Nonlinear Mean Reversion in Real Exchange Rates: Evidence from Developing and Emerging Market Economies

Mario Cerrato
London Metropolitan University

Nick Sarantis
London Metropolitan University

Abstract

We provide evidence on nonlinear mean reversion in the real exchange rates of developing and emerging market economies, using recently developed nonlinear unit root tests and a unique set of monthly data on black market exchange rates.

Citation: Cerrato, Mario and Nick Sarantis, (2006) "Nonlinear Mean Reversion in Real Exchange Rates: Evidence from Developing and Emerging Market Economies." *Economics Bulletin,* Vol. 6, No. 7 pp. 1-14
Submitted: March 29, 2006. **Accepted:** June 12, 2006.
URL: http://economicsbulletin.vanderbilt.edu/2006/volume6/EB-06F30004A.pdf

1. Introduction

The long-run PPP relationship remains the major building block of almost all theoretical open-economy macroeconomic models. However, the extensive empirical evidence against real exchange rate stationarity and hence the long-run PPP both for developed and developing economies (e.g. Sarno and Taylor, 2002; Cerrato and Sarantis, 2003), has proved an awkward puzzle for economists. Over the recent years, a number of researchers have argued that the failure to find mean reversion in real exchange rates may be due to the presence of nonlinearities in the data generating process for the real exchange rate which are ignored by the standard statistical tests. These nonlinearities can arise from transaction costs (e.g. Dumas, 1992; Sercu *et al*, 1995; Goswami *et al*, 2002), diversity in agents' beliefs (e.g. Brock and Holmes, 1998; De Grauwe and Grimadi, 2004), or heterogeneity in investors' objectives and investment horizons (e.g. Guilaume *et al* 1995).

A few papers have uncovered significant nonlinear real exchange rate behaviour (e.g. Michael, *et al*, 1997; Sarantis, 1999; Baum *et al*, 2001; Taylor *et al,* 2001; Liew *et al*, 2003). However, these papers assume that the series (or their differences) are stationary when testing the linearity hypothesis, so they do not investigate formally the interaction between nonstationarity and nonlinearity. In two recent papers, Sollis *et al* (2002) and Kapetanios *et al* (2003) address this issue by developing formal unit root tests against the alternative of nonlinear mean reversion. Sollis *et al* (2002) apply their test to real exchange rates against the US dollar for 17 OECD countries and find nonlinear mean reversion in 6 countries. The Kapetanios *et al* test has been applied to the real exchange rates of few industrial countries (Kapetanios *et al*, 2003) and Asian countries (Chortareas and Kapetanios, 2004; Liew, *et al*, 2004) with supportive results.

Our paper makes two important contributions to this nonlinear exchange rate literature. First, we apply for the first time both these newly developed nonlinear unit root tests to a large number of developing and emerging market economies. Second, we use a unique set of monthly data on black market real exchange rates that has not been used previously in the literature on nonlinear exchange rate adjustment[1]. In developing and emerging market economies, fixed exchange rate systems combined with foreign trade restrictions, capital controls, high inflation and external deficits have led to the development of thriving black markets for foreign exchange (see, Agenor, 1992; Kiguel and O'Connell, 1999). So these black markets play an important role in the economies of those countries and one could argue that the black market exchange rate reflects the true value of domestic currency much better than the official exchange rate in these countries. Reinhart and Rogoff (2004) have recently used the data on black market exchange rates for constructing a new historical classification of exchange rate regimes in the global economy.

The paper is organised as follows. The nonlinear unit root tests employed are outlined in Section 2. Sections 3 and 4 discuss the data and empirical results, while Section 5 summarises the major findings.

2. Nonlinear Unit Root Tests

Sollis *et al* (2002) and Kapetanios *et al* (2003) have developed new tests for mean reversion in time series based on smooth transition autoregressive (STAR) models. In both papers, the unit root null hypothesis is tested against the nonlinear STAR alternative. The major difference between the two tests is that Sollis *et al* (2002) use a

[1] Data for black market exchange rates have been used by a few studies for investigating the PPP hypothesis (see Cerrato and Sarantis, 2003, and references cited there), but none of these applied nonlinear tests or covered so many countries and time span.

logistic transition function, while Kapetanios *et al* (2003) use an exponential transition function.

2.1 Sollis et al (2002)

The authors develop tests for both symmetric and asymmetric STAR models. The symmetric LSTAR model is given by

$$\Delta y_t = \alpha S_t(\gamma, y_{t-d}) y_{t-1} + \sum_{i=1}^{k} \beta_i \Delta y_{t-i} + \varepsilon_t \tag{1}$$

$$S_t(\gamma, y_{t-d}) = \{1 + \exp(-\gamma^2 y^2_{t-d})\}^{-1} - 0.5 \tag{2}$$

where y_t is the de-meaned time series, d is the delay parameter that is assumed to be equal to one, equation (2) is the logistic transition function, and the parameter γ^2 determines the speed of mean reversion as y^2_{t-d} increases (that is, the further the time series is from its mean).

To allow for asymmetry in the mean reversion process, equations (1) and (2) are replaced by (3) and (4) respectively:

$$\Delta y_t = \alpha S_t(\gamma_1, \gamma_2, y_{t-d}) y_{t-1} + \sum_{i=1}^{k} \beta_i \Delta y_{t-i} + \varepsilon_t \tag{3}$$

$$S_t(\gamma_1, \gamma_2, y_{t-d}) = [1 + \exp\{-\gamma_1^2 y^2_{t-d} I_t - \gamma_2^2 y^2_{t-d}(1 - I_t)\}]^{-1} - 0.5 \tag{4}$$

where I_t is the Heaviside indicator defined as

$$I_t = 1 \text{ if } y_{t-1} \succ o \text{, and } I_t = 0 \text{ if } y_{t-1} \leq o \quad (5)$$

The asymmetric LSTAR model allows for different mean reversion behaviour depending on whether the real exchange rate is above or below its mean[2].

The unit root test statistics for the null hypothesis $\mathrm{H}_0 : \alpha = o$, against the symmetric and asymmetric mean reversion alternatives (1) and (3) are denoted by t_S and t_A respectively. These test statistics do not have an asymptotic normal distribution, so the authors use simulations to derive critical values for t_S and t_A for different sample sizes[3].

2.2 Kapetanios et al (2003)

The authors consider the following exponential STAR (ESTAR) model:

$$\Delta y_t = \phi y_{t-1} + \lambda y_{t-1}[1 - \exp(-\theta y^2{}_{t-d})] + \sum_{i=1}^{k} \rho_i \Delta y_{t-i} + \varepsilon_t \quad (6)$$

---

[2] Theoretical models based solely on proportional transport cost (Dumas, 1992) predict a symmetric adjustment process for exchange rates-hence the use of ESTAR models in many papers. However, in models with a transport cost structure that allows for both a proportional cost and economies of scale, and with diverse production technologies and consumer preferences (Goswami *et a*l, 2002), asymmetric behaviour may well arise. Differences between expansions and contractions in the real exchange rate can also be explained by the asymmetries discussed in the business cycle literature; these that could arise, for example, from asymmetric labour adjustment costs or asymmetries in the capital destruction and reconstruction. The literature on the heterogeneity of investors' expectations also implies potential asymmetric behaviour is asset prices (Brock and Holmes, 1998, De Grauwe and Grimadi, 2004). Such behaviour is best characterized by the LSTAR model.

[3] Sollis *et al* (2002) imposed $d = 1$ in the calculation of critical values and their empirical investigation, and this is also adopted in our study.

Where y_t is the de-meaned time series, d is the delay parameter, and θ determines the sped of mean reversion.

The null hypothesis of a unit root implies $\phi = 0$ and $\theta = 0$. Since the parameter λ is not identified under the null, direct testing of the null hypothesis is not feasible. The authors overcome this problem by using a first-order approximation of the ESTAR model to obtain the auxiliary equation[4]

$$\Delta y_t = \delta y^3{}_{t-1} + error \tag{7}$$

or

$$\Delta y_t = \delta y^3{}_{t-1} + \sum_{i=1}^{k} \rho_i \Delta y_{t-i} + error \tag{8}$$

in the case of serially correlated residuals.

The null hypothesis of a unit root becomes $\mathrm{H}_0 : \delta = 0$ against the alternative $\mathrm{H}_1 : \delta \succ 0$. The test statistic for this null hypothesis, denoted *NLADF*, is the *t*-statistic for the OLS estimate $\hat{\delta}$. Since the nonlinear test statistic *NLADF* does not have a standard normal distribution, the authors obtain critical values through stochastic simulations.

3. Data

We employ monthly data on black market exchange rates for a highly heterogeneous panel of thirty-five developing and emerging market countries over the period 1973-1998. These vary from poor developing countries (e.g. Nepal, Ghana) to semi-

---

[4] Note that the authors impose $\phi = 0$ and $d = 1$ in this derivation and, hence, in the calculation of critical values.

industrial countries (e.g. Korea, Mexico), with different growth experiences and quite diverge levels of per capita income The US Dollar is used as numeraire currency. The black market exchange rates are obtained from *Pick's World Currency Yearbook (*various publications). The consumer price index (CPI) is used as the price index in the construction of the real exchange rates. The sample ends in 1998 because of the unavailability of data on black market exchange rates beyond that year. The data used in the estimation are the de-meaned real exchange rates (measured in logs), as required by both nonlinear unit root tests.

4. Empirical Results

To provide a benchmark for our nonlinear results, we first estimated the standard (linear) augmented Dickey-Fuller (ADF) unit root statistics. These estimates are reported in Table 1. The number of lags used in the autoregressive models was chosen by employing the selection criterion suggested by Ng and Perron (1995). The ADF test is unable to reject the null hypothesis of a unit root in thirty out of thirty five countries, thus providing strong evidence against mean reversion in black market real exchange rates. These results are in line with previous evidence for developing and emerging markets obtained from linear (both time series and panel) unit root tests (e.g. Cerrato and Sarantis, 2003).

The estimates of the nonlinear unit root test statistics are shown in Table 2[5]. The picture changes dramatically when we look at the results from the nonlinear unit root tests. The Sollis *et al* (2002) asymmetric statistic (t_A) rejects the null hypothesis of nonstationarity in black market real exchange rates for nineteen countries out of thirty five (12 countries

[5] The Sollis *et al* (2002) nonlinear unit root statistics were estimated with a GAUSS algorithm, while the Kapetanios *et al* (2003) statistics were estimated using the econometric computer program E-Views 4.1.

at the 1% significance level, 3 at the 5% significance level and 4 at the 10% significance level)[6]. The symmetric statistic (t_S) shows that fourteen real exchange rates are stationary at the 1% or 5% level of significance, and 1 at the 10% significance level.

Overall, the t_A tests are more significant than the t_S tests, thus suggesting the presence of significant asymmetry in the mean reversion process for most real exchange rates[7]. Our evidence on nonlinear mean reversion in real exchange rates from developing and emerging market economies is stronger than that obtained from industrial countries by Sollis *et al* (2002)

The Kapetanios *et al* (2003)[8] test rejects the unit root null in eight countries at the 1% significance level, and in six countries at the 5% significance level. The total number of rejections is similar to that obtained with the Sollis *et al* t_S statistic. This is not surprising since both tests assume a symmetric mean reversion process. Our findings for the Asian countries are broadly similar to those reported by Liew *et al* (2004), which were obtained from official exchange rates, except for India, Malaysia, Pakistan and Philippines. The larger number of rejections of the unit root null by the Sollis *et al* (2002) asymmetric test (t_A) seems to provide some support in favour of the logistic (and asymmetric) rather than the exponential STAR mean reversion process in real exchange rates.

---

[6] The evidence for asymmetric mean reversion in real exchange rates is evenly spread across Africa, Asia and Latin America (including Central American countries); i.e. the unit root null hypothesis is rejected in approximately half of the countries included from each continent.

[7] Sollis *et al* (2002) found a similar result. It is interesting to note that evidence of asymmetric adjustment in real exchange rates was also found by Sarantis (1999) and Leon and Najarian (2003) using alternative nonlinear models –but these authors did not apply formal nonlinear unit root tests.

[8] Note that Kapetanios *et al* (2002) and Liew *et al* (2004) fixed the number of lags to 8. We believe that the optimum number of lags should be chosen on the basis of statistical criteria rather than fixed arbitrarily.

5. Conclusion

In this paper we provide for the first time evidence on nonlinear mean reversion in real exchange rates from thirty five developing and emerging market economies, using two newly developed nonlinear unit root tests and a unique set of monthly data on black market exchange rates.

In contrast to the results obtained from the standard linear ADF test, we find that the black market real exchange rate displays significant nonlinear mean reversion behaviour, characterised by the smooth transition autoregressive (STAR) model, in more than half of the thirty-five developing and emerging market economies. This evidence is much stronger than that reported for industrial countries. There is also evidence of significant asymmetries in the mean reversion process for most real exchange rates. Our empirical findings seem to provide more support for the logistic rather than the exponential STAR mean reversion process.

These empirical findings suggest that the exchange rate converges to its long-run PPP level in the majority of developing and emerging market economies, but the convergence path follows a nonlinear STAR process. Our results also imply that the linear methods employed in the literature for estimating half-life deviations from PPP might be inappropriate when the mean reversion process is nonlinear.

References

Agenor, P. R., 1992, *Parallel Currency Markets in Developing Countries: Theory, Evidence and Policy Implications*. Essays in International Finance No 188, Princeton University, Princeton, N. J.

Baum, C. F., Barkoulas, J. T. and Caglayan, M., 2001, Nonlinear Adjustment to Purchasing Power Parity in the Post-Bretton Woods Era", *Journal of International Money and Finance*, 20, 379-399.

Brock, W. A. and 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.

Cerrato, M. and Sarantis, N., 2003, "Black Market Exchange Rates and the Long-Run PPP Hypothesis in Emerging Markets", *Discussion Paper No 03-4*, Centre for International Capital Markets, London Metropolitan University

Chortareas, G. and Kapetanios, G., 2004, "The Yen Real Exchange Rate May Be Stationary After All: Evidence from Nonlinear Unit Root Tests", *Oxford Bulletin of Economics and Statistics*, 66, 113-131.

De Grauwe, P. and Grimadi, M., 2004, "Heterogeneity of Beliefs and Exchange Rate Dynamics", in: S. Lardic and V. Mignon (eds.), *Recent Developments on Exchange Rates*, Palgrave Macmillan.

Dumas, B., 1992, "Dynamic Equilibrium and the Real Exchange Rate in a Spatially Separated World", *Review of Financial Studies*, 5, 153-180.

Goswami, G., Shrikhande, M. and Wu, L., 2002, "A Dynamic Equilibrium Model of Real Exchange Rates with Transaction Costs", mimeo, Graduate School of Business, Fordham University.

Guillaume, D. M., Dacorogna, M. M., Dave, R. D., Muller, U. A., Olsen, R. B. and Pictet, O. V., 1995, "From the Bird's Eye to the Microscope: A Survey of New Stylized facts of the Intra-Daily Foreign Exchange Markets", Internal Document DMG. 1994-04-06, Olsen & Associates, Zurich.

Kapetanios, G., Shin, Y. and Snell, A., 2003, "Testing for a Unit Root in the Nonlinear STAR Framework", *Journal of Econometrics*, 112, 359-379.

Kiguel, M., and O'Connell, S., 1995, "Parallel Foreign Exchange markets in Developing Countries: Experience and Policy Lessons, *The World Bank Research Observer*, 10, 21-52.

Leon, H. and Najarian, S., 2003, "Asymmetric Adjustment and Nonlinear Dynamics in Real Exchange Rates", *IMF Working Paper*, WP/03/159.

Liew, V. K-S., Baharumshah, A. Z. and Chong, T. T-L., 2004, "Are Asian Real Exchange Rates Stationary?", *Economic Letters*, 83, 313-316.

Liew, V. K-S., Chong, T. T-L. and Lim, K. P., 2003, “The Inadequacy of Linear Autoregressive Models for Real Exchange Rates: Empirical Evidence from Asian Economies”, *Applied Economics*, 35, 1387-1392.

Michael, P., Nobay, A. R. and Peel, D. A., 1997, "Transactions Costs and Nonlinear Adjustment in Real Exchange Rates: An Empirical Investigation", *Journal of Political Economy*, 105, 862-879.

Ng., and Perron, P., 1995, “Unit Root Tests in ARMA Models with Data Dependent Methods for Selection of the Truncation Lag”, *Journal of American Statistical Association*, 90, 268-281”

Reinhart, C. M. and Rogoff, K. S., 2004, “The Modern History of Exchange Rate Arrangements: A Reinterpretation”, *Quarterly Journal of Economics*, CXIX, 1-48.

Sarantis, N., 1999, "Modelling Nonlinearities in Effective Exchange Rates", *Journal of International Money and Finance*, 18, 27-45.

Sarno, L. and Taylor, M. P., 2002, “Purchasing Power Parity and the Real Exchange Rate”, *IMF Staff Papers*, 49, 65-105.

Sercu, P., Uppal, R. and Van Hulle, C., 1995, “The Exchange Rate in the Presence of Transaction Costs: Implications for Tests of Purchasing Power Parity”, *Journal of Finance,* 50, 1309-1319.

Sollis, R., Leybourne, S. and Newbold, P., 2002, “Tests for Symmetric and Asymmetric Nonlinear mean reversion in Real Exchange Rates”, *Journal of Money, Credit and Banking*, 34, 686-700.

Taylor, M.P., Peel, D. A. and Sarno, L., 2001, “Nonlinear Mean-Reversion in Real Exchange Rates: Towards a Solution to the Purchasing Power Parity Puzzles”, *International Economic Review*, 42, 1015-1042.

Table 1
The Augmented Dickey-Fuller unit root test

Country	***k***	***ADF***
Algeria	11	-1.541
Argentina	9	-1.783
Bolivia	11	-2.870*
Brazil	3	-2.557
Chile	12	-1.921
Colombia	12	-1.264
Costa Rica	11	-2.365
Dom. Republic	6	-2.148
Ecuador	4	-1.844
Egypt	5	-4.628***
El Salvador	11	-0.868
Ethiopia	4	-1.406
Ghana	10	-5.581***
Hungary	12	-1.471
India	2	-1.220
Indonesia	5	-1.345
Kenya	9	-3.030**
Korea	12	-1.165
Kuwait	4	-1.484
Malaysia	7	-0.679
Mexico	6	-2.405
Morocco	9	-1.490
Nepal	5	-1.776
Nigeria	1	-1.379
Pakistan	12	-0.049
Paraguay	1	-1.273
Philippines	9	-2.807*
Singapore	7	-1.819
South Africa	12	-2.301
Sri Lanka	3	-2.265
Thailand	5	-1.720
Tunisia	10	2.356
Turkey	4	-1.840
Uruguay	1	-1.527
Venezuela	10	-1.645
Critical values:		
1%		-3.452
5%		-2.871
10%		-2.572

Note: k is the order of the autoregressive process. *ADF* is the augmented Dickey-Fuller linear unit root test.
(***), (**) and (*) denote significance at the 1%, 5% and 10% significance levels, respectively.

Table 2
Nonlinear unit root test results

		Sollis *et al* (2002)		**Kapetanios *et al* (2003)**
Country	***k***	t_A	t_S	***NLADF***
Algeria	11	-1.591	-1.655	-1.421
Argentina	9	-7.730***	-7.416***	-3.435**
Bolivia	11	-7.606***	-7.602***	-6.091***
Brazil	3	-4.243***	-3.299**	-3.320**
Chile	12	-1.225	-1.746	-2.069
Colombia	12	-1.465	-1.444	-0.331
Costa Rica	11	-4.158***	-3.961***	-4.566***
Dom. Republic	6	-2.763	-2.727	-3.225**
Ecuador	4	-2.472	-2.435	-2.626
Egypt	5	-5.629***	-5.638***	-6.078***
El Salvador	11	-6.367***	-4.391***	-3.237**
Ethiopia	4	-3.303**	-2.726	-2.492
Ghana	10	-8.249***	-5.907***	-5.546***
Hungary	12	-2.958*	-2.654	-1.958
India	2	-1.706	-1.675	-1.601
Indonesia	5	-4.453***	-4.452***	-4.932***
Kenya	9	-2.053	-1.774	-2.362
Korea	12	-9.978***	-9.876***	-0.906
Kuwait	4	-3.167*	-3.129**	-3.849***
Malaysia	7	-2.573	-2.315	-2.575
Mexico	6	-3.035*	-2.138	-2.127
Morocco	9	-3.028*	-2.852	-2.2903
Nepal	5	-2.419	-2.405	-2.467
Nigeria	1	-1.503	-1.424	-1.422
Pakistan	12	-1.899	-1.416	0.201
Paraguay	1	-2.277	-2.276	-2.289
Philippines	9	-5.395***	-5.393***	-6.708***
Singapore	7	-4.605***	-4.267***	-3.135**
South Africa	12	-5.198***	-5.057***	-3.963***
Sri Lanka	3	-2.259	-1.750	-1.706
Thailand	5	-3.454**	-2.948*	-2.403
Tunisia	10	-2.347	2.167	0.637
Turkey	4	-3.653**	-3.641**	-2.952**
Uruguay	1	-2.336	-1.568	-1.545
Venezuela	10	-1.929	-1.720	-1.916
Critical values:				
1%		-3.79	-3.70	-3.48
5%		-3.19	-3.12	-2.93
10%		-2.88	-2.86	-2.66

Table 2 continued

Note: k is the order of the autoregressive process. t_A and t_S are, respectively, the Sollis *et al* (2002) asymmetric and symmetric nonlinearly unit root tests (for T=300). *NLADF* is the Kapetanios *et al* (2003) nonlinear unit root test (for Case 2; i.e. non-zero mean).

(***), (**) and (*) denote significance at the 1%, 5% and 10% significance levels, respectively.