Nonlinear approaches in testing PPP: Evidence from Southern African development community

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Highlights

• The BDS and the Fourier stationarity tests are employed.

• Both tests confirm the non-linear behaviour in the real exchange series.

• Furthermore, the result from the Fourier test provides evidence of an OCA in the SADC.

• The findings in this study will encourage integration initiatives in the region.

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Conflict of Interest

Abstract

In this paper two nonlinearity tests are employed: the nonparametric test developed by Brock, Dechert and Scheinkman - known as the BDS test and the Fourier stationarity test. The BDS non-linearity test detects whether the independent and identically distribute (iid) assumption of the time series used in the analysis holds true or not while the Fourier approximation mimics a wide variety of breaks and other types of nonlinearities. Both tests confirm the non-linear nature of real exchange series in SADC. The result from the Fourier stationary test further provides strong evidence of an OCA among the 11 SADC countries included in this study.

1. INTRODUCTION

The objective of the regional integration agenda in southern Africa is to create a fully integrated internationally competitive region to ensure economic growth and poverty reduction. The region faces a number of challenges achieving this goal but according to the African Development Bank (AfDB, 2011), the region is well positioned to take advantage of them. The success of the integration process depends on stable economies in terms of inflation rates, interest rates, exchange rates and levels of employment, among other factors (UNECA, 2010). Member states should consider regional integration as part of their broader strategic development objectives. In meeting these strategic objectives, it is important to understand the impact of regional economic integration on the economies concerned. It is even more important that SADC policy makers understand the unintended consequences of monetary integration. SADC has a monetary

integration agenda and therefore much interest in studying optimum currency area (OCA) criteria in SADC.

To arrive at more conclusive results it is advisable to focus not only on PPP but also on the real interest rate parity (IRP). However, in this paper, we analyse only one of the criteria of modern optimal currency area (OCA) theory, namely purchasing power parity (PPP) since there is evidence that IRP holds among SADC countries (Aziakpono, et al., 2012).

According to OCA theory, if PPP holds, one of the criteria of OCA theory is met and there is potential that countries may form an OCA and therefore move toward full monetary integration. Literature on PPP in SADC is very limited. Usually PPP is studied by exploring the time series properties of real exchange rates. The vast majority of studies are based on linear tests for mean-reversion in real exchange rates such as the Engle–Granger and Johansen cointegration tests. Arghyrou and Gregorious (2007), argue that real exchange rate time series is stationary and non-linear, as is common with many macroeconomic variables in the literature. However, the implicit assumption of linearity of real exchange rates has made the majority of existing empirical literature on long-run PPP behaviour inconclusive and/or inconsistent.

Does the PPP hold for SADC member countries as an OCA criterion toward full monetary integration? To answer this question we make use of the BDS nonlinearity test to test for nonlinearity of the real exchange rate series and Fourier unit root tests to make inferences about the suitability of SADC member states to form a monetary union, based on whether or not there is PPP. To the best of our knowledge, this study is the first to utilize the BDS test and flexible Fourier stationary test to test for long-run PPP in SADC economies. The BDS test detects the independent and identically distributed (*iid*) assumption of the time series used in the analysis,

while the Fourier approximation mimics a wide variety of breaks and other types of nonlinearities. The investigation of nonlinearities and asymmetries in macroeconomic behaviour constitutes an increasingly popular area of empirical research (Holmes, 2001 and Su et al., 2014). A prior study in the SADC region (Mokoena, et al., 2009) using real exchange rates argued that non-linear approaches to exchange rate adjustments are likely to provide a firmer basis for inference and stronger support for PPP in the long term in the region. However, the authors haven't made any inference about monetary integration in the SADC region. These findings provide firm ground for our analysis and hence we test the hypothesis that PPP will hold for most of the member countries of SADC. The major contribution of this paper to the literature is the fact that we apply non-linear methods (BDS & Fourier) to investigate PPP, and hence testing criteria of OCA, which have not been applied to this type of investigation before.

The remainder of this paper is organized as follows. Section 2 reviews the theoretical background of the study in brief; Section 3 presents the data and methodology; Section 4 presents the empirical results and discussions and the last section concludes the paper.

2. THEORETICAL BACKGROUND IN BRIEF

In this section we present a brief theoretical review on three interrelated theories, namely the exchange rate-, PPP-, and OCA theory as they relate to monetary integration. These areas of research have seen a revival following the experience of the European Monetary Union (EMU), which is perceived to have been beneficial to its members (Dellas and Tavlas, 2009). OCA theory, an approach for analysing monetary unions, dates back to 1961 with Mundell's (1961) seminal article setting out the theoretical foundations of the theory. Following Mundell's works,

McKinnon (1963), Kenen (1969) and other economists made great contributions to refine the theory. Given the experience of the EMU, the degree of real convergence should be one of the criteria satisfied by prospective entrants prior to entry into the euro area (Buiter, 2008). The degree of real convergence also determines the choice of exchange rate regime. PPP of the real exchange rate, as a real convergence criterion for OCA, is supposed to hold among the countries aspiring to form a monetary union. Here it is important to highlight the fact that why exchange rate equilibrium and hence PPP is an OCA criterion. This follows from the fact that equilibrium exchange rate is defined as the real exchange rate that allows an economy to reach its internal and external equilibriums. Exchange rate misalignments constitute not only an indicator of competitiveness, but also a useful indicator of the viability of a monetary union (Coulibaly and Gnimassoun, 2013). Indeed, large differences in competitiveness between countries within a monetary union could lead to current account imbalances, as evidenced by the recent experience of the Euro area (Coudert et al., 2013). In the absence of PPP among member states, it would be difficult for the common central bank to set up common monetary and exchange rate policies, which in turn could challenge the stability of the union. Furthermore, as exchange rate misalignments are affected by many variables related to the OCA theory like; price differences and economic fundamentals such as terms of trade shocks, trade and fiscal policies, and productivity shocks; they can be viewed as an overall indicator of the viability of a monetary union compared to other OCA criteria. Moreover, Fielding (2005) argues the importance of the real exchange rate as well as that of the output and price shocks in analysing the costs and benefits of a monetary union.

PPP is based on the law of one price and implies that exchange rates should equalize the national price levels of different countries in terms of a common currency (Taylor, 2003). According to PPP, any change in relative national price levels between two countries should lead to a corresponding adjustment in their bilateral nominal exchange rate. This suggests that variations in the real exchange rate represent deviations from PPP. Consequently, one avenue for investigating the empirical validity of PPP is to examine the characteristics of the real exchange rate. In particular, since PPP implies the mean reversion of real exchange rates or their tendency to eventually return to PPP-determined levels in response to any disturbance, whether real exchange rates are stationary or non-stationary, becomes an issue of central significance. Stationary real exchange rates imply mean reversion and thus provide empirical support for PPP, according to Taylor et al. (2001).

Regarding the time series dynamic properties of real exchange rates, there are two strands identified in the literature; namely, linear and nonlinear. Recent studies have focused on exploring the nonlinear behaviour of real exchange rates (Aksoy and Leon-Ledesma, 2007, McMillan, 2007 and Mokoena et al., 2009). The literature further identifies factors that lead to the nonlinear nature of real exchange rate series such as transaction costs in various markets and policy intervention or the actions of market agents in financial speculation and arbitrage behaviour (McMillan, 2007).

3. DATA AND METHODOLOGY

3.1 Data

This study covers a sample of 11 SADC member countries. Four member states of SADC namely the DRC, Lesotho, Namibia and Zimbabwe are not included in this study because of incomplete data. Monthly data for the period January 1995 to August 2012 are used in this study. All data relating to consumer price indices (CPI) (based on 2005=100) and nominal exchange rates relative to the US dollar are from the IMF International Financial Statistics. Each of the consumer price index and nominal exchange rate series is transformed into natural logarithms before the econometric analysis. In logarithmic form, the real exchange rate ($y_{i,t}$) is calculated as follows:

$$y_{i,t} = s_{i,t} + p^*_{us,t} - p_{i,t} \tag{1}$$

where $y_{i,t}$ is the logarithm of the real exchange rate against the US dollar, $s_{i,t}$ is the logarithm of the nominal exchange rate against the US dollar, and $p^*_{us,t}$ and $p_{i,t}$ respectively, are the logarithms of consumer price indices in the US and country 'i'.

As shown in Table 1, Zambia has the highest mean real exchange rate followed by Madagascar and Tanzania, whereas Botswana has the lowest followed by Seychelles and South Africa. All the countries' exchange rates are symmetrically distributed around the mean since the measures of *skewness* for each country is close to zero. The Jarque-Bera test however, reveals that the (log) real exchange rate series of SADC countries are not normally distributed. This normality test is significant for all countries in the sample at a 1 percent level of significance, except for Madagascar which is significant at the 5 percent level. However, in this study the focus is not to

Table 1: Descriptive Statistics and Normality Test of SADC (Log) Real Exchange Rate

Country	Country Code	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
Angola	AGO	4.460	4.479	5.627	1.966	0.551	-0.867	5.800	95.768***
Botswana	BWA	1.714	1.696	2.129	1.493	0.143	0.743	2.945	19.527***
Madagascar	MDG	7.438	7.453	7.894	7.171	0.152	0.114	2.155	6.767**
Malawi	MWI	4.629	4.680	5.107	4.083	0.215	-0.910	3.432	30.886***
Mauritius	MUS	3.300	3.335	3.492	3.093	0.111	-0.262	1.833	14.453***
Mozambique	MOZ	3.118	3.104	3.457	2.874	0.146	0.559	2.463	13.603***
South Africa	ZAF	1.909	1.884	2.528	1.592	0.193	0.975	3.992	42.273***
Seychelles	SYC	1.798	1.733	2.263	1.558	0.158	1.054	3.212	39.619***
Swaziland	SWZ	1.949	1.911	2.580	1.581	0.207	0.832	3.416	25.979***
Tanzania	TZA	6.911	6.937	7.161	6.635	0.118	-0.470	2.462	10.357***
Zambia	ZMB	8.476	8.601	9.066	7.904	0.316	-0.284	1.481	23.240***

Source: own computation from sample data (1995m1-2012m8)
Note: ** and*** indicate significance at the 5% and 1% levels, respectively.

examine nonlinearity versus non-normality in real exchange rate dynamics. As discussed in the next section we use the BDS test to make inferences about nonlinearity from the non-normality test. For the details on nonlinearity versus non-normality in real exchange rate dynamics see (Arghyrou & Gregoriou, 2008).

3.2 Methodology

Many nonlinear models may be used to investigate the dynamic behaviour of real exchange rates. Exponential smooth transition autoregressive (ESTAR) models, threshold autoregressive (TAR) models, smooth transition autoregressive (STAR) models, and Markov switching models (MS) are the most widely used for this purpose. To prove the question posed empirically we first use the Brock *et al.*(1996) test (here after referred to as the BDS test) to test for non-linearity of the real exchange rate series. Thereafter we use the flexible Fourier stationarity test proposed by Becker *et al.(*2006) to confirm nonlinearity and test for PPP. Su *et al.* (2012) also employ the Fourier stationarity test for the analysis of real exchange rate dynamics in 20 selected African countries for the fact that such series are of low frequency and often exhibit structural breaks. In such cases, flexible Fourier tests are more suitable, according to Enders and Lee (2009 and 2012) and Pascalu (2010).

3.2.1   BDS Nonlinearity Test

The motivation for the BDS test goes with the 'independent and identically distributed' (*iid*) assumption in time series data. To detect this assumption non-parametric tests like BDS are more appropriate than parametric tests. It is generally believed that a non-parametric model provides a more robust approach to statistical inference because it is more likely to approximately capture

the true underlying structure (Delegado & Robinson, 1992; Yatchew, 1998; Epstein & Scheider, 2003). Following Belaire & Coutreras (2002), let Y_t be a univariate real exchange rate series that is *iid* from some distribution. Also, define

$$P_A = \Pr(|Y_t - Y_s| < \varepsilon) \tag{2}$$

as the probability that two points are within a distance 'ε' of each other. Further we can define:

$$P_B = \Pr(|Y_t - Y_s| < \varepsilon, |Y_{t-1} - Y_{s-1}| < \varepsilon) \tag{3}$$

Equation 3 holds true as the probability of a history of the two observations being within ε of each other. Under independence of Y_t, the two events contained in the event B are independent and therefore $P_B = P_A^2$. One can estimate P_A and P_B and also $P_B - P_A^2$, which has an expected value of zero under the null hypothesis. To estimate the probability that two m length vectors are within ε, define:

$$c_{m,n}(\varepsilon) = \frac{2}{(n-m+1)(n-m)} \sum_{s=m}^{n} \sum_{t=s+1}^{n} \prod_{j=0}^{m-1} I_\varepsilon(Y_{s-j}, Y_{t-j}) \tag{4}$$

where

$$I_\varepsilon(Y_{s-j}, Y_{t-j}) = \begin{cases} 1 & \text{if } |Y_{t-1} - Y_{s-1}| < \varepsilon \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

Here n is the sample size and m is the so-called embedding dimension. Under the null of *iid*,

$$E(C_{m,n}(\varepsilon)) = (E(C_{1,n}(\varepsilon)))^m \tag{6}$$

Brock et al. (1996) show that, given an embedding dimension, m, and a value of the radius, ε, the BDS statistic is given as:

$$w_{m,n}(\varepsilon) = \sqrt{n-m+1} \frac{c_{m,n}(\varepsilon) - c_{1,n-m+1}^m(\varepsilon)}{\sigma_{m,n}(\varepsilon)} \tag{7}$$

It is asymptotically distributed as N (0, 1). This formula uses the square root of the consistent estimator

Table 2: The BDS test results for the monthly exchange rate time series (fraction of pairs)

m	BDS Statistics of SADC Real Exchange Rates – country codes as local currency/USD H_o = independent and identically distributed (*iid*) , is rejected in all cases										
	Country Codes										
	ANG	BWA	MDG	MWI	MUS	MOZ	ZAF	SYC	SWZ	TZA	ZMB
2	0.169	0.1796	0.1650	0.1779	0.181	0.175	0.176	0.181	0.175	0.174	0.181
3	0.2857	0.3015	0.2745	0.2957	0.303	0.290	0.295	0.302	0.294	0.291	0.304
4	0.3610	0.3827	0.3446	0.3711	0.385	0.364	0.373	0.381	0.375	0.366	0.387
5	0.4114	0.4342	0.3869	0.4177	0.437	0.408	0.423	0.431	0.425	0.411	0.440
6	0.443	0.465	0.4103	0.4444	0.470	0.432	0.452	0.461	0.456	0.435	0.475
$c_{1,n}(\varepsilon)$	0.7701	0.208	0.243	0.298	0.181	0.217	0.262	0.240	0.293	0.179	0.562
$k_1(\varepsilon)$	3824810	3821906	3831102	3823116	3817066	3814646	3830134	3825536	3821180	3818034	3806902
V-Statistic	0.7033	0.7027	0.7045	0.7030	0.7019	0.701	0.7042	0.7034	0.702	0.702	0.700
	P***<0.001, m=embedding dimension, included observations (n): 2332										

Source: own computation from sample data (1995m1-2012m8)

$$\sigma^2_{m,n}(\varepsilon) = 4\left[k^m + 2\sum_{j=1}^{m-1}k^{m-j}c^{2j} + (m-1)^2c^{2m} - m^2kc^{2m-2}\right] \quad (8)$$

where

$$c = c_{1,n}(\varepsilon)$$

$$k = k_n(\varepsilon) = \frac{6}{n(n-1)(n-2)}\sum_{t=1}^{n}\sum_{s=t+1}^{n}\sum_{r=s+1}^{n}h_\varepsilon(Y_t,Y_s,Y_r) \quad (8)$$

$$h_\varepsilon(i,j,k) = \frac{1}{3}\left[I_\varepsilon(i,j)I_\varepsilon(j,k) + I_\varepsilon(i,k)I_\varepsilon(k,j) + I_\varepsilon(j,i)I_\varepsilon(i,k)\right] \quad (9)$$

The consistent estimators $c_{1,n}(\varepsilon)$ and $k_n(\varepsilon)$ are in the class of U-statistics and, as is pointed out by Kanzler (1999) they are the most efficient estimators of *c* and *k*, respectively (See BDS test result in Table 2).

3.2.2 Stationary test with a Fourier function

Motivations for Fourier Unit Root Test

There have been methodological problems testing the validity of the PPP hypothesis and hence to obtain robust results about the existence of PPP, which would satisfy one of the criteria of OCA theory and support monetary union. First, one has to know the exact number and location of the breaks in the series. These are not usually known and therefore need to be estimated. This in turn introduces an undesirable pre-selection bias (see Maddala & Kim, 1998). Second, current available tests account only for one to two breaks. Third, the use of dummies suggests sharp and sudden changes in the trend or level. However, for low frequency data it is more likely that structural changes take the form of large swings which cannot be captured well using only dummies. Breaks should therefore be approximated as smooth and gradual processes (see Leybourne *et al.,* 1998). These arguments motivate the use of a recently developed set of unit root and stationarity tests that avoid this problem. Both Becker *et al.* (2006) and Enders and Lee

(2009) develop tests that model any structural break of an unknown form as a smooth process via Flexible Fourier transformations. Several authors, including Becker *et al.* (2006), Enders and Lee (2009), and Pascalau (2010), show that a Fourier approximation can often capture the behaviour of an unknown function even if the function itself is not periodic.

Marcela *et al.* (2003) and Narayan (2006) provide evidence that, when structural breaks are included for individual countries, the real exchange rate is stationary, implying support for PPP. Chang *et al.* (2012) applied a flexible Fourier stationary test to test the validity of long-run PPP in a sample of East Asian countries over the period January 1986 to October 2009. The empirical results from this study indicate that PPP does not hold for most of the East Asian countries, with the exception of Indonesia and Japan.

This procedure allows us to study the non-linear mean-reverting behaviour of PPP without having to specify the kind of nonlinear adjustment process. Enders and Lee (2004, 2009) develop their unit root test using the Lagrange Multiplier (LM) principle. As indicated by Pascalau (2010), the LM has increased power over the Dickey-Fuller (DF) approach. Following Enders and Lee (2004, 2009), we consider the following Data Generating Process (DGP):

$$y_t = \alpha_0 + \theta_t + \gamma_1 \sin(2\pi k t/T) + \gamma_2 \cos(2\pi k t/T) + \varepsilon_t \tag{10}$$

$$\varepsilon_t = \beta \varepsilon_{t-1} + u_t \tag{11}$$

$$\Delta y_t = \delta_0 + \delta_1 \sin(2\pi k t/T) + \delta_2 \cos(2\pi k t/T) + v_t \tag{12}$$

Table 3: Stationary Test with a Nonlinear Fourier Unit Root Test

Country Code	Obs. (T)	SSRs	$\hat{k}$ Frequency	$F_\mu(\hat{k})$	$\tau_\mu(\hat{k})$
AGO	200	1.295	1	220.18***	-7.033***
BWA	203	0.146	1	446.14***	-2.731***
MDG	210	0.227	1	418.91***	-3.841***
MWI	199	0.311	1	360.60***	-2.731***
MUS	204	0.052	1	554.05***	-1.298***
MOZ	199	0.131	1	446.58***	-3.529***
ZAF	203	0.248	1	392.53***	-3.004***
SYC	200	0.195	1	409.52***	-2.461***
SWZ	203	0.311	1	369.82***	-2.653***
TZA	199	0.058	1	525.94***	-3.085***
ZMB	203	0.349	1	357.99***	-0.410***

Source: own computation from sample data (1995m1-2012m8)

Where $k(1 \leq k \leq 5)$ is the number of frequencies of the Fourier function, 't' is a trend term, 'T' is the number of usable observations in the regression analysis and the term $\left[\delta_1 \sin(2\pi kt/T) + \delta_2 \cos(2\pi kt/T)\right]$ captures structural change in the real exchange rate series $\{y_t\}$. There is non-linearity and unknown breaks if the hypothesis $\delta_1 = \delta_2 = 0$ is rejected using the F-statistics $F(k)$ of *Table 3* in Enders and Lee (2004). The 'k' in $F(k)$ is the k_{min} obtained by regressing equation (10), which gives the minimum residual sum of squares (RSS) for different frequencies. The rejection of the above hypothesis is indicative of the presence of structural breaks. If θ=0 (using the τ_{DF} statistics from *Table 3* in Enders and Lee 2004), there is a unit root. However, if θ is significantly different from zero, we reject the unit root taking into account nonlinearity and possible structural breaks. Therefore the series $\{y_t\}$ is stationary. That is the

series exhibits stochastic convergence (Nyong, 2013). Further details on the methodological aspects of this paper can be found in Enders and Lee (2004, 2009). The Fourier unit root test result is presented in Table 3.

4. RESULTS AND DISCUSSION

Univariate unit root tests show that the real exchange rate data of the SADC economies included in this study have a unit root and every series is non-stationary implying that linear specification in this case would be inappropriate (Mokoena *et al.*, 2009). Our results on non-stationarity of the series are not reported but are available on request. As discussed in section 2, real exchange rate series of 11 SADC countries were used in this study with monthly data from 1995 to 2012. Since the real exchange rate is found stationary by using the unit root test with structural break(s), the effects of shocks such as real and monetary shocks that cause deviations around a mean value or deterministic trend are only temporary. Thus, PPP is valid in the long run in SADC region.

Table 2 provides the BDS statistics for all eleven exchange rate series of SADC countries included in the study. The results strongly suggest that the real exchange rate series of all the SADC countries included in this study reject the *iid* null hypothesis at the 1 percent level significance implying the non-normality and non-linearity of the series by inference. The Fourier unit root test results are reported in Table 3 with the time paths of SADC countries included in this study. Given the findings from the BDS test, the Fourier approximations appear reasonable to use in detecting unit roots in SADC countries.

The third column in Table 3 shows the sum of square of residuals (SSRs). The F-test for SSRs for all the SADC countries included in the study is significant at the 1 percent level. Given the result in column four a single frequency works best for all of the SADC countries in the study. As shown in the fifth column of Table 3 the statistical values are all significant at a 1 percent level of significance. This condition implies that both the sine and cosine terms in equation (12) in the methodology section should be included in the estimated model. Thus, the hypothesis $\delta_1 = \delta_2 = 0$ is rejected using the F-statistics, F (k), of *Table 3* in Enders and Lee (2004). The last column in Table 3 reports the results of unit root tests with a nonlinear function based on the estimated frequencies. All the T-statistic values for the 11 SADC member countries are significant at a 1 percent significance level. The Fourier function provides evidence favouring the validity of long-run PPP for the SADC member countries included in this study. The logarithm of real exchange rate is nonlinear stationary, implying that deviations from the real exchange rate are mean reverting towards the PPP equilibrium. These findings are in line with the findings by Chi-Wei Su *et al.* (2013) and Zerihun *et al.* (2014) that strongly support PPP equilibrium for African countries analysed in both studies respectively. These authors further suggest that trade barriers as well as interventions in the exchange markets could be behind this nonlinear behaviour.

5. CONCLUSION

The goal of the regional integration agenda in southern Africa is to create a fully integrated internationally competitive region to ensure economic growth and poverty reduction. However, countries in the region need to conform to OCA criteria before forming a monetary union. Given the long run dynamics of real exchange rates for the 11 member countries of SADC using the

Fourier estimation method, our findings come out in support of the region being an OCA based on the PPP criteria. As this study suggests policy makers in these 11 SADC countries could use PPP to predict a common exchange rate which would determine whether a currency is over- or under-valued and experiencing differences between domestic and foreign inflation rates.

This study provides valuable findings for policy makers which evaluate the readiness of SADC economies to complete the process of monetary integration in the region. The findings in this study imply that the region is potentially an OCA, which may proceed with the envisaged monetary integration in the region and move toward monetary union and eventually a single currency. The findings in this study may avert pessimistic views of integration initiatives in the African continent in general and the SADC region in particular. However, policy makers ought to use the findings as insightful results rather than complete evidence given the relatively small sample period used in the study compared with studies in OECD countries. This study further finds that SADC real exchange rate series exhibit nonlinear behaviour. Exploring the explanations behind nonlinear behaviour of SADC real exchange rate series requires further research. Such studies are critical not only in respect of their contribution to the literature on OCA theory in SADC, but also to provide more substantial empirical evidence to policymakers.

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