359
LINEAR	0.855979	0.681526	0.963268
RANDOM WALK	0.885040	0.706655	1.006016

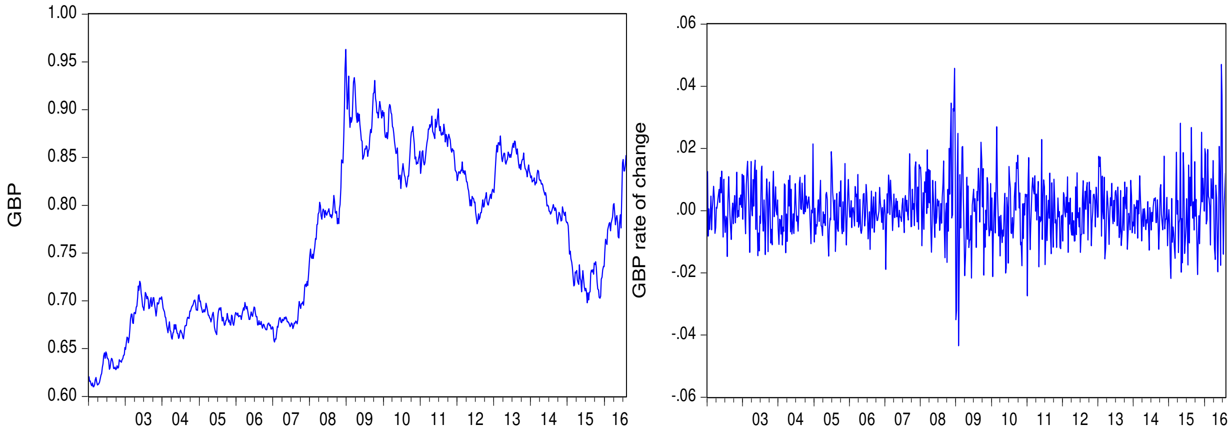
Notes: RMSE: Root Mean Square Error; MAE: Mean Absolute Error.

FIGURE 1

US dollars per euro



GB pounds per euro



JP yens per euro

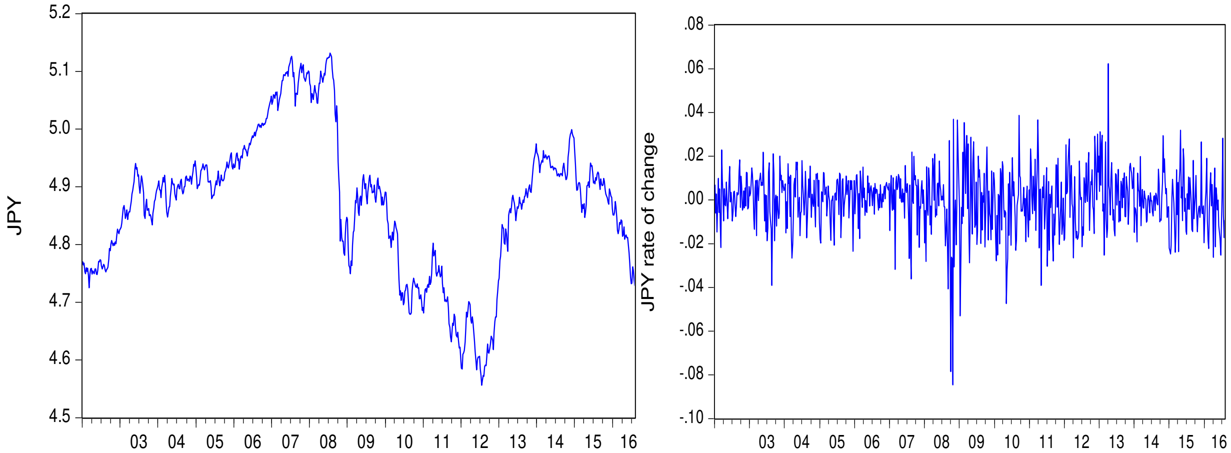
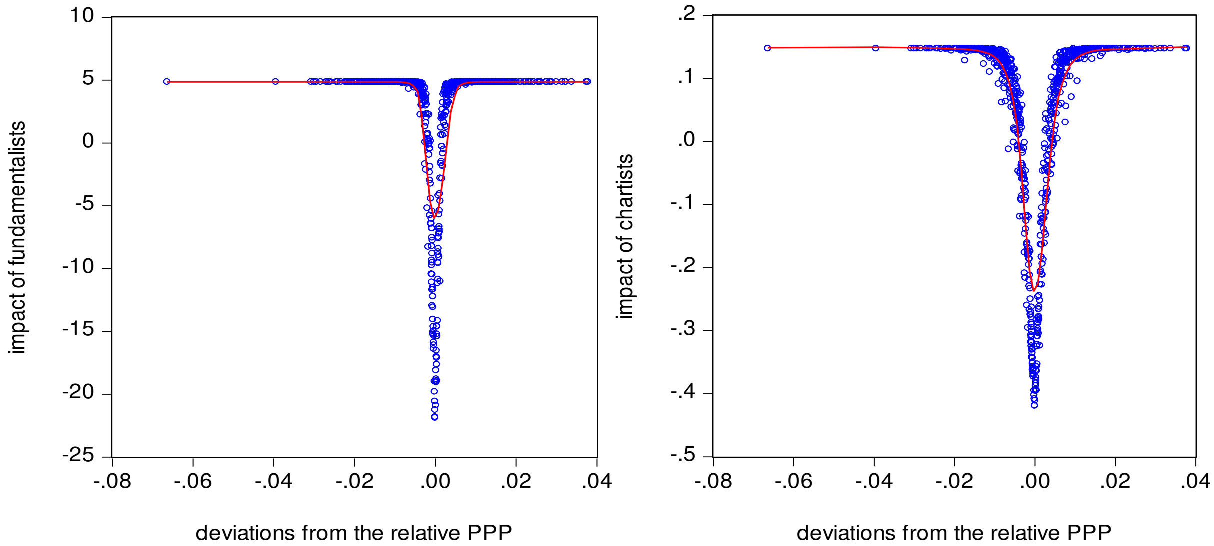
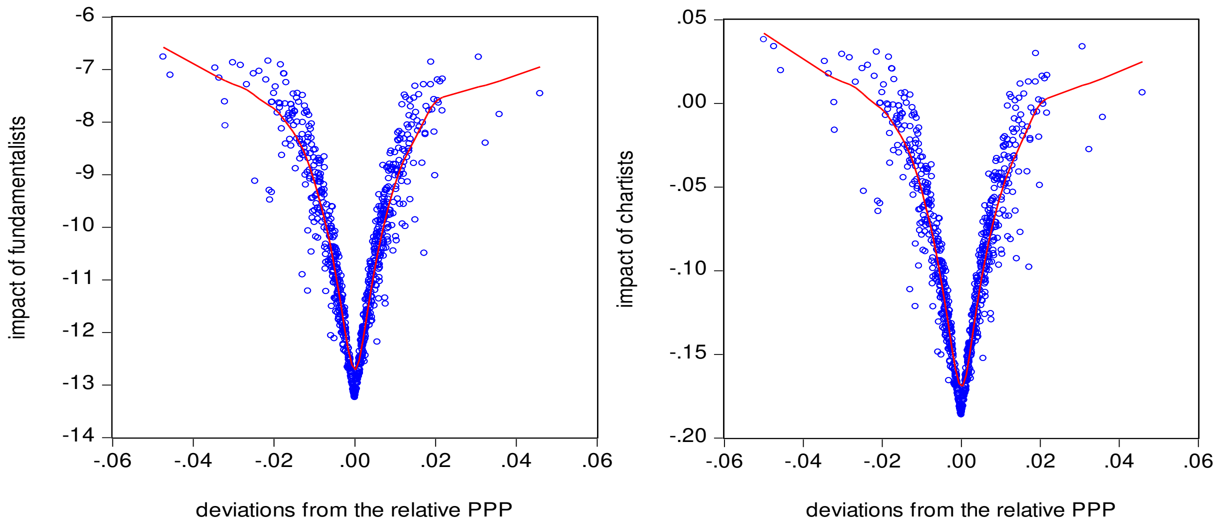


FIGURE 2

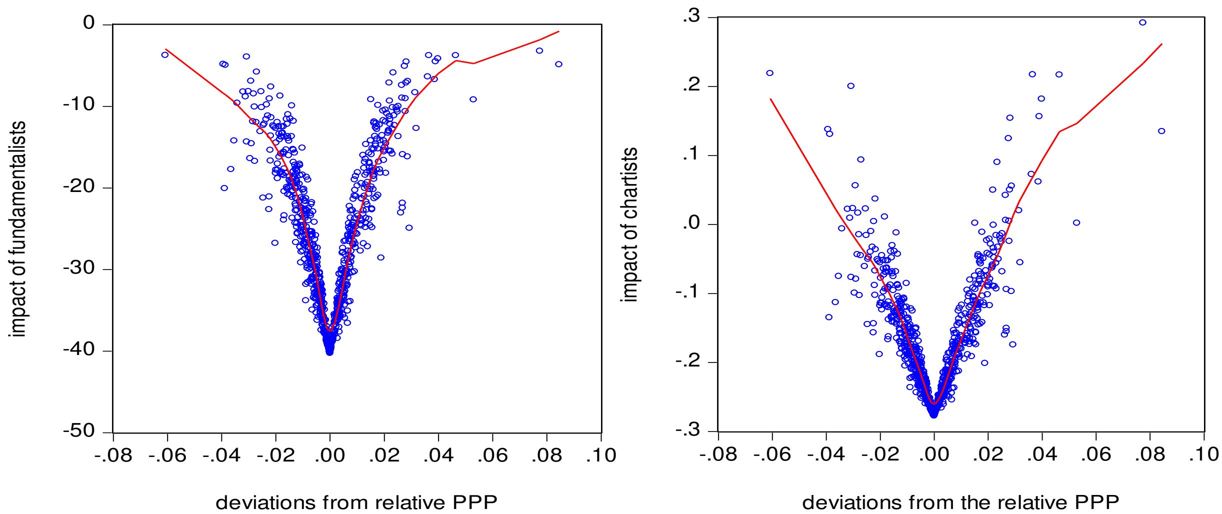
US dollars per euro



GB pounds per euro



JP yens per euro



References

Bollerslev, T., Wooldridge, J.M., (1992). Quasi-maximum likelihood estimation and dynamic models with time-varying covariances. Econometrics Review, 11, 143–172.

Boswijk, H.P., Hommes, C.H., & Manzan, S. (2007). Behavioral heterogeneity in stock prices. Journal of Economic Dynamics and Control, 31, 1938–1970

Brock W.A., Hommes C.H., (1997). A Rational Route to Randomness. Econometrica, 65: 1059-1095.

Brock W.A., Hommes C.H., (1998). Heterogeneous beliefs and routes to chaos in a simple asset pricing model. Journal of Economic Dynamics and Control, 22, 1235-1274.

Chia, W.-M., Li, M., & Zeng, H. (2014). Regime Switching Models in the Foreign Exchange Market, in Nonlinear Economic Dynamics and Financial Modelling, in Dieci, R., He, X.-Z., & Hommes, C. eds., Springer, Heidelberg, 201-224.

Chiarella, C., He, X., Huang,W., & Zheng, H. (2012). Estimating behavioural heterogeneity under regime switching. Journal of Economic Behavior and Organization, 83, 446–460.

DeGrauwe, P., Vansteenkiste, I. (2007). Exchange rates and fundamentals: a non-linear relationship? International Journal of Finance and Eonomics, 12, 37–54.

de Jong, E., Verschoor, W., & Zwinkels, R. (2010). Heterogeneity of agents and exchange rate dynamics: Evidence from the EMS. Journal of International Money and Finance, 29, 1652– 1669.

Eitrheim, Ø., Teräsvirta, T. (1996). Testing Adequacy of smooth transition autoregressive models. Journal of Econometrics, 74, 59-75.

Ellen ter, S., Verschoor, W., & Zwinkels, R. (2013). Dynamic expectation formation in the foreignexchange market. Journal of International Money and Finance, 37, 75–97.

Ellen ter, S., Verschoor, W., & Zwinkels, R. (2016). Agreeing on disagreement. Heterogeneity or uncertainty, Nordes Bank Research, WP, 4/2016.

Frankel, J., Froot, K. (1986). Understanding the US dollar in the eighties: the expectations of chartists and fundamentalists. Economic Record, The Economic Society of Australia, 24–38 (Reprinted in NBER Reprints, 1987, No. 0957).

Frenkel, M., Rulke, J.C., Stadtmann, G. (2009). Two currencies one model? Evidence from the Wall Street Journal forecast poll. Journal of International Financial Markets, Institutions and Money, 19, 588-596

Flaschel, P., Hartmann, F., Malikane, C., & Proaño C.R. (2015). A Behavioral Macroeconomic Model of Exchange Rate Fluctuations with Complex Market Expectations Formation, Computational Economics, 45, 669–691.

Kao C.-W, Wan J.-Y. (2012). Heterogeneous behaviors and the effectiveness of central bank intervention in the yen/dollar exchange rate market. Applied Financial Economics, 22, 967-975.

Kao C.W., Kleykamp D., & Wan J.Y. (2015). Nonlinear Oil Price Dynamics and the Impact of Heterogeneous Agents. Available on the web http://scholar.google.it/scholar?hl=it&as_sdt=0,5&q=Kao+kleykamp

Lof, M. (2012). Heterogeneity in stock prices: A STAR model with multivariate transition function. Journal of Economic Dynamics and Control, 36, 1845–1854.

Luukkonen R., Saikkonen, P., & Teräsvirta T. (1988). Testing Linearity against Smooth Transition Autoregressive Models, Biometrika, 75, 491-499.

Manzan, S., Westerhoff, F. (2007). Heterogeneous expectations, exchange rate dynamics and predictability. Journal of Economic Behavior and Organization, 64, 111–128.

Menkhoff, L., Rebitzky, R., & Schroder, M. (2009). Heterogeneity in exchange rate expectations: Evidence on the chartist-fundamentalist approach. Journal of Economic Behavior and Organization, 70, 241–252.

Reitz, S., Taylor, M. (2008). The coordination channel of foreign exchange rate intervention: a nonlinear microstructural analysis. European Economic Review, 52, 55-76.

Sarno, L., Taylor, M., 2002. The Economics of Exchange Rates. Cambridge University
Press, Cambridge.

Shleifer A., Vishny, R. (1997). The limits of arbitrage. Journal of Finance, 52, 35-55.

Prat, G., Unctum, R., (2015). Expectation formation in the foreign exchange market: a time-varying heterogeneity approach using survey data. Applied Economics, 47, 3673-3695.

Teräsvirta, T. (1994.a). Specification, Estimation, and Evaluation of Smooth Transition Autoregressive Models, Journal of the American Statistical Association, 89: 208-218.

Teräsvirta, T. (1994.b). Testing linearity and modelling nonlinear time series. Kybernetika, 30, 319-330.

Vogelsang, T., Perron, P. (1998). Additional tests for a unit root allowing for a break in the trend function at an unknown time. International Economic Review, 39, 1073-1100.

Wan J.-Y., Kao C.-W. (2009). Evidence on the Contrarian Trading in the Foreign Exchange Markets, Economic Modelling, 26, 1420-1431.

Westerhoff, F.H. (2004). Multiasset Market Dynamics, Macroeconomic Dynamics, 8, 596-616.

Westerhoff, F., Reitz, S. (2005). Commodity price dynamics and the nonlinear market impact of technical traders: Empirical evidence for the US corn market. Physica A: Statistical Mechanics and its Applications, 349, 641–648.