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Nonlinearities and Cyclical Behavior: The Role of Chartists and Fundamentalists

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Abstract

We develop a behavioral exchange rate model with chartists and fundamentalists to study cyclical behavior in foreign exchange markets. Within our model, the market impact of fundamentalists depends on the strength of their belief in fundamental analysis. Estimation of a STAR GARCH model shows that the more the exchange rate deviates from its fundamental value, the more fundamentalists leave the market. In contrast to previous findings, our paper indicates that due to the nonlinear presence of fundamentalists, market stability decreases with increasing misalignments. A stabilization policy such as central bank interventions may help to deflate bubbles.

1. Introduction

Recent empirical studies (Sarantis 1999, Taylor and Peel 2000, Taylor et al. 2001, Chortareas et al. 2002) reveal evidence of nonlinear mean reversion in foreign exchange markets. The statistical findings are obtained by applying relatively new nonlinear methods such as the smooth transition autoregressive (STAR) family of models. STAR models imply the existence of two distinct regimes in exchange rates, with potentially different dynamic properties, but the transition between the regimes is smooth. Cyclical motion is also detected on stock markets (Sarantis 2001, Nam et al. 2001, 2002). Sarantis (1999) and Kilian and Taylor (2001) presume that agent heterogeneity may be a cause for nonlinear mean reversion in the price process.

Interactions between chartists and fundamentalists may indeed generate cyclical dynamics. In Day and Huang (1990), Chiarella (1992), Chiarella et al. (2002) and Farmer and Joshi (2002), heterogeneous traders rely on nonlinear trading rules to determine their orders. Frankel and Froot (1986), Kirman (1991), Brock and Hommes (1998) and Lux and Marchesi (1999) derive nonlinearities by the traders´ switching between technical and fundamental forecast rule. Which kind of predictor an agent applies depends on past realized profits and on social interactions. According to the chartist-fundamentalist approach, the price process is therefore not only driven by exogenous news, but is at least partially due to an endogenous nonlinear law of motion. These theoretical models have shown considerable success in replicating the stylized facts of financial markets such as excess volatility, fat tails for the distribution of the returns, and volatility clustering.

Our paper aims at relating both strands of the literature more closely. We present a simple behavioral model with chartists and fundamentalists to explore nonlinearities and cyclical movements in exchange rates. To be precise, agents rely on linear trading rules and the market impact of chartists is fixed. However, the strength of fundamental trading varies over time. Estimation of the model using daily data for the major currencies vis-á-vis the US dollar demonstrates that if the exchange rate disconnects from its fundamental value, fundamentalists lose their confidence in the usefulness of their trading rule and consequently abstain from trading. Put differently, if the distance between the exchange rate and its fundamental value decreases – as predicted by fundamental analysis – they re-enter the market.

Overall, our model indicates that foreign exchange markets become increasingly unstable during bubbles. The diminishing force of fundamentalists alone may not suffice to bring exchange rates back in line. Our paper may thus help explain the lasting misalignment of the US dollar in the mid 1980s. Exogenous shocks are necessary to end a bubble. Such an impulse may, however, be triggered by central bank interventions.

The remainder of this paper is organized as follows. In section 2, we develop a simple chartist-fundamentalist model. Section 3 presents empirical analysis of three daily US dollar exchange rates. The final section concludes the paper.

2. The Model

Exchange rates are determined on an order-driven market. Demand for currency is expressed in terms of market orders, that is, traders ask for an immediate transaction at the best available price. All orders are filled by market makers at an exchange rate that is shifted from the previous exchange rate by an amount that depends on the excess demand. Following Farmer and Joshi (2002), we assume a log-linear price impact function

$$S_{t+1} = S_t + a^M(D_t^C + W_t D_t^F) + \varepsilon_t\,, \tag{2.1}$$

where S_t is the log of the exchange rate at time t and a^M is a positive reaction coefficient of the market maker. The excess demand is given as the sum of the orders of chartists D_t^C and fundamentalists D_t^F. The transactions of fundamentalists are weighted by their market impact W_t. According to (2.1), buying drives the exchange rate up and selling drives it down. The noise term ε_t captures all additional perturbations that may affect the market maker´s price setting decision.

Survey studies such as Taylor and Allen (1992) confirm that professional foreign exchange traders rely on technical and fundamental analysis to determine their orders. Technical trading rules aim at identifying trading signals out of past price movements (Murphy 1999). Technical analysis suggests buying (selling) when prices increase (decrease). The excess demand of chartists may be approximated as

$$D_t^C = a^C(S_t - S_{t-1})\,, \tag{2.2}$$

where a^C is a positive reaction coefficient. Spurgin (1999) and Lequeux and Acar (1998) point out that leverage currency fund managers tend to be trend-followers too.

Fundamental analysis presumes that exchange rates converge towards their fundamental values. The excess demand of fundamentalists may be expressed as

$$D_t^F = a^F(F_t - S_t)\,, \tag{2.3}$$

where a^F is a positive reaction coefficient and F stands for the log of the fundamental value. According to Xu (2001) and Euromoney (2003) such behavior is quite common among fund managers. Hawker (2002) reports that buying (selling) undervalued (overvalued) currencies – as measured by the Bic Mac Index – may generate positive trading returns. Note that excess demand functions such as (2.2) and (2.3) are regularly employed in theoretical models to characterize the behavior of traders (Hommes 2001).

The evolution of the fundamental value is due to the news arrival process. Its log follows an arithmetic Brownian motion

$$F_{t+1} = F_t + \eta_t\,. \tag{2.4}$$

News incorporated in η_t is iid Normal with mean zero and time invariant variance.

Our setting is novel in the way we model the market impact of fundamentalists. We assume that there exists a pool of latent agents who may use fundamental analysis. The number of these agents engaged in trading depends on their confidence in fundamental analysis. Two aspects are relevant. First, if the distance between the exchange rate and its fundamental value increases, fundamental analysis wrongly predicts the sign of the exchange rate change. In such a situation, the agents disregard fundamental analysis. Conversely, if misalignments decrease, fundamental analysis delivers correct predictions and regains its popularity. Second, misalignments are conditioned on volatility. If exchange rate fluctuations decline, fundamentalists expect mean reversion to be less likely (adjustments without volatility are, of course, impossible).

Putting the arguments together, we formalize the belief function as

$$B_t = -\varphi \frac{|F_t - S_t|}{\sigma_t^S}. \quad (2.5)$$

Since, $\varphi > 0$, B_t is bounded between $-\infty$ and 0. The belief function reaches its maximum at $F = S$. In a high volatility regime, measured by the conditional exchange rate standard deviation σ_t^S, a given departure $|F-S|$ leads to a low loss of confidence in fundamental analysis and vice versa. Let us normalize the belief function into market shares

$$W_t = \frac{2Exp[B_t]}{1 + Exp[B_t]}, \quad (2.6)$$

with $0 \leq W \leq 1$. The market impact of fundamentalists obviously increases in B. The fraction of agents who abstain from trading is given by $(1-W)$.

Combining (2.1)–(2.6), the solution for the exchange rate is

$$S_{t+1} = S_t + \alpha(S_t - S_{t-1}) + \delta W_t (F_t - S_t) + \varepsilon_t, \quad (2.7)$$

where $\alpha = a^M a^C$ and $\delta = a^M a^F$.

Before we turn to the econometric part of this paper, let us briefly clarify the impact of the fundamentalists on the dynamics. The left-hand side panel of figure 1 shows the fundamentalists´ market shares as a function of the distance between the exchange rate and its fundamental value for different values of φ. The higher φ, the more quickly the agents abstain from trading as the distance between the exchange rate and its fundamental value increases (from top to bottom: φ=0.02, φ=0.05, φ=0.08).

In such a situation, the fundamental trading rule simultaneously suggests to take a larger position. So, what is the joint impact of the fundamentalists? The right-hand side panel of figure 1 displays the product of the market shares and the demand generated by the fundamental trading rule (again from top to bottom: φ=0.02, φ=0.05, φ=0.08). As can be seen, the effective demand first increases, but then drops again. Clearly, if no fundamentalist remains in the market, their demand becomes zero. Note that the lower φ, the stronger is the stabilizing impact of the fundamentalists.

In how far the fundamentalists are indeed able to stabilize foreign exchange markets is an econometric question, which will be explored in the next section.

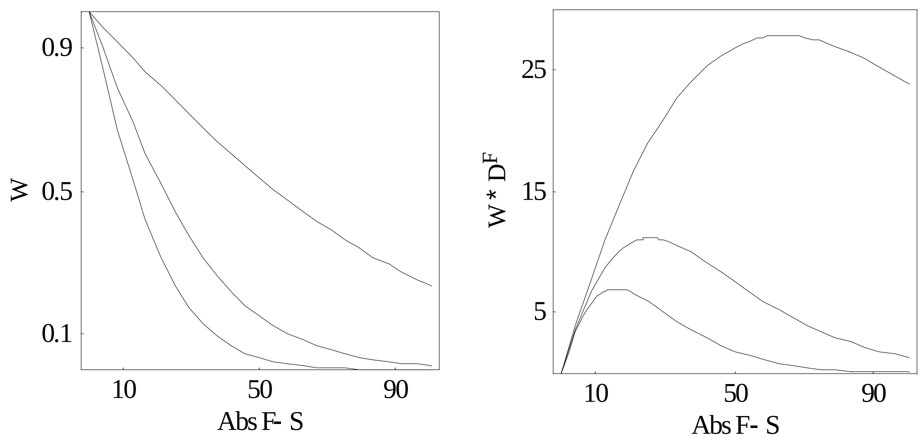

Figure 1: The impact of the fundamentalists. The left-hand side panel shows the market shares of active fundamentalists as a function of the distance between the exchange rate and its fundamental value for different values of φ. From top to bottom: $\varphi=0.02$, $\varphi=0.05$, $\varphi=0.08$. The right-hand side panel displays the product of the market shares and the demand generated by the fundamental trading rule. From top to bottom: φ=0.02, φ=0.05, φ=0.08. We set $a^F=1$ and $\sigma^S=1$.

3. Specification and Estimation of the Model

3.1 Specification of the model

The aim of this section is to investigate nonlinearities in daily dollar nominal exchange rates on the basis of the above theoretical approach. Our approach belongs to the STAR (Smooth Transition Autoregressive) model family, originally proposed by Teräsvirta and Anderson (1992) and developed further by Granger and Teräsvirta (1993) and Teräsvirta (1994). These models have been applied to quarterly and monthly exchange rates by Sarantis (1999), Kilian and Taylor (2000), Taylor and Peel (2000) and Taylor et al. (2001). These show nonlinear mean reversion of the real exchange rate and provide superior performance in an out-of-sample context compared to the random walk benchmark and other competing approaches such as the Markov switching model.

In order to examine the empirical evidence of the chartist-fundamentalist model outlined in section 2, we use daily data, implying that the conditional variance of exchange rate returns cannot be treated as constant over time. To cope with the heteroskedastic properties of daily exchange rate returns we apply the STAR GARCH procedure developed by Lundbergh and Teräsvirta (1998).

To be specific, our empirical model consists of a mean equation containing a smooth transition variable and a standard GARCH(1,1) volatility equation:

$$\Delta S_t = \alpha \Delta S_{t-1} + \left[\delta\left(F_{t-1} - S_{t-1}\right)\right] W\left(\varphi; F_{t-1} - S_{t-1}; h_{t-1}\right) + \gamma ID_t + \varepsilon_t \,, \tag{3.1}$$

$$W\left(\varphi; F_{t-1} - S_{t-1}; h_{t-1}\right) = 2\left\{1 - \left[1 + \exp\left(-\varphi \frac{\left|F_{t-1} - S_{t-1}\right|}{\sqrt{h_{t-1}}}\right)\right]^{-1}\right\} \tag{3.2}$$

$$h_t = \beta_0 + \beta_1 \varepsilon_{t-1}^2 + \beta_2 h_{t-1} \,, \tag{3.3}$$

where $\varepsilon_t = \nu_t \cdot \sqrt{h_t}$ and $\nu_t \overset{iid}{\sim}$ N(0,1). Remember that the parameter α in (3.1) stands for the time invariant impact of the chartists. Due to the interest parity condition, a significant fraction of daily exchange rate changes might be explained by changes of the interest differential. Since this is clearly not a matter of chartist and fundamentalist speculation, the mean equation is augmented by the interest differential ID_t. The relative number of fundamentalists who are engaged in trading $W(\varphi; F_{t-1} - S_{t-1}; h_{t-1})$ is bounded between zero and unity and depends on the transition variable $|F_{t-1} - S_{t-1}| / \sqrt{h_{t-1}}$. The transition parameter φ is a slope parameter and determines the speed of transition between the two extreme regimes, with low absolute values of φ resulting in slower transition. Remember that for $\varphi = 0$, all fundamentalists enter the market and when $\varphi \to \infty$, $W(\varphi; F_{t-1} - S_{t-1}; h_{t-1})$ becomes a step function. Since (3.2) is a linear transformation of the standard logistic transition function proposed by Teräsvirta and Anderson (1992), robust standard errors may be derived. To capture heteroskedasticity in daily exchange rate returns we specify the conditional volatility as a standard GARCH(1,1) process.

3.2 Data description

We use daily spot US dollar exchange rates against the British pound (BP), the German mark (DM), and the Japanese yen (YEN) over the period from 1980:1:1 to 1996:12:31 to calculate percentage exchange rate returns as $100\Delta(S_t)$.[1] Table 1 provides some descriptive statistics showing standard properties of exchange rate returns such as skewness and excess kurtosis.

The interest differential at time t is calculated as $ID_t = log(1+i_t) - log(1+i_t^*)$, where i_t is the daily overnight US dollar interest rate and i_t^* is the daily overnight interest rate of the BP, DM and YEN, respectively. We assume that the fundamental value can be described by purchasing power parity (ppp). Taylor and Allen (1992) provide evidence from survey data that foreign exchange market participants in fact accept ppp as a valid relationship in the long run. Monthly observations of consumer price indices (cpi) for the US, the UK, Germany and Japan were taken from the International Monetary Fund's International Financial Statistics database to construct ppp as $log\,(cpi^*) - log\,(cpi^{US})$. We transform ppp data to the daily frequency, taking the observed value for the entire month, which seems to be compatible with the information environment of a market participant in a daily trading context.[2] The (log) exchange rate and the cpi series were normalized on values of 1990:01:02, assuming that ppp holds at the beginning of the 1990s. However, to adjust the model for a possible misleading normalization of the data we estimate a shift parameter θ, so that $F_t = ppp_t - \theta$. For the sake of parsimony

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[1] The price of one US dollar is in units of foreign currency. We thank Christopher Neely for making the data set available.

[2] To check whether or not the estimation results are driven by this simplifying assumption we experimented with interpolated data. According to standard unit root tests, the ppp values have also been interpolated as an I(1) process. However, the estimation results do not change significantly.

we decided on the basis of likelihood ratio tests (5 percent level) to remove a statistically insignificant parameter θ from the estimation equation.

Table 1: Summary statistics of the dollar spot exchange rate returns (in percent) from 1980:01:02 to 1996:12:31.

	BP	DM	YEN
Observations	4431	4431	4431
Mean	0.006	–0.002	–0.016
Standard deviation	0.668	0.688	0.641
Skewness	0.065 (0.08)	–0.129 (0.00)	–0.382 (0.00)
Excess Kurtosis	3.083 (0.00)	2.143 (0.00)	2.957 (0.00)
Lbq(1)	14.52 (0.00)	4.98 (0.03)	4.66 (0.03)
Lbq(2)	16.91 (0.00)	5.61 (0.06)	5.45 (0.06)
Lbq(3)	17.10 (0.00)	6.10 (0.11)	7.14 (0.07)
Lbq(4)	17.19 (0.00)	6.33 (0.18)	8.01 (0.09)
Lbq(5)	24.26 (0.00)	8.79 (0.12)	9.64 (0.09)
$Lbq^2(1)$	44.49 (0.00)	52.58 (0.00)	24.63 (0.00)
$Lbq^2(2)$	94.74 (0.00)	83.01 (0.00)	42.70 (0.00)
$Lbq^2(3)$	140.81 (0.00)	118.46 (0.00)	86.58 (0.00)
$Lbq^2(4)$	211.45 (0.00)	145.29 (0.00)	94.26 (0.00)
$Lbq^2(5)$	259.45 (0.00)	185.60 (0.00)	118.39 (0.00)
JB	1759 (0.00)	861 (0.00)	1722 (0.00)

Notes: Lbq(L) and $Lbq^2(L)$ denote the Ljung Box-Q statistics for the returns and the squared returns, respectively. JB denotes the Jarque Bera test statistic. p-values are in parantheses.

3.3 Estimation results and interpretation

We use RATS 5.0 programming for the quasi maximum likelihood estimation method. Since the assumption of conditional normality cannot be maintained, robust estimates of the covariance matrices of the parameter estimates are calculated using the BFGS algorithm. Under fairly weak conditions, the resulting estimates are even consistent when the conditional distribution of the residuals is non-normal (Bollerslev and Wooldridge 1992). Teräsvirta (1994) points out that estimating the transition parameter φ may cause particular problems such as slow convergence of the estimation routine or overestimation. However, the recommended rescaling of the transition variable by means of the conditional standard deviation is already introduced due to theoretical considerations. On the basis of this standardization, we set $\varphi = 1$ as a starting value for the estimation routine.[3]

The estimation results in table 2 are quite similar to each other, indicating that the specified model is robust when applied to different exchange rates. The parameter of the interest differential is statistically significant at the one percent level in either case, but of the wrong sign with respect to the interest parity condition. For the period under consideration, this is a familiar result in the empirical finance literature (Lewis 1995). Concerning the shift parameter θ the data normalization on the basis of 1990 values seems to be appropriate in the case of the BP and the DM. For the dollar/yen exchange rate, in contrast, the estimated fundamental value is significantly lower than ppp on the basis of 1990 values.

We now turn to the central question as to whether there is evidence in favor of chartist- and fundamentalist-driven exchange rate dynamics. The answer is given by the likelihood ratio test statistics and the t – statistics of the respective parameter estimates. To provide likelihood ratio test statistics we also estimate the above model, restricting the chartist and fundamentalist parameters to zero, i.e. $\alpha = \delta = \varphi = 0$. The resulting test statistics reported in the last line of table 2. They show that the introduction of chartist and fundamentalist parameters increase the log likelihood with significance levels of one percent in the case of the DM and the YEN, but only at the ten percent level in the case of the BP.

The chartist and fundamentalist coefficients are of the correct sign and are statistically significant at least at the five percent level, except for chartist trading in the dollar/yen market and fundamentalist trading in the dollar/BP market. Statistically significant estimates of φ point to moderate transition between regimes in the case of Germany and Japan. Traders in the dollar/BP market change their confidence in fundamental analysis more quickly to observed departures of the exchange rate from ppp.

This is also visible in figure 2, which displays the dynamics of confidence in fundamental analysis measured as the relative number of fundamentalists in the foreign exchange market. In fact, the market impact of fundamentalists in the dollar/BP markets switches back and forth quite rapidly whereas in the dollar/DM and the dollar/YEN market the strength of fundamentalists varies more slowly. Note that the strong dollar appreciation against all other currencies was

[3] Experimentation showed that the results reported in the text are robust with respect to various starting values.

accompanied by a deep fall of confidence in ppp as a proxy for the fundamental exchange rate. Less than ten percent of potentially active fundamentalists were in the market when the dollar peaked in mid 1985.

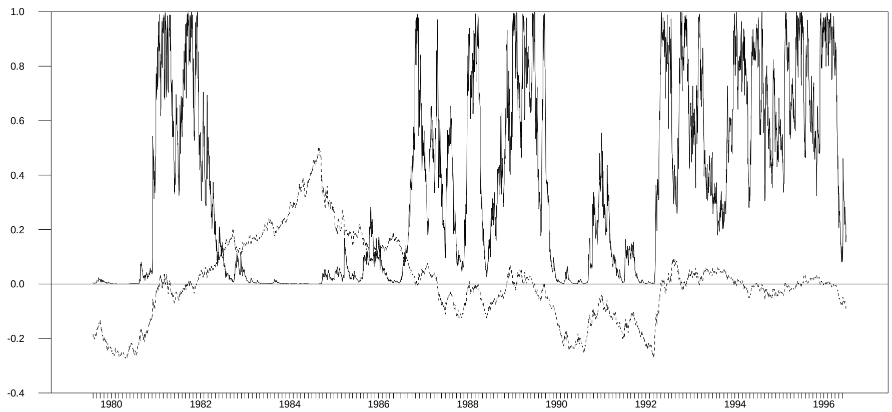
To sum up, one may conclude that estimation results provide support for the heterogeneous agents approach outlined in section 2.

Table 2: Parameter estimates of (STAR) GARCH models for the dollar spot exchange rate of the BP, DM, and YEN (1980 – 1996).

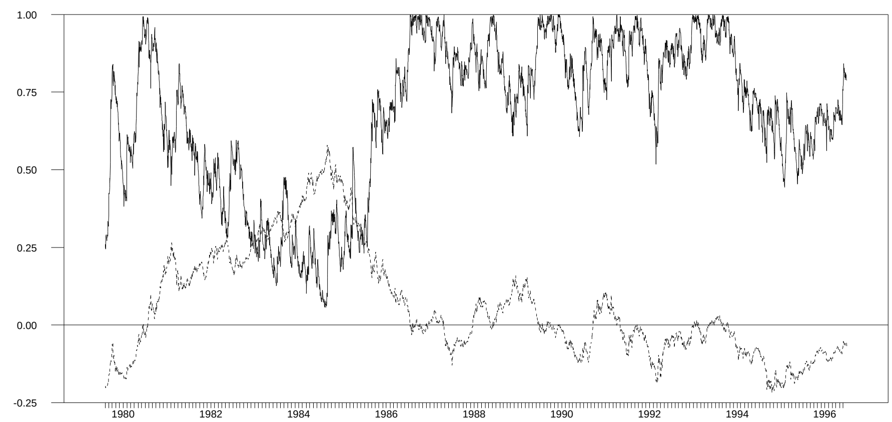
	BP	**DM**	**YEN**
γ	2.61 (2.73)***	3.03 (3.30)***	2.71 (3.58)***
α	0.04 (2.36)**	0.03 (2.37)**	0.02 (1.87)*
δ	0.019 (1.78)*	0.004 (2.34)**	0.004 (2.26)**
θ	–	–	27.02 (3.20)***
φ	0.172 (2.48)**	0.035 (2.34)**	0.021 (3.17)***
β_0	0.004 (2.71)***	0.011 (4.03)***	0.013 (2.67)***
β_1	0.047 (6.22)***	0.069 (7.93)***	0.052 (4.54)***
β_2	0.945 (101.9)***	0.909 (79.47)***	0.916 (41.64)***
LLh	– 112.13	– 313.53	– 82.64
LRT	6.92*	21.18***	17.82***

Notes: The sample contains daily observations of the dollar spot exchange rate against the DM, the BP and the YEN from January 1980 to December 1996. α, δ, γ, θ, indicate the estimated parameters of the mean equations (in percent), β_0, β_1, and β_2 are the estimated GARCH(1,1) parameters (in percent), LLh is the log likelihood value and LRT the likelihood ratio test statistic with restrictions $\alpha = \delta = \varphi = 0$. t-statistics in parentheses are based on robust estimates of the covariance matrices of the parameter estimates. * (**, ***) denotes significance at the 10% (5%, 1%) level.

United Kingdom *(1990:01:02 = 0)*:



Germany *(1990:01:02 = 0)*:



Japan *(1990:01:02 = 0.27)*:

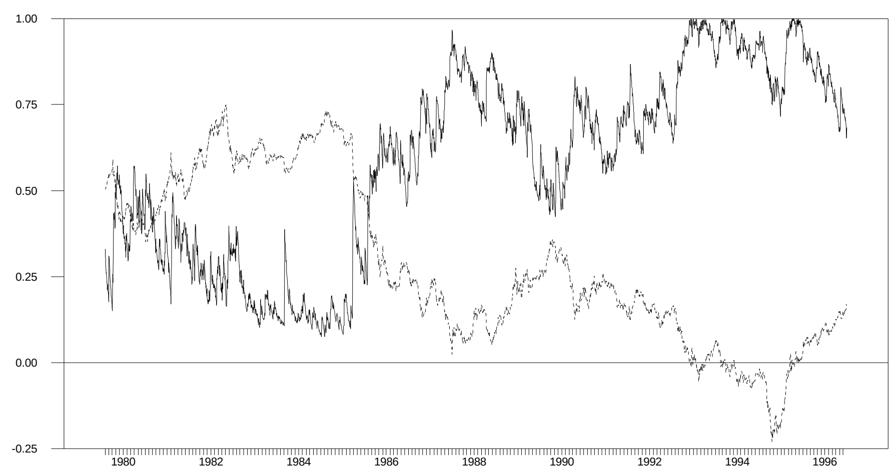


Figure 2: Log dollar real exchange rates and relative number of fundamentalists. Daily data form 1980:01:02 to 1996:12:31.

3.4 Diagnostics

We perform diagnostics with the Ljung-Box Q tests on the standardized residuals and the squared standardized residuals from each of the three exchange rates. The Ljung-Box Q statistics AR(p) in table 3 check serial correlation in the standardized residuals, while the ARCH(p) statistics check serial dependence in the conditional variance.

The reported p-values indicate that the model is able to capture the serial dependence of the conditional mean and variance process. However, the diagnostics reveal a familiar problem in STAR GARCH models. In the case of the DM and the BP, the Jarque Bera test statistic of the standardized residuals is indeed lower than those of the raw returns, but still indicate a persisting nonnormality. In the case of the YEN it is even slightly higher (Lundbergh and Teräsvirta, 1998).

Table 3: Estimation diagnostics.

	BP	**DM**	**YEN**
AR(1)	0.68 (0.41)	0.66 (0.41)	0.39 (0.53)
AR(2)	3.17 (0.20)	1.88 (0.39)	1.33 (0.51)
AR(3)	3.49 (0.32)	2.88 (0.41)	4.62 (0.20)
AR(4)	3.69 (0.45)	5.27 (0.26)	5.34 (0.25)
AR(5)	6.63 (0.25)	8.52 (0.13)	7.38 (0.19)
ARCH(1)	0.19 (0.66)	0.00 (0.97)	0.52 (0.47)
ARCH(2)	0.49 (0.78)	2.16 (0.34)	0.59 (0.74)
ARCH(3)	2.30 (0.51)	2.16 (0.54)	2.89 (0.41)
ARCH(4)	2.64 (0.62)	3.69 (0.45)	4.88 (0.30)
ARCH(5)	3.26 (0.66)	4.22 (0.52)	5.45 (0.36)
JB	712 (0.00)	411 (0.00)	1750 (0.00)

Notes: AR(p) denotes the Ljung-Box statistic for serial correlation of the residuals out to p lags. ARCH(q) denotes the Ljung-Box statistic for serial correlation of the standardized squared residuals out to q lags. JB denotes the Jarque Bera test statistic. p-values are in parantheses.

4 Conclusions

We present a simple nonlinear exchange rate model with chartists and fundamentalists to study nonlinear mean reversion in foreign exchange markets. Within our model, the market impact of fundamentalists depends on the strength of their belief in fundamental analysis. Empirical evidence is provided, applying a

STAR GARCH model to daily US dollar spot exchange rates against the German mark, the British pound and the Japanese yen. Statistically significant parameter estimates of the transition variable show that the more the exchange rate deviates from purchasing power parity (ppp), the lower the remaining number of fundamentalists in the foreign exchange market. Put differently, if the exchange rate converges towards the ppp value – as predicted by fundamental analysis – fundamentalists re-enter the market. The loss of confidence in ppp is accelerated when low conditional volatility makes mean reversion appear more unlikely.

Our results throw some doubt on the often presumed stabilizing impact of fundamentalists on exchange rates (see also the argument put forward in De Long et al. 1990). Fundamentalists leave the market as distortions grow. Instead of countering the activity of chartists, mean reversion pressure weakens so that bubbles may gain additional momentum. Indeed, we observe strong and persistent periods of misalignments.

Our model suggests that by breaking a destabilizing exchange rate trend via interventions, a central bank may encourage fundamental trading again. This hypothesis may be tested in a simulation analysis. Given the fact that our model is supported by the data, one may even expect to obtain reasonable results from such an exercise. We think that such an analysis could be a promising line for future research.

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