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Nonlinearities in real exchange rate determination: Do African exchange rates follow a random walk?

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Nonlinearities in real exchange rate determination: Do African exchange rates follow a random walk?

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September 4, 2008

Abstract

In this paper we aim at modelling the long run behaviour of the Real Effective Exchange Rates (REER) for a pool of African countries. Not much attention has been paid to this group of countries, in particular, to the existence of nonlinearities in the long run path of such a variable. Controlling for two sources of nonlinearities, i.e. asymmetric adjustment to equilibrium and nonlinear deterministic trends allows us to gain some insight about the behaviour of the African REER. We find that these sources of nonlinearities help us to explain the apparent unit root behaviour found applying linear unit root tests for most of the countries.

J.E.L. Classification : C32, F15.

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1 Introduction

Real exchange rate modelling has become a very popular topic within international economics during the last decades. Its understanding has several implications not only from then theoretical, but also from the applied point of view. From the theoretical point of view, many macroeconomic models assume a constant equilibrium real exchange rate. Moreover, the real exchange rate can be used as a means to assess the overvaluation or undervaluation of currencies and, therefore, it is a tool for exchange rate policy making. In addition, real exchange rate misalignment can be understood as a measure of economic integration (in the real markets) among countries (Wei and Parsley, 1995). Finally, as Faria and León-Ledesma (2003, 2005) point out, the real exchange rate has an impact on long run relative growth rates and unemployment. This adds another feature to exchange rate modelling: it can be used as a means of promoting growth, in particular in developing countries.

During the last decades, several authors have tried to contribute to the literature on the issue of whether monetary models of exchange determination are able to explain observed exchange rates movements. However, the results of the empirical applications have not been that successful (see Taylor, 2006, for a recent literature review).

Recent contributions to this literature claim that the failure of the former empirical literature lies on the fact of not taking into account the possibility of nonlinearities in the long run path of the real exchange rates. There are several reasons for assuming a nonlinear behaviour in this variable. First, as Dumas (1992), Taylor and Peel (2000), Taylor et al. (2001), Kilian and Taylor (2003) point out, the existence of trade barriers, transport costs and exchange rate intervention, may prevent the economic agents from getting a profit from arbitrage. This implies that the real exchange rate might behave as a unit root process within a threshold, but as a stationary variable outside of the threshold, yielding to an asymmetric speed of adjustment towards the equilibrium, i.e. the exchange rate tends to revert faster to the equilibrium the more misaligned it becomes

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6 after a shock.

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8 Furthermore, Taylor (2004) and Reitz and Taylor (2008) evidence non-
9 linearities in real and nominal exchange rate movements through the ef-
10 fect of official exchange rate intervention operations or announcements -'oral
11 intervention'-, since the intervention is more likely to occur and be effective
12 the greater the degree of misalignment is. The coordinating role of the author-
13 ities' intervention or the 'coordination channel' is then displayed, i.e. given
14 their coordinating influence on informed traders, they raise the confidence of
15 the latter and lead to the stabilisation of the exchange rates (see also Taylor,
16 1995, and Sarno and Taylor, 2001).
17

18
19 In addition, nonlinearities may affect the real exchange rate in the form of structural
20 changes. Devaluations/revaluations of the nominal exchange rates, as well as other ex-
21 ogenous events that can affect the exchange rates with permanent effects, might generate
22 a broken time trend.
23

24
25 These sources of nonlinearities might affect the power of the unit root tests (see
26 Kapetanios et al., 2003, and Bierens, 1997 among others), and, therefore, traditional
27 (linear) unit root tests may be biased towards the non-rejection of the unit root hypoth-
28 esis. In economic terms this implies that these unit root tests may incorrectly conclude
29 that there is no evidence of stationary behaviour in the real exchange rate, rejecting,
30 thus, the Purchasing Power Parity (PPP) hypothesis.
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33 In this paper we aim at contributing on the analysis of the empirical fulfilment of
34 PPP in a group of African countries, in order to gain some insight about the long run be-
35 haviour of their real exchange rates. As Kargbo (2006) pin points, African countries have
36 performed a number of economic reforms (see section 3), mainly focussed on exchange
37 rates adjustment in order to improve their competitiveness and economic growth, based
38 on the assumption that PPP holds. Hence, the empirical analysis of PPP becomes the
39 corner stone for the success of these policies and neglecting these reforms and its effects
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6 on the real exchange rate, may yield to wrong conclusions.
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8 In order to test for the order of integration of the African real exchange rates, we
9 apply three groups of unit root tests. The first are the Ng and Perron (2001) (linear) unit
10 root tests that are modified version of existing unit root tests in order to obtain tests with
11 better properties in terms of size and power. Second, we account for the possibility of
12 asymmetric speed of mean reversion by means of the Kapetanios et al. (2003) unit root
13 test. For those stationary real exchange rates, we also estimate an exponential smooth
14 transition autoregressive (ESTAR) model so as to understand the equilibrium values of
15 the variable. Finally, for those countries where we cannot reject the null hypothesis of unit
16 root, we apply the Bierens (1997) unit root tests, that takes the possibility of nonlinear
17 trend stationary under the alternative.
18

19 The remainder of this paper is organized as follows. Section 2 summarizes the PPP
20 theory and the recent contributions on the PPP analysis for African countries, apply-
21 ing nonlinear techniques. Section 3 describes the data. In section 4, we describe the
22 methodology applied in this empirical research and the results. Finally, the last section
23 summarizes the main contributions.
24
25

26 **2 The PPP hypothesis**

27 The PPP hypothesis, in its strict form (or so-called Absolute PPP) contends that the
28 nominal exchange rate¹ (e_t) between two countries should be equal to the price ratio
29 between the countries. This means that the real exchange rate, defined as
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$$35 q_t = \frac{e_t p_t}{p_t^*} \quad (1)$$

36 should be equal to one, where p_t^* and p_t are respectively the foreign and domestic price
37 indices. However, rejection of the absolute version of PPP does not necessarily imply
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¹Units of foreign currency for a unit of domestic currency.

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6 that prices in common currency are only explained by idiosyncratic factors; prices may
7 still react with proportional instead of identical deterministic components. In this case
8 it is said that is the Relative version of PPP the one that holds, i.e. the real exchange
9 rate is equal to a constant different from one.
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13 It is well known that PPP only holds in the long run, which implies that the real
14 exchange rate has to be a $I(0)$ process, thus, testing for unit roots in real exchange rates
15 became a popular way to test for PPP empirically (see Meese and Rogoff, 1988; Mark,
16 1990; Ardeni and Lubian, 1991; Huizinga, 1987; and Chowdhury and Sdogati, 1993,
17 among the more relevant contributions), although the results are ambiguous.
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23 However, as mentioned in the previous section, the traditional unit root tests might
24 not be able to distinguish between a unit root and a stationary process when the autore-
25 gressive parameter is near unity and data generating process follows a nonlinear path.
26 For these reasons, another strand of the literature apply univariate techniques that takes
27 into account asymmetric adjustment towards the equilibrium (Obstfeld and Taylor, 1997;
28 Michael et al., 1997; Taylor and Peel, 2000; Taylor et al., 2001; and Baum et al., 2001),
29 and structural changes and nonlinear trends (Papell, 2002; Sollis, 2005; Camarero, et al.,
30 2006, 2008; Cushman, 2008; Cuestas, 2008; and Christopoulos and León-Ledesma, 2007,
31 among others), finding more favourable results towards the stationarity of real exchange
32 rates.
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41 Although the evidence is pretty abundant for industrialized countries, the empirical
42 literature for African countries is quite scarce. As Kargbo (2006) summarizes, there is a
43 number of authors that have applied multivariate techniques, within the linear framework,
44 finding fairly mixed results for this group of countries. Nevertheless, more recently some
45 other authors (Anoruo et al., 2006; Bahmani-Oskooee and Gelan, 2006) have started to
46 apply unit root tests controlling for nonlinearities, when testing for the order of integration
47 of the real exchange rates for African countries. Whereas Anoruo et al. (2006) applies
48 the Kapetanios et al. (2003) unit root test to the real exchange rate vs. the US dollar of
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6 a sample of 13 African countries, finding evidence of nonlinear mean reversion for only
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8 4 of them, Bahmani-Oskooee and Gelan (2006) apply the same unit root test for a pool
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10 of 21 Real Effective Exchange Rates (REER), obtaining evidence of asymmetric mean
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12 reversion for 8 of them.

13
14 Although in both papers the authors consider the case of a linear trend, it is not
15
16 considered the case of a nonlinear trend, as a proxy of structural changes. Hence, in
17
18 this paper we aim at complementing Bahmani-Oskooee and Gelan (2006) first using a
19
20 Modified Information Criterion (Ng and Perron, 2001) to obtain the lag length in the
21
22 auxiliary regression of the Kapetanios et al. (2003) nonlinear unit root test, estimating a
23
24 nonlinear ESTAR model for the exchange rates and, finally, allowing for the possibility
25
26 of nonlinear trend stationary real exchange rates under the alternative hypothesis.

27 28 29 **3 The Data**

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31 The data used for this empirical application are REER for a pool of African countries,
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33 i.e. Burkina Faso, Burundi, Cameroon, Ivory Coast, Egypt, Ethiopia, Gabon, Ghana,
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35 Kenya, Madagascar, Mauritius, Morocco, Niger, Nigeria, Rwanda, Senegal, Seychelles,
36
37 Sierra Leone, South Africa, Tanzania and Togo. The data for REER have been obtained
38
39 from Bahmani-Oskooee and Gelan (2007). These authors compute the nominal and
40
41 effective exchange rates for several African countries as a weighted average of indexes of
42
43 real bilateral exchange rates of all trading partners, i.e.

$$44
45
46 REER_j = \sum_{i=1}^{20} \omega_{ij} \left[\frac{(p_j e_{ij}/p_i)_t}{(p_j e_{ij}/p_i)_{2003}} \times 100 \right] \quad (2)$$

47
48 where ω_{ij} is the imports share of partner i with country j ²; e_{ij} is the nominal bilateral
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50 exchange rate defined as number of units of country i 's per unit of j 's currency; p_i is
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52 country i price level; and p_j is country j price level.

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55 ²For major trading partners see Bahmani-Oskooee and Gelan (2007) Table 1.

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6 We have displayed the series of REER in figures 1 - 4. From these graphs we can
7 highlight several features; first, for some of the countries there is clear downward pattern,
8 implying a general depreciation of the currencies in real terms. Secondly, it is pretty
9 obvious that these countries' REER have suffered for a number of structural changes.
10 For instance, the sharp fall in the REER of Burkina Faso, Ivory Coast, Niger, Senegal
11 and Togo in 1994 was caused by a devaluation of their currencies by the Central Bank of
12 West African countries against the French Frank. Likewise, the Central Bank of Central
13 African States devaluated the currencies of Cameroon and Gabon at the end of 1993 that
14 were pegged with the French Frank. For the case of Egypt, in 1990 the president Mubarak
15 devaluated the currency against the US dollar. In the case of Ghana, there is a significant
16 appreciation of the national currency during 1982-1984. This was due to an economic
17 and political turmoil that raised inflation and the national currency was overvalued. The
18 currency returned to its normal levels after the devaluation of 1984 when an economic
19 recovery programme was set.
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32 All these interventions and structural changes might have generated a nonlinear be-
33 haviour in the long run paths of these countries' REER.
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38 **4 Unit root testing and nonlinear modelling**

39 **4.1 Unit root testing**

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42 In order to test for the order of integration of the REER in this group of countries, in
43 this section we apply two different types of unit root tests.
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48 The first are the Ng and Perron (2001) unit root tests. Following these authors,
49 traditional unit root tests might suffer from two main problems. First, they might suffer
50 from power problems when the autoregressive parameter is close to 1 and, second, when
51 the errors of a Moving Average process are close to -1, it is necessary a high lag length
52 in order to avoid size problems. However, the Akaike Information Criterion (AIC) and
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6 Bayesian Information Criterion (BIC) tend to select a low order of the lag length. In
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8 order to overcome these issues, Ng and Perron (2001) propose a Modified Information
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10 Criterion (MIC) that controls for the sample size. Additionally, the authors propose a
11
12 method to avoid the power problem associated to the aforementioned traditional unit
13
14 root tests. Combining these two approaches, Ng and Perron (2001) obtain the following
15
16 unit root tests: MZ_α and MZ_t that are the modified versions of the Phillips (1987) and
17
18 Phillips and Perron (1988) Z_α and Z_t tests; the MSB that is related to the Bhargava
19
20 (1986) R_1 test; and, finally, the MP_T test that is a modified version of the Elliot et al.
21
22 (1996) Point Optimal Test.

23
24 Moreover, the presence of the aforementioned nonlinearities in the REER has impli-
25
26 cations for the power of the technique and, therefore, traditional (linear) unit root tests
27
28 tend to accept a false unit root null hypothesis (Kapetanios et al., 2003, among others).
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30 Thus, nonlinearities can be present in REER in the form of different behaviour of the
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32 variable depending on its values, i.e. the variable behaves as a nonstationary process
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34 when it is within a band, but is stationary when it is outside of the band. As stated
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36 by Dumas (1994) and Michael et al. (1997), among others, it is sensible to assume that
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38 the shift between regimes is smooth rather than sudden, due to time aggregation and
39
40 individuals' behaviour.

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42 In order to account for this source of nonlinearity we apply the Kapetanios, Shin and
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44 Snell (2003) (KSS) unit root tests. KSS propose a unit root test that takes into account
45
46 the possibility of smooth transitions between regimes. Thus, the null hypothesis of unit
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48 root is tested against the alternative of globally stationary nonlinear process, i.e.

$$49 \quad q_t = \beta q_{t-1} + \phi q_{t-1}(1 - \exp\{-\theta q_{t-1}^2\}) + \epsilon_t \quad (3)$$

50
51 where $\epsilon_t \sim iid(0, \sigma^2)$. Note that KSS assume that the transition function is an exponential
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53 smooth transition autoregressive (ESTAR) one. A ESTAR function is appropriate to
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55 model REER movements, since this type of function assume that the shocks have a
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6 symmetric effect over the variable, regardless the sign of the shock (Taylor and Peel,
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8 2000). It is a common practice to reparameterize equation (3) as
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$$10 \quad \Delta q_t = \alpha q_{t-1} + \gamma q_{t-1}(1 - \exp\{-\theta q_{t-1}^2\}) + \epsilon_t. \quad (4)$$

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14 in order to test for unit roots. KSS impose $\alpha = 0$, which is equivalent to saying that
15
16 the variable is a I(1) process in the central regime. In order to test the null hypothesis
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18 $H_0 : \theta = 0$ against $H_1 : \theta > 0$ outside of the threshold³, Kapetanios et al. (2003) propose
19
20 a Taylor approximation of the ESTAR model since, in practice, the coefficient γ cannot
21
22 be identified under H_0 . Thus, under the null, the model becomes
23

$$24 \quad \Delta q_t = \delta q_{t-1}^3 + \eta_t \quad (5)$$

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28 where η_t is an error term. Now, it is possible to apply a t -statistic to test whether q_t is a
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30 I(1) process, $H_0 : \delta = 0$, or is a I(0) process, $H_1 : \delta < 0$.
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33 The results of these unit root tests are reported in table 6. The first feature is that
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35 the results of applying both types of tests are pretty similar, i.e. for Ethiopia, Gabon,
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37 Ghana, Sierra Leone and Tanzania it is not possible to reject the null hypothesis of unit
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39 root at the 5% significance level. In addition, with the KSS test we find that the REER
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41 of Burundi and Egypt is also stationary. Finally, with the Ng-Perron test, it is possible
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43 to reject the null hypothesis, but only at the 10% significance level. In summary, we find
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45 that the REER of these countries is stationary with drift in 8 up to 21 countries⁴.
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48 For these 8 countries we estimate nonlinear models in order to gain some insight about
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50 their long run behaviour (see next section).
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³Note that the process is globally stationary provided that $-2 < \phi < 0$.

⁴Note that our results are similar to those obtained by Bhamani-Oskooee and Gelan (2006), although we have used the MAIC in order to select the lag length of the auxiliary ADF regression.

4.2 Estimated models

4.2.1 Foundations

Smooth transition (ST) models are members of the family of state-dependent models; these are a local linearization of the general nonlinear specification. The data generating process is a linear one that switches between a certain number of regimes according to some rule; the regime is characterized as a continuous function of a predetermined variable, so that interactions between variables are permitted, as well as intermediate states between the extreme regimes.

This paper focuses on STs over other usual specifications because, among other reasons: their flexibility enables the description of a wide range of nonlinear behaviours; there exists a modelling cycle; once the state is given, the model is locally linear and easy to interpret; and standard nonlinear estimation techniques can be used. See Granger and Teräsvirta (1993), Teräsvirta (1994, 1998) and van Dijk et al. (2002) for a deeper insight on STs.

The smooth transition autoregression (STAR) is the basic univariate version of the ST model; all predetermined variables are lags of the dependent variable and regimes are endogenously determined. Suppose y_t a stationary, ergodic process, the STAR model of order p is given by

$$y_t = \pi_0 + \sum_{i=1}^p \pi_i y_{t-i} + F(y_{t-d}) \left[\theta_0 + \sum_{i=1}^p \theta_i y_{t-i} \right] + u_t \quad (6)$$

where $F(y_{t-d})$ is a transition function customarily bounded between 0 and 1 that makes the STAR coefficients vary between π_i and $\pi_i + \theta_i$ ($i = 1, \dots, p$), respectively; d is the transition lag; and u_t is an error process, $u_t \sim Niid(0, \sigma^2)$. The transition variable, y_{t-d} , and the associated value of $F(y_{t-d})$ determine the regime at each t . In its basic version, the regime-switching STAR model considers two extreme regimes, corresponding to $F = 0$ and $F = 1$; the transition from one regime to the other is smooth over time,

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6 involving that parameters in (6) gradually change with the state variable.

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8 The STAR model links two linear components by means of $F(y_{t-d})$, so that the
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10 formulation for this function comes out a key issue when investigating nonlinearities.
11 Two specifications are the most commonly used. First, the logistic function, which has
12 the form:
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$$15 \quad F(y_{t-d}) = \frac{1}{1 + \exp[-\gamma(y_{t-d} - c)]} \quad (7)$$

16
17 and the resulting model is the Logistic STAR or LSTAR. This function usually represents
18 the odd case in the literature, meaning that $F(-\infty) = 0$ and $F(\infty) = 1$. The slope
19 parameter γ ($\gamma > 0$) determines the smoothness of the transition; the higher it is, the
20 more rapid the change from one extreme regime to the other. The location parameter c
21 indicates the threshold between the two regimes; here, $F(c) = 0.5$, so that regimes are
22 associated with low and high values of y_{t-d} relative to c .
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31 Second, the exponential function

$$32 \quad F(y_{t-d}) = 1 - \exp[-\gamma(y_{t-d} - c)^2] \quad (8)$$

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34 is the habitual one in the case of an even transition and provides the Exponential STAR
35 or ESTAR model. This specification implies $F(c) = 0$ and $F(\pm\infty) = 1$ for some finite c ,
36 defining the inner and the outer regime, respectively.
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43 LSTAR and ESTAR models describe quite different types of behaviour. In the logistic
44 model the extreme regimes are associated with y_{t-d} values far above or below c , where
45 dynamics may be different; the ESTAR model suggests rather similar dynamics in the
46 extreme regimes, related to low and high y_{t-d} absolute values, while it can be different
47 in the transition period.
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52 As it was anticipated in 4.1, the exponential specification comes out the most suitable
53 one for describing the evolution of real exchange rates; the appeal of this function lies
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6 in allowing a symmetric adjustment of the variable for deviations below and above the
7 equilibrium value. The location parameter would reflect the equilibrium real exchange
8 rate and the dynamics of the variable would change according to the proximity/distance
9 to the equilibrium state; in the last case, there would not be differences between highly
10 overvaluated or highly undervaluated exchange rates.
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15 Going now into the modelling cycle for STAR models, it has traditionally been based
16 on reproducing Box and Jenkins (1970) iterative methodology; search for specification,
17 estimation and evaluation of the model. There is a well-established STAR modelling pro-
18 cedure in the literature (see Granger and Teräsvirta, 1993; Teräsvirta, 1994). Nonetheless,
19 the most recent investigations do not follow this strategy in a strict manner. Öcal and
20 Osborn (2000), van Dijk et al. (2002) and Sensier et al. (2002), among others, argue that
21 it is possible to develop valid nonlinear formulations that improve the fit of the linear
22 ones by means of an extensive search of STAR models; any possible inadequacy of the
23 models will be unveiled at the validation stage.
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32 We define several combinations of p and d , trying for different values of γ and using
33 a value close to the sample mean of the transition variable for c ; the lag order p ranges
34 from 1 to 8 (eighth-order dynamics seem to be general enough for quarterly data) and
35 the transition lag d varies from 1 to p . STAR models are estimated by nonlinear least
36 squares; following the recommendations of Teräsvirta (1994), the argument of the ex-
37 ponential transition function is scaled by dividing it by the variance of the dependent
38 variable. Where parameter convergence is reached, models are subject to further refine-
39 ment. First, nonsignificant coefficients are excluded to conserve degrees of freedom; then,
40 we simplify this first set of estimations through cross-parameter restrictions in order to in-
41 crease efficiency. We take 1.6 as the limit t-value for these coefficients, since the variables
42 are stationary.
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52 The properties of the finally proposed models are evaluated using several misspecifi-
53 cation tests. We consider the test of no autoregressive conditional heteroskedasticity with
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6 four lags (ARCH) and the test of business cycle heteroskedasticity (BCH) posed by Öcal
7 and Osborn (2000). Particular attention is also paid to significant estimated coefficients,
8 the features of the transition functions and the results of the following diagnostic statis-
9 tics: the residual standard error (s), the adjusted determination coefficient (\bar{R}^2) and the
10 variance ratio of the residuals from the nonlinear model and the best linear specification
11 (s^2/s_L^2).
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17 18 19 **4.2.2 Empirical results**

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21 As a starting point, we determine the linear models that would describe the behaviour
22 of the exchange rates in the eight countries where we find that the REER is stationary
23 around a drift. An ordinary least squares estimation is carried out, where the proper
24 number of lags is selected using the Akaike Information Criterion. These models are not
25 reported for space reasons but they are available from authors upon request.
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31 The next step involves estimation and specification of the STAR models for all coun-
32 tries following the aforementioned extensive search strategy. A large number of STAR
33 models are generated, although parameter convergence is not attained in some of them⁵.
34 The final selected models are reported in table 3, along with several descriptive statistics
35 and diagnostic tests. These specifications reflect how high absolute values for the lagged
36 exchange rate generate nonlinear effects on the variable at present time. Linearity tests
37 against the estimated ESTAR models prove evidence of nonlinearities for all countries;
38 table 4 displays the p-values of the F tests (significance level, 0.05).
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46 The dependence of the exchange rates on their own recent history is moderate for
47 some countries. The transition from one regime to the other is rather fast in the majority
48 of the countries; in particular, Burundi and Sierra Leone models behave like threshold
49 ones, as they display sharp switches. The values of the location parameter are reasonably
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53 ⁵For Tanzania and Ghana it is not possible to obtain adequate specifications with endogenous tran-
54 sition that explain their respective behaviours; convergence problems in the estimation, as well as not
55 very satisfactory results of the latter, are the main justifications
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6 close to the sample means of the exchange rates for four out of the six countries; for
7 the two remaining, Gabon and Nigeria, almost all the observations lie to the right of c ,
8 making the transition a logistic one in practice (see figure 5). The latter would mean
9 the pretty absence of a devaluation regime in both countries, which is confirmed by
10 figures 2 and 3. The reason for this behaviour may be found in that Gabon and Nigeria
11 are leading oil exporters; this brings about a surplus in their current account balances,
12 causing appreciation in the currencies.
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19 The evaluation stage does not unveil signs of misspecification in the models, so the
20 proposed ESTARs are adequate. According to the variance ratio, the estimated nonlinear
21 models explain 7% to 24% of the residual variance of the best linear autoregression in all
22 six countries.
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26 The evaluation of the estimated nonlinear specifications is completed with the analysis
27 of their local dynamic properties, which will allow us to better characterize the variables.
28 The necessary information is obtained from the roots of the characteristic polynomials
29 associated to the models; in this paper, we compute the roots for the two extreme values
30 of the transition function, $F = 0$ and $F = 1$. To save space, table 5 only displays the
31 dominant root, i.e., the root with the highest modulus that is determining the long-run
32 behaviour of the series within each regime.
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39 Table 5 reveals, on the one hand, that the estimated ESTAR models are stable in
40 the inner and in the outer regime for three out of the six countries, i.e. Ethiopia, Gabon
41 and Nigeria, especially in Gabon, which might have to do with being the only country
42 with fixed (strict) exchange rates. On the other hand, Burundi, Egypt and Sierra Leone
43 have globally stationary although locally unstable models. This second group of countries
44 shows explosive roots in the inner regime, involving that exchange rates pass this regime
45 rapidly on their way up or down; the outer regime is a stable one, so that once the variable
46 undergoes an overvaluation or an undervaluation, it will tend to remain there unless an
47 exogenous shock occurred.
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6 The asymmetry between the extreme regimes is particularly severe in Egypt and Sierra
7 Leone. Both countries are characterized by the following pattern of two opposite forces;
8 on the one hand, they have a well-recognized and high-added value main export product
9 (oil and derivatives in Egypt, diamonds in Sierra Leone) but, on the other hand, they are
10 great importers (Egypt is a major food importers on worldwide scale and Sierra Leone
11 highly demands hydrocarbons and food). The dynamics of these two opposite forces are
12 expected to determine the evolution of the exchange rates in both countries, as they are
13 not fixed (rigid) ones.
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20 Lastly, in Burundi the transition between the extreme regimes is nearly abrupt and,
21 moreover, the unstable inner regime contains few observations. As a result, the currency
22 almost always suffers from a greater or lesser overvaluation/undervaluation in this agri-
23 cultural economy whose foreign trade depends on imports and on a vulnerable exporting
24 balance caused by food products with volatile prices in international markets.
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31 32 **5 Allowing for deterministic trends**

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35 In this section we relax the assumption that the REER is stationary around a drift under
36 the alternative hypothesis and we allow for the possibility of nonlinear deterministic
37 trends. It is well known within the literature that misspecification of the deterministic
38 components might bias the results of the unit root tests towards the acceptance of the
39 null hypothesis of unit root (Perron and Phillips, 1987; West, 1988; Bierens, 1997). As
40 it was mentioned earlier, nonlinearities can be present in the form of structural changes
41 and, therefore, these nonlinearities affect the deterministic components. Many authors
42 have applied unit root tests with structural changes in order to test for PPP, finding in
43 general more favourable results towards PPP empirical fulfillment. However, a broken
44 time trend can be understood as a particular case for a nonlinear trend. Thus, even unit
45 root tests with structural changes may suffer from power problems (Bierens, 1997).
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Bierens (1997) proposes some tests which take into account the possibility of stationarity around a nonlinear deterministic trend under the alternative hypothesis. This author generalizes the ADF auxiliary regression to incorporate Chebishev polynomials to approximate the nonlinear deterministic trend. Following Bierens (1997), the reason for using Chebishev polynomials instead of regular time polynomials (Park and Choi, 1988; Ouliaris et al., 1989) to approximate the nonlinear deterministic trend is that the former create less power distortions. Thus, the auxiliary regression becomes

$$\Delta q_t = \alpha q_{t-1} + \sum_{j=1}^p \phi_j \Delta q_{t-j} + \theta^T P_{t,n}^{(m)} + \varepsilon_t \quad (9)$$

where $P_{t,n}^{(m)}$ are the Chebishev polynomials and m is the order of the polynomials, such that $P_{0,t}$ through $P_{m,t}$, where $P_{0,t}$ equals 1, $P_{1,t}$ is equivalent to a linear trend, and $P_{2,t}$ through $P_{m,t}$ are cosine functions. In order to test for the order of integration of the variables, Bierens (1997) proposes several tests. In this paper we apply the t -test over the coefficient α , $\hat{t}(m)$. Moreover, this can be tested by means of the $\hat{A}(m) = \frac{n\hat{\alpha}}{|1 - \sum_{i=1}^p \hat{\phi}_i|}$ test. The last one is an F -test, $\hat{F}(m)$, for the joint hypothesis that $\hat{\alpha}$ and the last m components of the parameter vector θ in model (9) are zero under the null. The conclusions from these tests are different under the alternative hypothesis depending upon the side of the rejection. Whereas with the $\hat{A}(m)$ and t test right side rejection implies stationarity around a nonlinear trend, left side rejection does not allow us to distinguish between mean stationarity, linear trend stationary and nonlinear trend stationarity. With the F test it is not possible to distinguish between those alternatives (see table 2).

A number of authors have applied Bierens' (1997) approach in order to test for the order of integration of the RER (see Sollis, 2005; Assaf, 2006; Cushman, 2008; Camarero et al., 2008; Cuestas, 2008; and Cuestas and Regis, 2008) finding that in general it is possible to reject the null hypothesis once nonlinear deterministic trends are accounted for.

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6 In table 6 we present the results of the Bierens (1997) tests. Following this author,
7 these tests suffer from important size distortions (Bierens, 1997), therefore the critical
8 values have been obtained by Monte Carlo experiment based on 5,000 replications of a
9 Gaussian $AR(p)$ process for Δq_t . The parameters and error variances are equal to the
10 estimated $AR(p)$ null model, where the order p of the ADF auxiliary regression has been
11 obtained by the AIC and the initial values have been taken from the actual series. Note
12 that we have only performed the Bierens' tests for those countries we could not reject
13 the null hypothesis with the Ng-Perron and KSS tests. The results show that in 8 of the
14 remaining 13 countries, we can reject the null hypothesis of unit root. Additionally, it is
15 worth highlighting that in all cases, except for Senegal, we obtain left side rejection which
16 means that the series could be stationary around a drift, linear or nonlinear trend. For
17 Senegal the results point to nonlinear trend stationarity process. This is not surprising
18 since the order to the Chebishev polynomial necessary to reject the null hypothesis is
19 pretty high⁶. Figures 6 - 7 display the nonlinear trends adjustment for these 8 countries.
20 Since a higher order of m implies a higher degree of nonlinearity, for some countries such
21 as Senegal of Seychelles it is necessary to use a high order for m in order to approximate
22 structural changes.

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37 This implies that for these 8 countries the strict hypothesis of PPP needs to be relaxed
38 in order to account for structural changes, finding thus, a non-constant or time varying
39 equilibrium real exchange rate.
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44 **In parallel to this analysis of nonlinearities in real exchange rate adjust-**
45 **ment, Lothian and Taylor (2000) and Lothian and Taylor (2008) evidence**
46 **the so-called Harrod-Balassa-Samuelson effect for certain real exchange rates,**
47 **that is, the dependence of the equilibrium real exchange rate on productivity**
48 **differentials; the first empirical work considers nonlinear time trends prox-**
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53 ⁶As Bierens (1997) claims, there is not a unique way to choose the order of m . Since we know the
54 ADF test tends to over-accept the null hypothesis, we have selected the order of m that yields more
55 evidence against the alternative hypothesis.
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ying for this effect. These findings justify our interest in allowing for real shocks in the African countries and, as a future research, we intend to consider the effect of real shocks to the equilibrium real exchange in this group of countries.

6 Conclusions

Aimed at contributing to the literature on PPP in Africa, in this paper we have applied several unit root tests that account for different forms of nonlinearities, i.e. asymmetric speed of adjustment and nonlinear deterministic trends. In the former, stationarity is found in 8 up to 13 countries and ESTAR models can adequately capture the behaviour of the real exchange rates for some of these countries; in fact, modelling the nonlinearity in the data explains 7% to 24% of the residual variance of the best linear autoregression. In most of the countries, the transition from the equilibrium location to the overvaluation/undervaluation stage takes place quite fast, which strengthens the nonlinearity hypotheses; in addition, the threshold value between both regimes is generally in the neighbourhood of the variable's sample mean. Furthermore, half of the countries evidence explosive roots in the inner regime, involving real exchange rates pass rapidly this stage to reach the outer regime. The intrinsic features of each economy may underlie this behaviour.

Further, the evidence in favour of the alternative hypothesis of stationarity increases when allowing for nonlinear deterministic trends, approximated by means of Chebishev polynomials. This implies that the real exchange rate tends to revert to a time dependent equilibrium value. This feature is important since structural changes might drive us to wrong conclusions when testing for PPP, in particular for developing countries.

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Table 1: Ng-Perron and KSS unit root test results

Country	MZ_a	MZ_t	MSB	MP_T	\hat{t}_{NL}	\hat{t}_{NLD}
Burkina Faso	0.786	0.773	0.983	64.943	-1.893	-0.907
Burundi	0.871	1.276	1.464	138.026	-4.122**	-3.542**
Cameroon	-6.521	-1.771	0.271	3.878	-0.892	-1.914
Ivory Coast	-6.297	-1.756	0.278	3.950	-0.839	-2.281
Egypt	-6.632	-1.655	0.249	4.259	-2.230*	-3.949**
Ethiopia	-5.797*	-1.591	0.274*	4.570	-2.257**	-4.571**
Gabon	-9.905**	-2.161**	0.218**	2.727**	-1.531	-2.926**
Ghana	-16.190**	-2.843**	0.175**	1.518**	-8.131**	-8.687**
Kenya	-2.051	-0.808	0.394	10.135	-0.550	-2.559
Madagascar	-2.549	-0.897	0.351	8.628	-1.246	-2.384
Mauritius	-1.670	-0.759	0.454	12.279	-1.238	-2.469
Morocco	0.736	0.649	0.881	53.002	-1.889	-1.043
Niger	-0.764	-0.379	0.496	16.409	-1.311	-1.925
Nigeria	-7.337*	-1.892*	0.257*	3.425*	-1.645	-1.628
Rwanda	-2.510	-1.090	0.434	9.610	-0.980	-1.056
Senegal	-3.511	-1.167	0.332	6.971	-1.013	-1.524
Seychelles	-1.321	-0.729	0.552	16.293	-0.513	-1.916
Sierra Leone	-8.399**	-2.038**	0.242*	2.958**	-2.359**	-3.216**
South Africa	-2.738	-1.050	0.383	8.558	-1.229	-2.316
Tanzania	-7.849*	-1.931*	0.246*	3.3115	-3.670**	-5.665**
Togo	-0.375	-0.210	0.560	20.684	-1.314	-1.600

Note: The order of lag to compute the tests has been chosen using the modified AIC (MAIC) suggested by Ng and Perron (2001). The Ng-Perron tests include an intercept, whereas the KSS test has been applied to the raw data, \hat{t}_{NL} say, and to the demeaned data, \hat{t}_{NLD} say. The symbols * and ** mean rejection of the null hypothesis of unit root at the 10% and 5% respectively. The critical values for the Ng-Perron tests have been taken from Ng and Perron (2001), whereas those for the KSS have been obtained by Monte Carlo simulations with 50,000 replications:

	MZ_a	MZ_t	MSB	MP_T	\hat{t}_{NL}	\hat{t}_{NLD}
5%	-8.100	-1.980	0.233	3.170	-2.196	-2.925
10%	-5.700	-1.620	0.275	4.450	-1.906	-2.633

Table 2: Alternative hypotheses

Test	Left-side rejection	Right-side rejection
$\hat{t}(m)$	MS, LTS or NLTS	NLTS
$\hat{A}(m)$	MS, LTS or NLTS	NLTS
$\hat{F}(m)$	-	MS, LTS or NLTS

Note: MS= mean stationarity, LTS= linear trend stationarity, NLTS= nonlinear trend stationarity.

Table 3: Estimated ESTAR models for exchange rates

BURUNDI	
$e_t = \frac{2369.69}{(873.88)} + \frac{1.80e_{t-1}}{(0.26)} - \frac{0.39e_{t-2}}{(0.13)} + \frac{0.19e_{t-3}}{(0.08)} - \frac{5.84e_{t-6}}{(2.13)} + \frac{0.45e_{t-7}}{(0.29)} + \left(\frac{-2367.55}{(873.85)} - \frac{0.62e_{t-1}}{(0.25)} + \frac{5.84e_{t-6}}{(2.13)} - \frac{0.45e_{t-7}}{(0.29)} \right) \times \left[1 - \exp \left\{ -\frac{160.11}{(68.97)} \times 2.12 \left(e_{t-6} - \frac{489.26}{(2.89)} \right)^2 \right\} \right] + a_t$	
s=18.97; $\bar{R}^2 = 0.99$; $s^2/s_L^2 = 0.84$; ARCH=0.54 (0.71); BCH=0.02 (0.88)	
EGYPT	
$e_t = \frac{-26.32}{(31.08)} + \frac{1.24e_{t-1}}{(0.10)} + \frac{0.73e_{t-4}}{(0.20)} - \frac{0.87e_{t-5}}{(0.18)} + \left(\frac{46.71}{(30.49)} - \frac{0.58e_{t-1}}{(0.15)} + \frac{0.27e_{t-2}}{(0.12)} - \frac{0.79e_{t-4}}{(0.21)} + \frac{0.87e_{t-5}}{(0.18)} \right) \times \left[1 - \exp \left\{ -\frac{1.56}{(0.95)} \times 0.0003 \left(e_{t-3} - \frac{254.04}{(9.95)} \right)^2 \right\} \right] + a_t$	
s=17.62; $\bar{R}^2 = 0.91$; $s^2/s_L^2 = 0.76$; ARCH=0.72 (0.58); BCH=0.005 (0.94)	
ETHIOPIA	
$e_t = \frac{34.63}{(74.93)} + \frac{1.56e_{t-1}}{(0.25)} - \frac{1.09e_{t-2}}{(0.46)} + \frac{0.92e_{t-3}}{(0.53)} - \frac{0.53e_{t-4}}{(0.48)} + \left(\frac{-11.93}{(77.34)} - \frac{0.89e_{t-1}}{(0.26)} + \frac{1.09e_{t-2}}{(0.46)} - \frac{0.92e_{t-3}}{(0.53)} + \frac{0.64e_{t-4}}{(0.49)} \right) \times \left[1 - \exp \left\{ -\frac{1.11}{(0.57)} \times 0.0003 \left(e_{t-4} - \frac{220.26}{(15.64)} \right)^2 \right\} \right] + a_t$	
s=16.73; $\bar{R}^2 = 0.91$; $s^2/s_L^2 = 0.79$; ARCH=0.89 (0.47); BCH=0.97 (0.33)	
GABON	
$e_t = \frac{114.78}{(62.82)} - \frac{0.40e_{t-1}}{(0.81)} + \left(\frac{-79.66}{(59.64)} + \frac{1.67e_{t-1}}{(0.71)} - \frac{0.54e_{t-2}}{(0.17)} \right) \times \left[1 - \exp \left\{ -\frac{0.42}{(0.37)} \times 0.0022 \left(e_{t-1} - \frac{62.12}{(14.96)} \right)^2 \right\} \right] + a_t$	
s=7.64; $\bar{R}^2 = 0.86$; $s^2/s_L^2 = 0.93$; ARCH=0.06 (0.99); BCH=1.62 (0.20)	
NIGERIA	
$e_t = \frac{7.33}{(22.28)} + \frac{0.93e_{t-1}}{(0.23)} + \left(\frac{6.07}{(21.34)} + \frac{0.96e_{t-1}}{(0.25)} - \frac{0.95e_{t-2}}{(0.14)} \right) \times \left[1 - \exp \left\{ -\frac{2.67}{(4.46)} \times 0.00005 \left(e_{t-1} - \frac{85.29}{(39.65)} \right)^2 \right\} \right] + a_t$	
s=27.68; $\bar{R}^2 = 0.96$; $s^2/s_L^2 = 0.81$; ARCH=0.01 (0.99); BCH=2.01 (0.16)	
SIERRA LEONE	
$e_t = \frac{-172.52}{(76.34)} + \frac{0.76e_{t-1}}{(0.06)} + \frac{1.06e_{t-2}}{(0.40)} - \frac{0.90e_{t-3}}{(0.52)} + \frac{0.54e_{t-4}}{(0.40)} + \frac{0.83e_{t-7}}{(0.34)} + \left(\frac{200.70}{(76.80)} - \frac{1.06e_{t-2}}{(0.40)} + \frac{0.90e_{t-3}}{(0.52)} - \frac{0.71e_{t-4}}{(0.42)} + \frac{0.33e_{t-5}}{(0.12)} + \frac{0.30e_{t-6}}{(0.11)} - \frac{1.29e_{t-7}}{(0.36)} \right) \times \left[1 - \exp \left\{ -\frac{19.07}{(7.28)} \times 0.0004 \left(e_{t-6} - \frac{134.43}{(1.51)} \right)^2 \right\} \right] + a_t$	
s=25.43; $\bar{R}^2 = 0.73$; $s^2/s_L^2 = 0.76$; ARCH=2.20 (0.07); BCH=1.38 (0.24)	

Notes: e_t denotes the real exchange rate. Values under regression coefficients are standard errors of the estimates; s is the residual standard error; \bar{R}^2 the adjusted determination coefficient; s^2/s_L^2 is the variance ratio of the residuals from the nonlinear model and the best linear AR selected with AIC; ARCH is the statistic of no ARCH based on four lags; BCH is a business cycle heteroskedasticity test. Numbers in parentheses after values of ARCH and BCH are p-values.

Table 4: Linearity tests against estimated ESTAR models

Country (lag order)	p-value
Burundi (p=7)	0.00003
Egypt (p=5)	0.000002
Ethiopia (p=4)	0.00001
Gabon (p=2)	0.0363
Nigeria (p=2)	0.00001
Sierra Leone (p=7)	0.0001

Table 5: Local dynamics: dominant roots in each regime

Country	Regime (value of F)	Root	Modulus
Burundi	Inner (F=0)	$1.5796 \pm 0.4820i$	1.65
	Outer (F=1)	0.9745	0.97
Egypt	Inner (F=0)	1.2636	1.26
	Outer (F=1)	0.8919	0.89
Ethiopia	Inner (F=0)	$0.8889 \pm 0.2481i$	0.92
	Outer (F=1)	0.8570	0.86
Gabon	Inner (F=0)	-0.3996	0.40
	Outer (F=1)	$0.6352 \pm 0.3674i$	0.73
Nigeria	Inner (F=0)	0.9352	0.93
	Outer (F=1)	$0.9470 \pm 0.2354i$	0.97
Sierra Leone	Inner (F=0)	1.3833	1.38
	Outer (F=1)	$0.4383 \pm 0.8342i$	0.94

Table 6: Bierens (1997) unit root tests

Country	m	p	t(m)	A(m)	F(m)
Burkina Faso	2	0	0.0166	0.0130	0.9736
Cameroon	-	-	$I(1)$	$I(1)$	$I(1)$
Ivory Coast	-	-	$I(1)$	$I(1)$	$I(1)$
Kenya	4	0	0.0162	0.0138	0.9610
Madagascar	-	-	$I(1)$	$I(1)$	$I(1)$
Mauritius	9	2	0.0376	0.0354	0.9234
Morocco	5	1	0.0010	0.0004	0.9994
Niger	2	0	0.0094	0.0204	0.9904
Rwanda	-	-	$I(1)$	$I(1)$	$I(1)$
Senegal	20	0	0.9614	0.9558	$I(1)$
Seychelles	17	0	0.0328	0.0608	0.9000
South Africa	-	-	$I(1)$	$I(1)$	$I(1)$
Togo	2	0	0.0050	0.0026	0.9926

Note: The values on the table are p-values.

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Figure 1: Real exchange rates

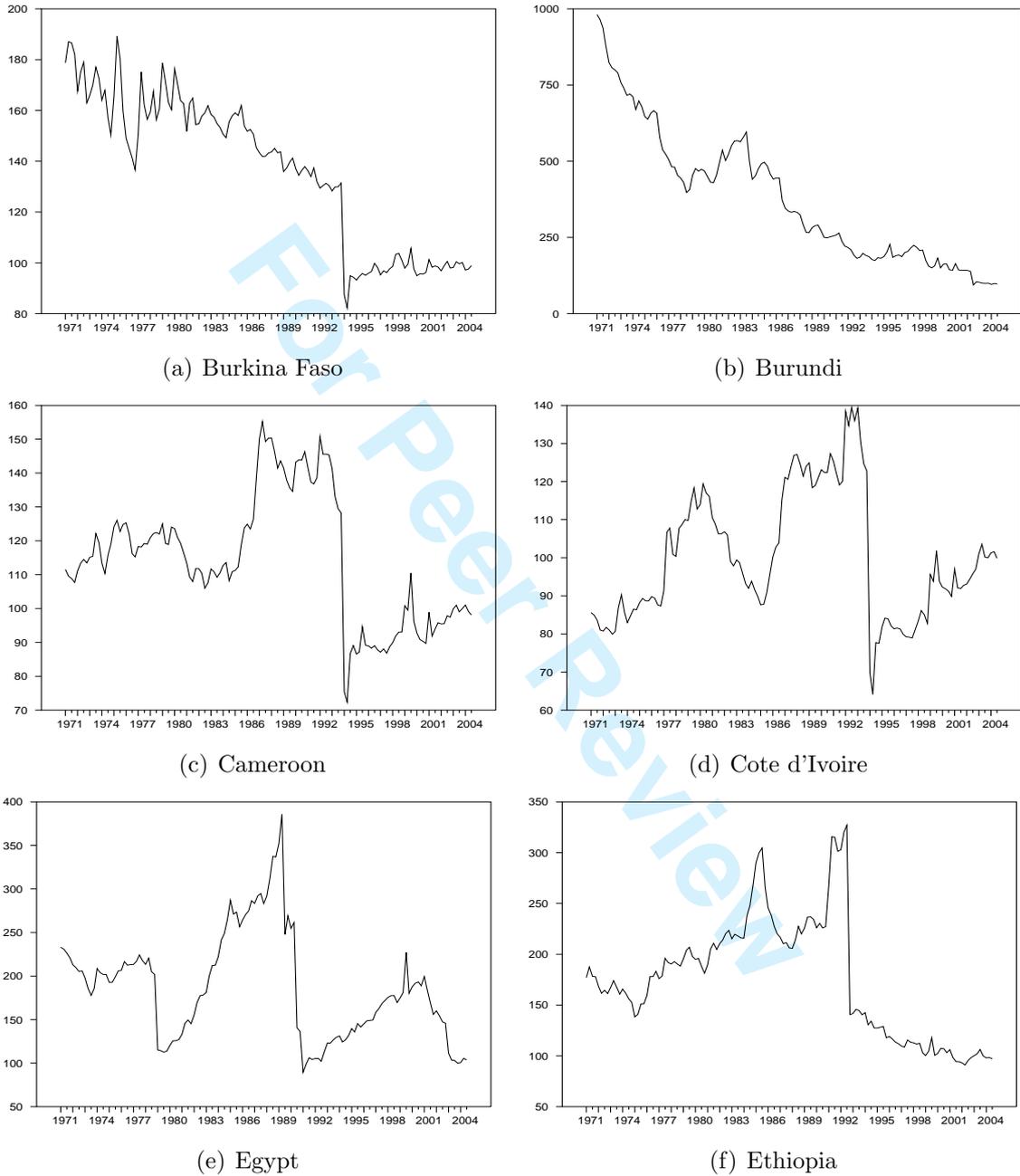
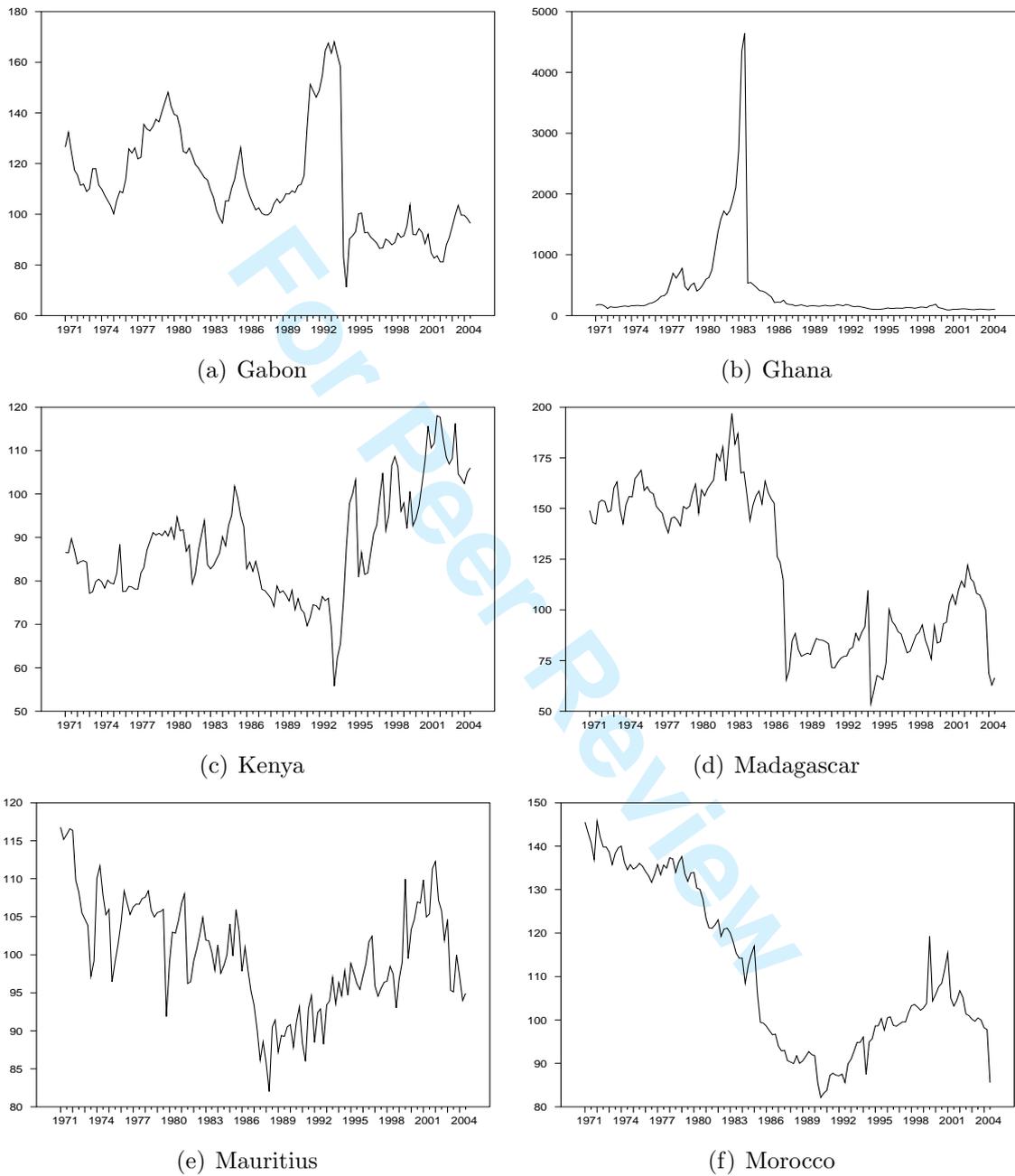


Figure 2: Real exchange rates (cont.)



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Figure 3: Real exchange rates (cont.)

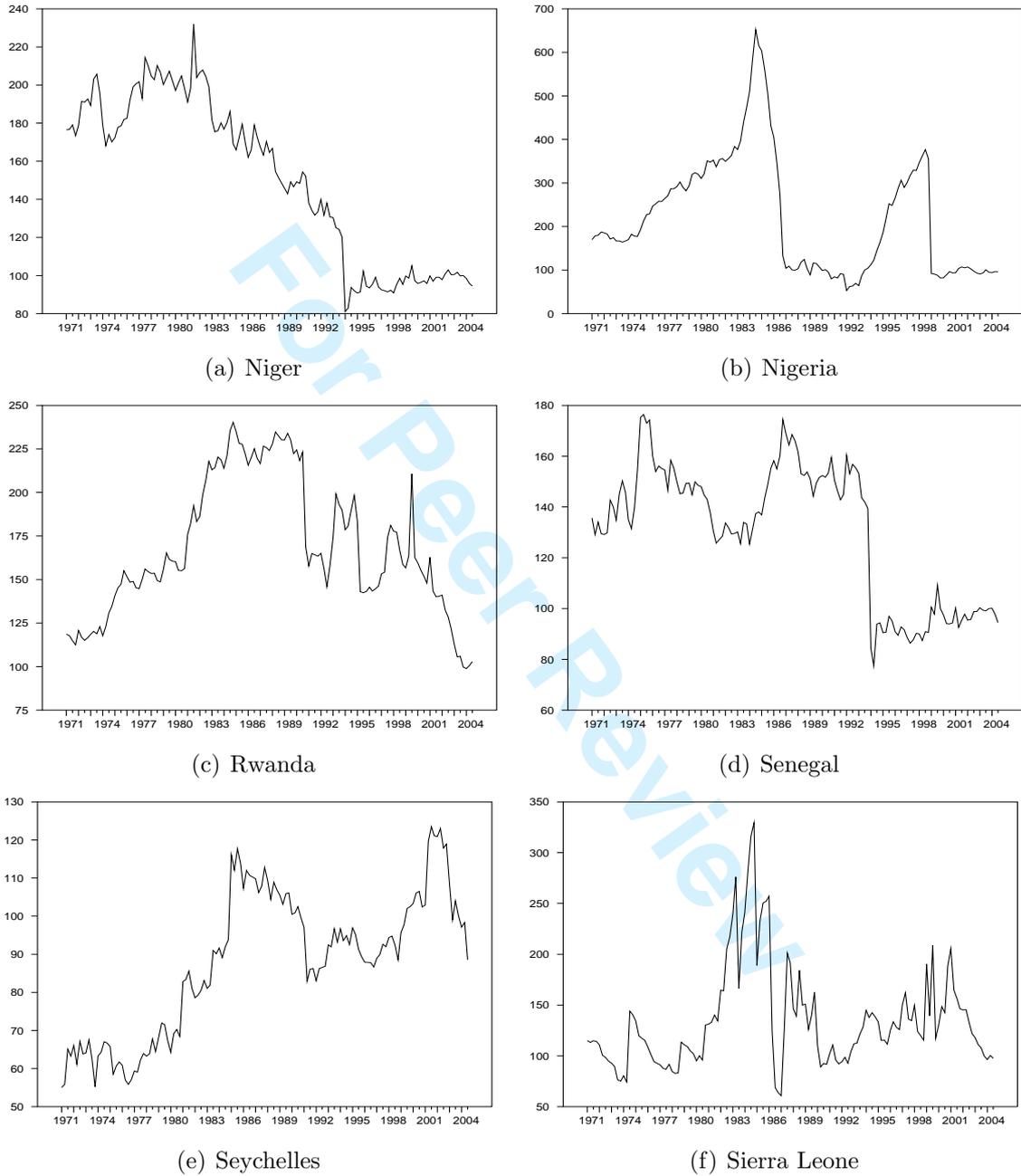
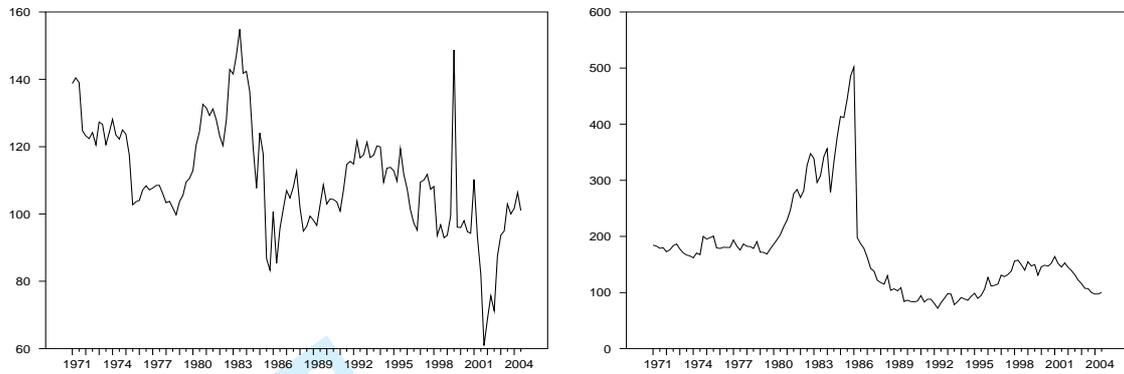
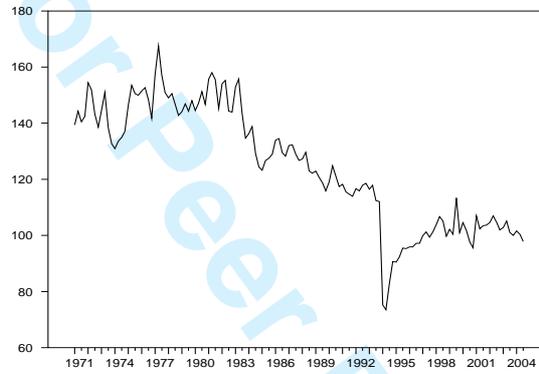


Figure 4: Real exchange rates (cont.)



(a) South Africa

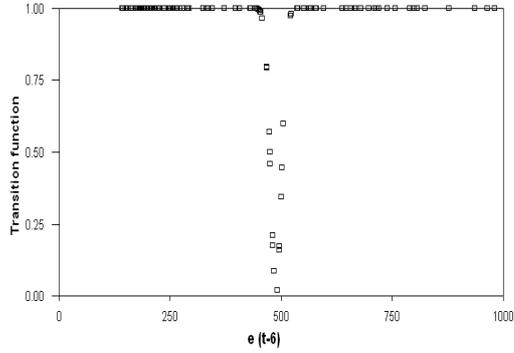
(b) Tanzania



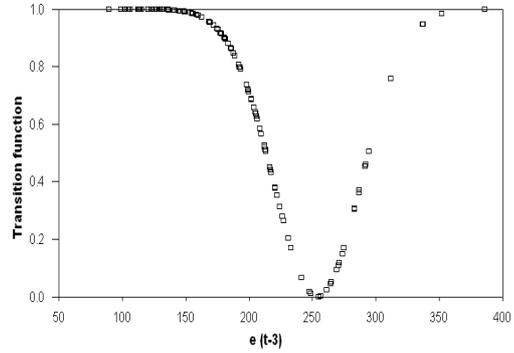
(c) Togo

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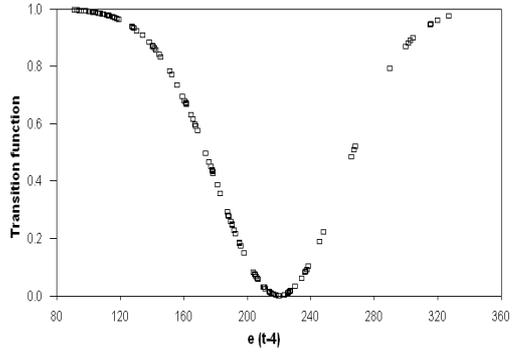
Figure 5: Estimated transition functions



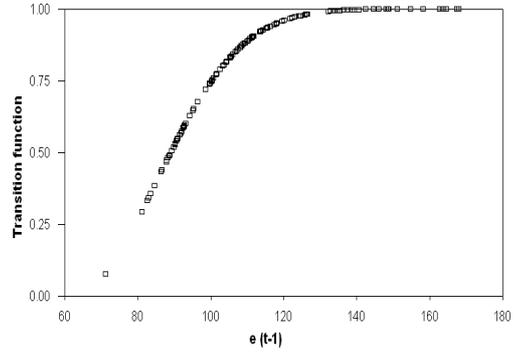
(a) Burundi



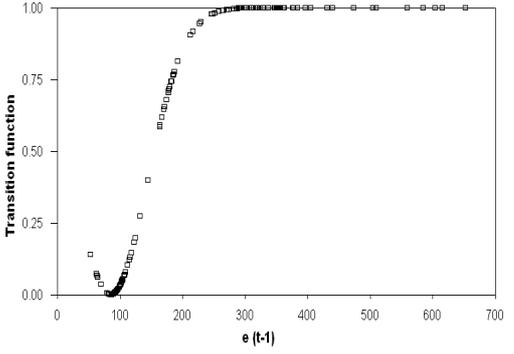
(b) Egypt



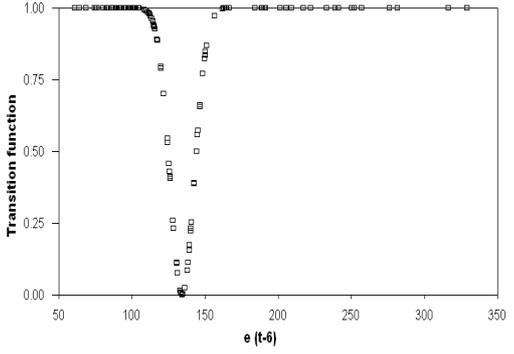
(c) Ethiopia



(d) Gabon



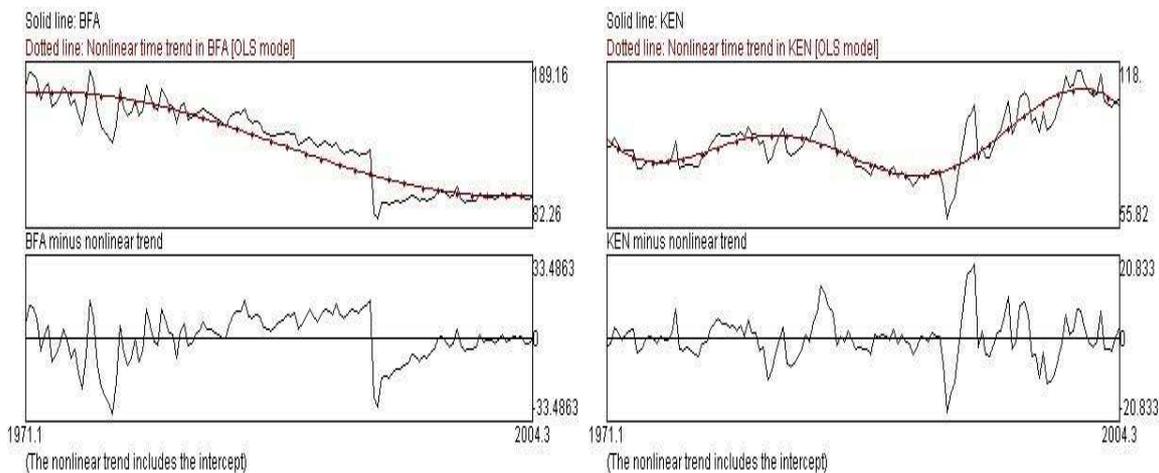
(e) Nigeria



(f) Sierra Leone

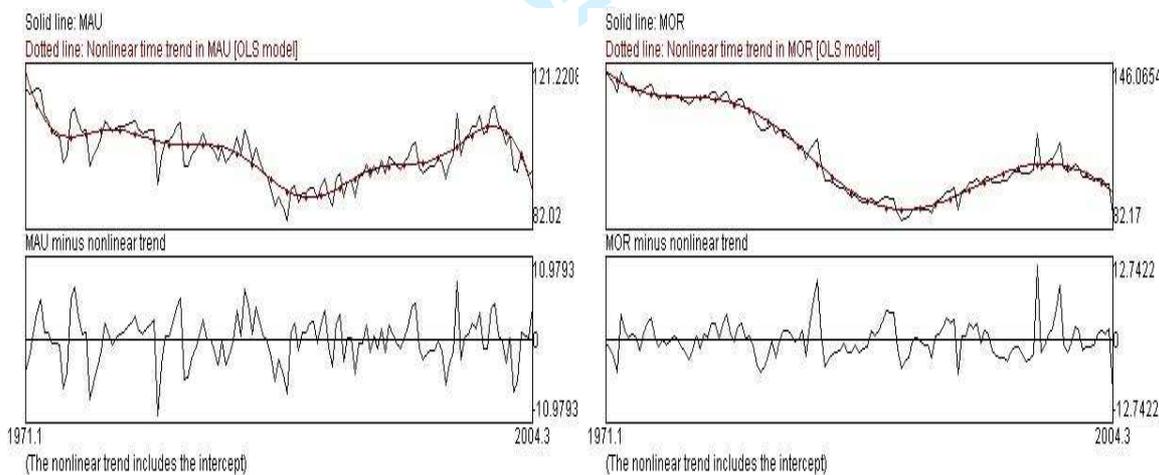
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Figure 6: Nonlinear trends



(a) Burkina Faso

(b) Kenya

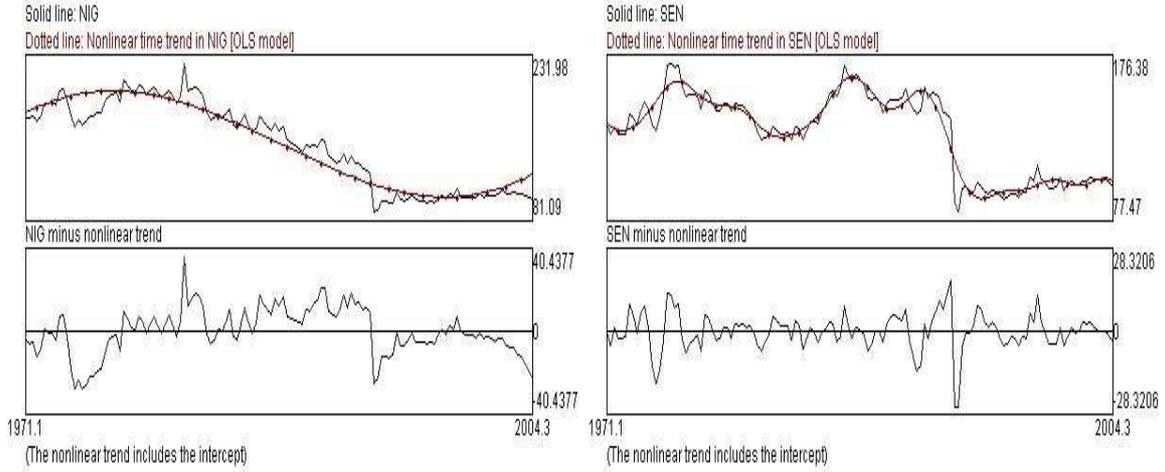


(c) Mauritius

(d) Morocco

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Figure 7: Nonlinear trends (cont.)



(a) Niger

(b) Senegal

(c) Seychelles

(d) Togo