Robust analysis of convergence in per capita GDP in BRICS economies

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ABSTRACT: Whilst the issue of whether or not per capita GDP adheres to the convergence theory continues to draw increasing attention within the academic paradigm, with very little consensus having been reached in the literature thus far. Our study contributes to the literature by examining the stationarity of per capita GDP for BRICS countries using annual data collected between 1971 and 2015. Considering that our sample covers a period underlying a number of crisis and structural breaks within and amongst the BRICS countries, we rely on a robust nonlinear unit root testing procedure which captures a series of unobserved structural breaks. Our results confirm on Brazil and China being the only two BRICS economies who present the most convincing evidence of per capita GDP converging back to it's natural equilibrium after an economic shock, whilst Russia and South Africa provide less convincing evidence of convergence dynamics in the time series and India having the weakest convergence properties.

Keywords: Per capita GDP; Convergence; unit root tests; nonlinearities; structural breaks; BRICS Emerging economies.

JEL Classification Code: C12; C13; C21; C22; C51; C52; O47.

1 INTRODUCTION

The debate concerning the stationary properties of real GDP or per capita GDP gained prominence following the novel study of Nelson and Posser (1982) whose finding of non-stationary behaviour in real GDP for the US economy has received overwhelming empirical support in the academic paradigm (see Cogley (1990), Kormendi and Meguire (1990), Ben-David and Papell (1995), Cheung and Chinn (1996), Rapach (2002)). Empirically, the existence of unit root behaviour in real per capita GDP implies that aggregate demand shocks have permanent effects on output growth and that real GDP never reverts back to it's natural rate in the face of disturbances to the economy. Theoretically, unit root behaviour in real GDP is contrary to both Neo-Keynesian and monetarist economic fundamentals which otherwise insinuates that business cycles evolve as stationary fluctuations around a deterministic trend. Thus, when real GDP is found to be a non-stationary process, Keynesian economics suggests that active monetary and fiscal stabilization policies must be implemented in order to ensure that the economy reverts to it's state of potential GDP (Solarin and Anoruo, 2015).

Notably, the proposition of a unit root process in real per capita GDP output has not gone uncontested as there exists a handful of studies which find that real GDP evolves as a stationary process and by doing so, advocate that the business cycle is a transitory phenomenon, with real output growth adjusting back to its natural rate over the steady-state (see Duck (1992), Haan and Zelhorst (1993), Ohara (1999), Fleissig and Strauss (1999), Vougas (2007)). This view is consistent with New Classical economics, which assumes that disturbances to the economy will be self-corrected by 'invisible forces' working within the economy and these 'forces' continuously revert output growth towards it's potential. When real output growth is thus found to be trend stationary, the logical implication is that government-initiated structural reforms policies aimed at changing economic fundamentals will have at least a semi-permanent effects on long-run growth path (Ozturk and Kalyoncu, 2007). Therefore, the modelling of real output growth as being either a trend stationary or a difference stationary process has far reaching ramifications, not only from an empirical or academic perspective, but also towards practical macroeconomic policy making and forecasting (Nelson and Posser, 1982).

Nonetheless, research conducted up-to-date has been criticised on the premise of two arguments. Firstly, it is argued that much of the available empirical literature has assumed linearity in the evolution of per capita GDP over the long term (see Loewy and Papell (1996); Nelson and Murray (2000) for the US; Rapach (2002) and Narayan (2007) for G7 countries, Bahmani-Oskooee and Akbari (2015) for the OPEC countries; Cogley (1990), Kormendi and Meguire (1990), Fleissig and Strauss (1999), Christopoulos (2006)) for Asian countries; as well as Narayan (2008), Tiwari et. al. (2012), Tiwari and Suresh (2014) for OECD countries). Nonetheless, Enders and Granger (1998), Craner and Hansen (2001), Kapetanois et al. (2003), Ucar and Omay (2009), Kruse et al. (2011), have all demonstrated on how the assumption of linearity when testing for unit roots in macroeconomic time series undermines the testing ability in distinguishing unit roots from stationary, nonlinear processes.

The second criticism directed towards the current empirical works is their frequent ignorance of important structural breaks in per capita GDP. As pointed out in the seminal paper of Perron (1989), failing to account for structural breaks caused by exogenous shocks in macroeconomic time series produces a low testing power in identifying random walk structures. Zivot and Andrews (2001), Lumsdaine and Papell (1997), Lee and Strazicich (2004, 2013) as well as Kim and Perron (2009) later confirmed the 'structural break criticism' albeit under varying assumptions under the null and alternative hypotheses of the resting regressions. Notably, not all the literature is prone to this criticism as Ben-David et al. (2003), Narayan and Smyth (2005), Narayan (2008), Cunado (2011) for 15 OPEC countries and Kejriwal and Lopez (2013) for 19 OECD countries amongst others have previously applied a variety of unit root tests which account for exogenous and endogenous shocks. Nevertheless, in more recent literature there has emerged a consensus on structural breaks within time series being best captured using an unobserved frequency component of a Fourier function (see Gallant (1981), Becker et al. (2006), Enders and Lee (2012), Rodrigues and Taylor (2012) and Su and Nguyen (2013)). FFF based unit root tests have been recently applied with a high degree of success by Christopoulos (2006); Pascalau (2010); Su and Chang (2011); Shen et al. (2013); Chang et al. (2012) and Ying et al. (2014) in the context of per capita GDP for the case of OECD countries, the US, CEE countries, eastern European countries and African countries, respectively. In this study we extend upon the body of novel empirical literature towards BRICS economies as the most dynamic group of emerging economies since the turn of the 21st Century.

Currently, the BRICS (Brazil, Russia, India, China and South Africa) countries have taken centre stage in global economics and these countries are believed to have a common agenda of becoming increasingly influential in international economic governance. Whilst BRICS countries collectively boast an impressive combination of market productivity growth levels on a global front, the same cannot be mentioned for their per capita GDP growth rates, which can be described as being moderate at best. The relatively low levels of real GDP per capita associated with BRICS countries are concerning statistics since per capita GDP has been found to be the most adequate measure of economic welfare (Dipietro and Anoruo, 2006). Therefore, our study's main concern is that whilst BRICS countries collectively present strong market economies, the overall development in these countries is hindered by their fragile social economies as measured by their per capita GDP performance. In our study, we examine the integration properties for a panel of time series consisting of per capita GDP growth rates collected for each of the BRICS countries. We carry out our empirical analysis by using the nonlinear unit root testing procedure described in Kapetanois et al. (2003) which we augment with a Flexible Fourier form (i.e. FFF). To the best of our knowledge, our study becomes the first to do so for the BRICS countries as a collective unit.

We proceed through the rest of the paper as follows. The next section provides an overview of real GDP per capita in BRICS countries. The third section presents the data and methodology whereas the empirical results are presented in the fourth section. The study is then concluded in the fifth section of the paper.

2 AN OVERVIEW OF REAL PER CAPITA GDP IN BRICS ECONOMIES

The acronym BRIC (which in December 2010 became BRICS after China pushed for the inclusion of South Africa) was first coined by O'Neal (2001), who in a Goldman Sachs global economics working paper advocated for the inclusion of BRIC (Brazil, Russia, India and China) countries within the G7 group of countries in order to allow for more effective global policymaking. At that time, the aggregate size of the BRIC countries was 23.3 percent of world GDP and O'Neal's (2001) seminal work predicts that the economies of the BRIC countries will eclipse most of the G7 countries by the year 2050. Currently, BRICS countries collectively account for 40 percent of the world's total foreign reserves, with the four BRIC countries being in the top ten largest accumulators of reserves worldwide and this contributes to the influence which these countries have on the global economy. Whilst growth potential in BRICS countries has been diligently noted, with China being expected to be largest economy in the world within the next two decades, less optimism exists concerning the per capita GDP levels. This is mainly because BRICS countries are generally characterized by overpopulated economies which collectively account for almost 40 percent of the world's population, with the four BRIC countries being listed amongst the top 10 most populous countries in the world. Therefore, the high levels of real GDP in BRICS countries are often offset by the high population rates in these countries and this becomes exceedingly obvious as none of the BRICS countries are ranked in the top 70 countries worldwide in terms of per capita GDP. Moreover, high levels of income inequality exist within the BRICS countries, especially in South Africa and Brazil which are currently ranked at forth and thirteenth place, respectively, as the most unequal countries in the world. BRICS countries are also notorious for having low levels in the quality of governance and therefore substantial institutional reforms are needed in these countries if they want to exploit their future growth potentials (Oehler-Sincai, 2015). However, given relatively high literacy rates in BRIC countries, especially in Russia, India and China, ensures that the rising population increases the quality of workforce, which, in turn, could translate into improved output growth levels in these countries. Currently BRICS countries account for approximately 45 percent of the world's total labour force.

Historically, per capita GDP growth in BRICS countries have fluctuated variously over the last five decades. As can be observed from Table 1, world averages of per capita GDP growth rates were relatively high in the 1960's, even though the figures from the BRICS countries (with the exception of Brazil and Russia) were, at the time, below world averages. The oil embargo of 1973 by OAPEC (Organization of Arab Petroleum Exporting Countries) triggered by sharp increases in oil and energy prices which led to global recession experienced throughout the 1970's to early 1980's. As can also be seen in Table 1, world per capita GDP rates plummeted between 1973 and 1979 as a consequence of the global recession. In BRICS countries, per capita GDP growth fell sharply in Russia, India and South Africa between 1973 and 1979, whereas Brazil and China began to pick up momentum in these times as average per capita GDP growth in these countries was well above world averages. In a turn of events, India quickly surpassed Brazil to join China as being leaders in per capita GDP growth for BRICS countries in the 1980's, with India's per capita GDP growth rates more than tripling from the previous decade. The remaining BRICS countries of Russia, Brazil and South Africa experienced falling levels of per capita GDP in the 1980's due to political instability in South Africa; unsustainable budget deficits, hyperinflation and overvaluation of currencies experienced in Brazil as well as the failure of the Agriculture sector and the very low oil prices in Russia. In the early 1990's, BRICS countries began to follow in pursuit of so-called neoliberal policies, which basically involves trade and financial liberalization, privatization of state-owned enterprises and capital account convertibility (Nassif et. al., 2015). At this time per capita GDP was reaching it's lowest in terms of world averages as well as for averages in Brazil, Russia and South Africa. Contrariwise, per capita GDP growth continued to rise steadily for both India and China throughout the decade of the 1990's.

In the late 1990's, a number of countries worldwide were affected by the Asian financial crisis of 1997 caused by a collapse of the Thai currency which spread to other ASEAN countries. The Asian financial crisis resulted in in large scale withdrawal of investment funds from many emerging economies worldwide, inclusive of BRICS countries.

Brazil, Russia and South Africa were affected the most in terms of economic welfare as all three of these countries suffered negative per capita GDP growth rates in the 1998. Moreover, the Russian currency crisis of 1998 further added to Russia's economic woes, as the country was forced to devalue it's currency as well as default it's private and public debt. And yet, during the period of 2000 to 2008, per capita GDP in all BRICS countries exceeded world averages, with Russia surpassing India to have the second best per capita GDP rate amongst BRICS countries just behind that of China's. Russia's speedy economic recovery after the Ruble crisis is largely attributed to her currency devaluation and implementation of pro-growth economic policies. However, the crashing of the US housing market in 2007 and the subsequent collapse of the Lehman Brothers Holdings Inc. in 2008, sparked the infamous global financial crisis which has been described by many as the worst financial crisis since the Great Depression of the 1930's. Brazil, Russia and South Africa are the only BRICS countries which experienced negative per capita GDP growth rates during the accompanying global economic recession of 2009, averaging -1.1 percent, -7.8 percent and -2.9 percent per capita GDP growth, respectively. Notably, during the global recession both China and India continued to average rather impressive per capita GDP growth rates of 7.0 percent and 8.7 percent, respectively. Both India's and China's steadfast improvement of per capita GDP growth rates during this recession period is primarily due to strong current accounts and stimulus packages used by the governments of these Asian countries. And even though the other BRICS countries (i.e. Brazil, Russia and South Africa) made quick recoveries from the aftermath of the crisis, economic welfare performance in these countries during the post-crisis era has been rather disappointing, with per capita GDP growth rates in Russia and South Africa falling below world averages in periods subsequent to the global recession. On the other hand, both India and China continue to be current leaders in per capita GDP growth rates among the BRICS countries in the post-crisis even though India currently has the second lowest dollar values of per capita GDP within these countries, with China, Brazil, Russia and South Africa being ranked first, second, third and last within the bloc, respectively.

Table 1: Average per capita GDP rates: BRICS countries vs the world (1960-2015)

Period	World	Brazil	Russia	India	China	South Africa
1960-1972	3.23	3.26	3.6	1.3	2.71	3.03
1973-1979	1.89	4.95	0.30	0.91	4.59	0.83
1980-1989	1.28	0.82	-2.39	3.34	8.19	-0.25
1990-1999	1.17	0.27	-4.89	3.73	8.77	-0.8
2000-2008	1.84	2.44	7.32	5.02	9.74	2.59
2009-2017	0.78	1.77	0.68	6.05	8.15	0.28

Note: Authors own computation using per capita GDP growth figures collected from UNTAC and Angus Maddison online databases. Since per capita GDP rates are only available from 1991 onwards on the FRED database for the Russian economy, we collect the remaining per capita GDP growth data (i.e. 1960-1991) from the Angus Maddison database under the heading of Union of Soviet Socialist Republics (USSR) time series data.

3 DATA AND METHODOLOGY

The data used in our empirical study consists of the dollar value of per capita real GDP collected for Brazil, Russian, India, China and South Africa. All data has been collected in annual intervals and has been collected between the periods of 1971-2017 from the United Nations Conference on Trade and Development (UNCTAD) online database. Note the exception of GDP per capita data for Russia which are only available from 1992, a period which coincides with the dissolving of the Union of Soviet Socialist Republics (USSR) and the establishment of the Russian Federation. The summary statistics the time series variables are reported in Table 1. Over the entire sample period, Brazil exhibits the highest dollar value average of per capita GDP, followed by Russia, South Africa, Chain and finally India. In terms of volatility, as measured by the standard deviations, Russia has the most volatile per capita GDP, followed by Chain, Brazil, South Africa and China. Moreover, the reported Jarque-Bera statistics fail to reject the null hypothesis of the third and fourth moments of the per capita GDP having a normal, 'bell-shaped' distribution for all the observed series, which is expected as these are non-financial time series.

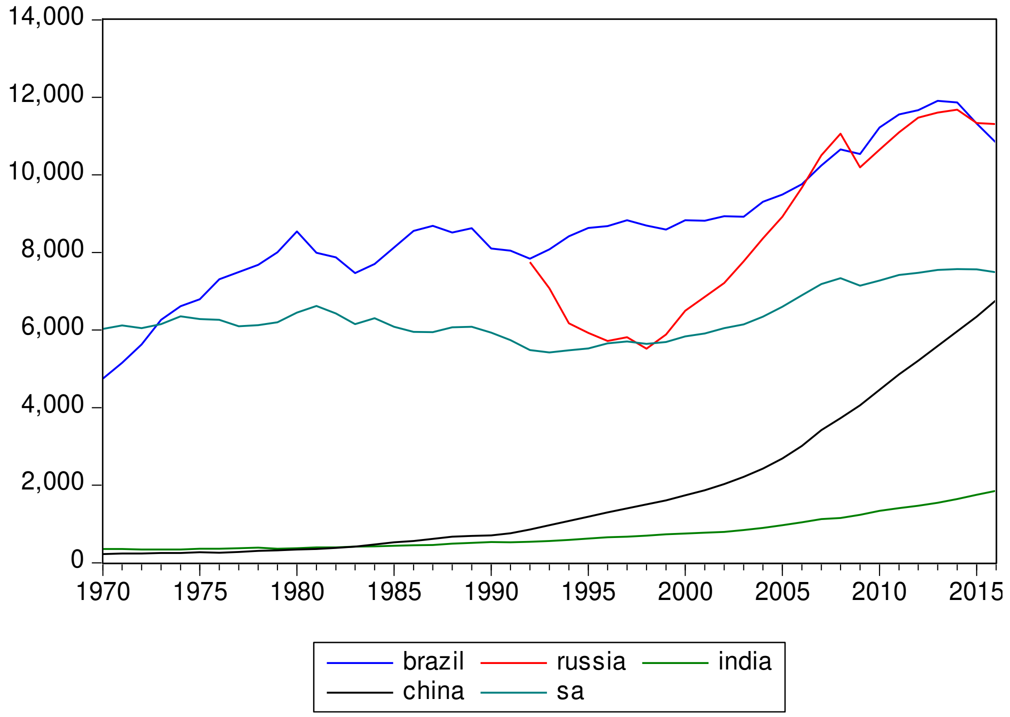
Table 2: Summary statistics

	Brazil	Russia	India	China	South Africa
Mean	9746.21	8643.91	1026.63	3051.18	6496.75
Medium	9308.87	8362.12	899.64	2425.91	3643.87
Maximum	11911.96	11680.78	1854.77	6772.57	7572.89
Minimum	7836.97	5516.74	542.33	856.65	5424.31
Std. dev.	1304.74	2279.13	402.27	1862.26	831.19
Skew.	0.379	0.02	0.60	0.61	0.07
Kurt.	1.70	1.38	2.10	2.03	1.30
J-B	2.37	2.72	2.36	2.52	3.02
Prob.	0.31	0.26	0.31	0.28	0.22

Note: Authors own calculations.

We also examine the time series in their raw excel format to manually identify potential structural break periods in the form of 'recessionary periods' associated with each country. Theses recessions are defined as periods in which per capita GDP consecutively decreased from one year to the next or more. For Brazilian recessions we identify 8 periods (i.e. 1980-1983, 1987-1988, 1989-1993, 1998-1999, 2000-2001, 2002-2003, 2008-2009 and 2013-2016); for Russia we find 4 periods (1992-1996, 1997-1998, 2008-2009 and 2014-2016); for India there are 5 periods (i.e. 1970-1972, 1973-1974, 1975-1976, 1978-1979 and 1990-1991); for China 1 periods (i.e. 1975-1976) whilst for South Africa we count 8 periods 1970-1972, 1974-1977, 1981-1983, 1984-1987, 1989-1993, 1997-1998, 2008-2009 and 2014-2016). In order to appropriately account for these identified recessions we shall specify a unit root testing procedure which can account for multiple unobserved smooth structural beaks. Moreover, based on a visual inspection of the time series provided in Figure 1, none of the time series appears to be linear process which raises further concerns of possible asymmetries in the data generating process of the observed variables.

Figure 1: Time series plots of variables



In considering the above mentioned, it is imperative to account for asymmetries and possible structural breaks in the design of the unit root testing regressions to be used in our empirical analysis. Beechey and Osterholm (2008), Murray and Anoruo (2009), Cuestas and Garratt (2011), Shelley and Wallace (2011) and Solarin and Anoruo (2015) all recommend that nonlinearities in the per capita GDP time series can be best captured as an exponential smooth transition autoregressive (i.e. ESTAR) function. Kapetanois et al. (2003) particularly specify the following ESTAR unit root testing regressions:

$$\Delta y_t = \gamma_i y_{t-1} [1-\exp(-\Phi y_{t-1}^2)] + \sum_{j=1}^{p} \rho_i \Delta y_{t-i} + e_t \quad (1)$$

From which the unit root null hypothesis can be tested in a conventional manner of imposing the restriction $\Phi = 0$. However, given the existence of nuisance parameters under the null hypothesis, directly testing for unit roots using regression (1) is not feasible. To circumvent this, Kapetanois et al. (2003) follow Luukkonen et al. (1988) by computing the first order Taylor approximation, of which the following auxiliary regression can be specified:

$\Delta y_t = \delta_i y_{t-1}^3 + e_t$ (2)

And by adding lags to the auxiliary regression which are designed used to soak up serial correlation in the residuals, results in the following nonlinear testing regression:

$\Delta y_t = \mu_t + \delta_i y_{t-1}^3 + \sum_{j=1}^{p} \rho_j \Delta y_{t-j} + e_t$ (3)

And henceforth the null hypothesis of a unit root is formally tested as:

$H_0\text{: } \delta_i = 0$ (4)

Against the ESTAR stationary alternative of:

$H_0\text{: } \delta_i < 0$ (5)

Using the following test statistic:

$$t_{kss} = \frac{\sum_{t=1}^{T} y_{t-1}^3 \, \Delta y_t}{\sqrt{\widehat{\sigma^2} \sum_{t=1}^{T} y_{t-1}^6}} \quad (6)$$

Which has the following asymptotic distribution:

$$t_{kss} \Rightarrow \frac{\frac{1}{4} W(r)^4 - \frac{1}{4} \int_0^1 W(r)^2 dr}{\sqrt{\int W(r)^6 dr}} \quad (7)$$

Where W(r) is the standard Brownian motion. The computed t_{kss} statistic is then compared against the corresponding critical values which are tabulated in Kapetanois et al. (2003). Note that regressions (1) through (7) do not cater for cases of time series with a nonzero mean and thus Kapetanois et al. (2003) suggest that the test can be additionally performed with de-meaned data i.e.

$$y_{\text{de-meaned}} = y_t - y^* \tag{8}$$

As well as for the de-trended case:

$$y_{\text{de-trended}} = y_t - \hat{u}_t - \hat{\delta} \tag{9}$$

With y^* being the sample mean, $\hat{u}_t$ and $\hat{\delta}$ are the OLS estimates of u_t and δ. As previously mentioned, we supplemented the KSS test with a flexible Fourier form (FFF) approximation which by design can capturing a sequence of smooth structural breaks using the low frequency components of a Fourier approximation (Becker et al., 2006). The general flexible Fourier function can be specified as follows:

$$d(t) = \beta_0 + \sum_{k=1}^{n} a_k \sin\left(\frac{2\pi Kt}{T}\right) + \sum_{k=1}^{n} b_k \cos\left(\frac{2\pi Kt}{T}\right), \; n \le T/2 \tag{10}$$

Where n is the number of cumulative frequency components, a and b measure the amplitude and displacement of the sinusoidal and K is the singular approximated frequency selected for the approximation. Becker et al. (2006) and Enders and Lee (2012) suggest the restriction of n=1 (i.e. single frequency components) to avoid overuse of degrees of freedom and over-fitting as well as to ensure that the evolution of the nonlinear trend is gradual over time. The resulting low frequency component can mimic structural changes which are characterized by spectral density functions which tend towards a zero frequency. In placing the restricting n=1 in equation (10) and substituting the resulting regression into (3) results in the following augmented unit root testing regression:

$$\Delta y_t = \delta_i y_{t-1}^3 + \sum_{j=1}^{p} \rho_j \Delta y_{t-j} + a_i \sin\left(\frac{2\pi Kt}{T}\right) + b_i \cos\left(\frac{2\pi Kt}{T}\right) + v_t, \qquad t = 1,2,\ldots,T. \tag{11}$$

Where v_t is a $N(0, \sigma^2)$ process. Following recommendations of Enders and Lee (2012) we perform a grid search for optimal values of frequency, K, and lag length, j, which is obtained by selecting the estimated regression which produces the lowest sum of squared residuals (SSR).

4 EMPIRICAL RESULTS

The ADF (Dickey and Fuller, 1979), PP (Phillips and Perron, 1988) and KPSS (Kwaiotkowski et al., 1992) tests are amongst the most commonly used unit root testing procedures used in the examining the intergration properties of the per capita GDP time series (see Cogley (1990), Kormendi and Meguire (1990), Fleissig and Strauss (1999), Nelson and Murray (2000) and Rapach (2002)). We therefore begin our empirical analysis by performing these conventional unit root tests for the per capita GDP series for the BRICS countries. In order to effectively test for unit roots it is critical to determine the optimal lag used for each test regression. We set our maximum lag length on the test regressions at 6 lags, and consecutively estimate whilst simultaneously trimming down the lag length until lag zero. The optimal lag length selected is that associated with the minimum AIC and SC values.

Table 3 reports the results of these tests with Panel A bearing the results of the tests performed with a drift whereas Panel B displays the results inclusive of both a drift and a trend. As can be easily observed from both panels in Table 1, the findings from conventional unit root tests tend to lean towards the implication of a non-stationary per capita GDP series in all BRICS countries. The findings presented in Panel A unanimously reject stationarity in all 15 cases whilst those in Panel B identify 13 out of the 15 cases which find unit roots. The two exceptions were found for KPSS test with both an intercept and a trend performed on Brail and China. Notably, this overwhelming finding of non-convergence of per capita GDP levels are in line with for those performed for similar developing and emerging economies as found in Smyth and Inder (2004) for Chinese provinces; Lima and Resende (2007) for Brazil; and Narayan (2008) for Asian countries such as India and China, as well as Murray and Anoruo (2009) for African countries inclusive of South Africa.

Table 3: Preliminary unit root tests on levels of time series

	ADF		PP		KPSS	
	t-stat	lag	t-stat	lag	t-stat	lag
Panel A: intercept						
Brazil	-2.31	0	-2.10	3	0.81***	5
Russia	0.08	0	-0.24	2	0.63**	3
India	12.58	0	17.14	7	0.80***	5
China	1.64	1	11.72	4	0.77***	5
South Africa	-0.61	1	-0.23	3	0.40*	5
Panel B: drift and trend						
Brazil	-2.71	1	-2.59	3	0.10	5
Russia	-3.20	0	-3.02	2	0.11	3
India	3.98	0	6.05	8	0.22***	5
China	1.24	1	4.15	4	0.22***	5
South Africa	-1.31	1	-0.92	2	0.20**	5

Notes: '***', '**', '*' denote 1, 5 and 10 percent critical levels respectively

Nonetheless, we do not consider the results obtained from these preliminary unit root tests as reliable since it is well acknowledged that these conventional unit root tests suffer from low testing power in rejecting the unit root null hypothesis when the autoregressive polynomial root is close to but less than unity (Ng and Perron, 2001). Moreover, these conventional tests suffer from severe size distortions when the moving-average polynomial of the first differenced series has a large negative root (Perron and Ng, 1995). One way of circumventing these criticisms would be to follow Elliot et al. (1996) DF-GLS de-trending unit root procedure which is known to produce strong power within a small, finite sample size in comparison to regular testing procedures. In addition to these tests, Ng-Perron (1995, 2001) introduced a class of modified unit root tests based on the local de-trending technique of Eliot et al. (1996) that are more robust to size distortions and power when the modified tests are estimated using an autoregressive spectral density estimator at frequency zero. The authors particularly argue for the use of a modified AIC in selecting an optimal truncation lag, since this modified information criterion better accounts for the ‘costs of overfitting’ and this bears directly on the power of the test regression in smaller samples.

The findings of the aforementioned ‘modified’ tests performed on our empirical series, along with their selected optimal lag lengths are reported in Table 4. When the test is performed with a drift as shown in Panel A of Table 4, the unit root null hypothesis of both ERS and N-G tests cannot be rejected for 21 out of the 25 cases and this finding is consistent across all BRICS countries with the sole exception of India, for which all Ng-Perron statistics (MZA, MZT, MSB and MPT) manage to reject the unit root null hypothesis at all levels of significance. When a trend is added to the test regression, then we find unit roots in 17 out of the 25 cases with Ng-Perron tests rejecting the unit root hypothesis for Indian data at all critical levels and for Chinese data at a 10 percent critical level. Therefore these modified test statistics find per capita GDP convergence in India and to a lesser extend China, but in none of the remaining countries.

Table 4: Preliminary unit root tests on levels of time series

	Unit root test statistic				
	DF-GLS	MZA	MZT	MSB	MPT
	t-stat [lag]	t-stat [lag]	t-stat [lag]	t-stat [lag]	t-stat [lag]
Panel A: intercept					
Brazil	0.25[0]	0.85[0]	0.83[0]	0.97[0]	64.11[0]
Russia	-0.82[1]	-1.37[1]	-0.66[1]	0.49[1]	13.97[1]
India	0.54[3]	-55.43***[3]	-5.06***[3]	0.09***[3]	0.93***[3]
China	-0.25[1]	1.65[1]	0.68[1]	0.42[1]	19.22[1]
SA	-0.62[1]	-1.74[1]	-0.64[1]	0.37[1]	10.27[1]
Panel B: drift and trend					
Brazil	-2.11 [1]	-10.27 [1]	-2.22[1]	0.22[1]	9.07[1]
Russia	-2.16 [1]	-2.47 [1]	-1.09 [1]	0.44 [1]	36.07 [1]
India	-0.65[3]	-212***[3]	-10.2***[3]	0.05***[3]	0.63***[3]
China	-1.58[1]	-17.27*[1]	-2.73*[1]	0.16**[1]	6.49*[1]
SA	-1.37[1]	-4.03[1]	-1.34[1]	0.33[1]	21.75[1]

Notes: '***', '**', '*' denote 1, 5 and 10 percent critical levels respectively.

Whilst it is reasonable to appreciate the sample size advantages evidently presented by the ERS and N-G tests, we consider this empirical procedure as rather incomplete by itself as the tests performed so far have not addressed the issue of possible asymmetries and structural breaks which were visually highlighted for our empirical data in the previous section of the paper. Table 5 presents the results of the KSS nonlinear test whereas Table 6 displays the results from the KSS test augmented with a FFF (i.e. KSS-FFF). When the KSS test is performed without a FF we set a maximum of 6 lags on the test regression and trim down until lag 0 with the optimal lag length being selected via the minimization of the modified SC criterion. When the test is augmented with a FFF, a grid search is performed as a means to obtaining the optimal Fourier frequency component, K, and the optimal lag length, J, by initially setting $K_{MAX} = 5$, $J_{MAX} = 6$, and then trimming down in consecutive estimations until we have exhausted all possible combinations at $K_{MAX} = 5$, $J_{MAX} = 0$. Also note that, for robustness sake, all tests have been performed on the raw, de-meaned and de-trended transformations of the time series.

In screening through the information provided in Tables 5, we find that the results from the KSS test without a FFF produces very conflicting evidences. For instance, Table 5 shows that none of the BRICS countries can reject the unit root hypothesis when the KSS test is performed on the raw and the de-meaned data. However, the test statistic associated with the de-trended data reject the unit root null hypothesis in favour of stationary nonlinearities for Russia (5% significance), India (5% significance), China (10% significance) and South Africa (5% significance), whilst failing to do so for the Brazilian series. Overall none of the report statistics in Table 5 produces consistent findings across the three forms of data for all BRICS countries with only 4 out of the 15 cases finding significant stationarity in the per capita GDP series. These results hence imply that solely accounting for ESTAR-type nonlinearities in our regressions may not be sufficient enough to capture other unobserved structural breaks in the data.

When the KSS test is supplemented with a FFF, as shown in Table 6, then the test results are more consistent especially across the raw and de-meaned data whereby the unit root null hypothesis is mutually rejected for Brazil, Russia, China and South Africa at a critical level of at least 10 percent, whilst failing to do so for Indian data. The is a slight deviation in the results for the de-trended series as the unit root null hypothesis cannot be rejected for Brazil as well as South Africa; and is instead rejected for India. In summarizing the results from Table 6, we find that only Russia and China, provide consistent evidence of stationarity in per capita GDP across the raw, de-meaned and de-trended series whereas 2 out of 3 cases exist for Brazil (raw and de-meaned series) and South Africa (raw and de-meaned series) and only in singular case (de-trended series) for Indian series. Overall, 11 out of the 15 test regressions find stationarity in the series. Similar findings of per capita GDP convergence using FFF-based unit root tests have been recently found in Su and Chang (2011) for Central and Eastern Europe, Chang et al. (2012) for 5 South Eastern European countries and Ying et al. (2014) for 32 Africa countries, for other developing and merging economies. Henceforth, our study joins this list of previous studies albeit for BRICS countries.

Table 5: The KSS unit root tests performed without FFF

Country	Raw data		De-meaned data		De-trended data	
	KSS	lag	KSS	lag	KSS	lag
Brazil	-1.78 (0.08)	1	-2.34 (0.02)	1	-1.16 (0.25)	1
Russia	-1.40 (0.18)	2	-1.32 (0.20)	2	-3.75** (0.00)	1
India	3.34 (0.00)	1	2.21 (0.03)	1	-3.76** (0.00)	1
China	0.28 (0.78)	1	0.39 (0.70)	1	-3.08* (0.00)	2
SA	-0.59 (0.56)	1	-0.74 (0.47)	1	-4.25** (0.00)	1

Notes: p-values bootstrapped with 10000 replications and reported in parenthesis (). The critical levels are -1.92 (10%), -2.22 (5%) and -2.82 (1%) for the raw data; are -2.66 (10%), -2.93 (5%) and -3.48 (1%) for the de-meaned data; and are -3.13 (10%), -3.40 (5%) and -3.93 (1%) for the de-trended data.

Table 6: The KSS unit root tests performed inclusive of FFF

Country	Raw data			De-meaned data			De-trended data		
	KSS	lag	K	KSS	lag	k	KSS	lag	K
Brazil	-2.37** (0.02)	6	1	-3.18* (0.00)	5	1	-1.20 (0.24)	5	1
Russia	2.02* (0.08)	6	1	-2.96** (0.02)	6	3	-3.17* (0.00)	6	3
India	0.48 (0.15)	6	1	-0.98 (0.34)	6	5	-3.89** (0.00)	6	5
China	-2.55** (0.01)	5	4	-2.76* (0.01)	5	4	-5.65*** (0.00)	5	4
SA	-2.36** (0.00)	6	1	-2.81* (0.01)	6	1	-2.33 (0.03)	6	5

Notes: p-values bootstrapped with 10000 replications and reported in parenthesis (). The critical levels are -1.92 (10%), -2.22 (5%) and -2.82 (1%) for the raw data; are -2.66 (10%), -2.93 (5%) and -3.48 (1%) for the de-meaned data; and are -3.13 (10%), -3.40 (5%) and -3.93 (1%) for the de-trended data.

5 CONCLUSION

The convergence of per capita GDP is nucleus to modern dynamic growth theory most notable amongst Neo-Classical and New growth theorists. The proposition that poorer countries will grow their per capita income at a rate faster than other first world economies via 'catch-up effects' forms the gist of the convergence theory and can be empirically tested in a straightforward manner by examining the univariate integration properties of the per capita GDP variable. The hypothesis tested is that of convergence which is reflected by per capita GDP time series being a stationary, mean-reverting process and this is tested against the alternative of non-convergence in which per capita GDP does not revert back to it's steady-state equilibrium after a disturbance to the series.

In this study we apply this unit root principle to five of the World's most dynamic emerging market economies, the BRICS (Brazil, Russia, India, China and South Africa) over the period 1971 to 2017. At its inception, the pioneer of the BRICS acronym, Jim O'Neal, predicted on growth patterns in Brazil, Russia, India and China converging towards and surpassing those of other industrialized, G7 countries over the next couple of decades. Note that South Africa's inclusion into the BLOC was based purely on China's influence. Through the application of unit root tests which robust to asymmetries and smooth structural breaks, we are able to verify on Jim O'Neal's prediction of long-run convergence for China and Brazil, and to a lesser extent Russia and South Africa but not for India. Therefore, amongst the current BRICS countries Russia, South Africa and India are 'outliers' in the sense of providing no concrete evidence of convergence towards other industrialized countries. Henceforth policy intervention in these outlier countries is highly recommended as well as economic reform policies which mutually strengthen the BRICS economies as a collective unit in areas such as improved competitiveness and institutionalization as well as lower greenhouse gas emissions.

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