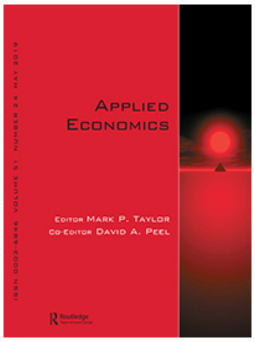

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Stochastic convergence in per capita energy consumption and its catch-up rate: evidence from 26 African countries

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ABSTRACT
Using annual data from 1971 to 2014, we examine stochastic conditional convergence in per capita energy consumption for 26 low income, lower middle-income and upper-middle-income African countries. To do so, we use panel unit root tests that allow for cross-sectional dependence and structural breaks as well as the recently developed univariate Residual Augmented Least Squares-Lagrange multiplier (RALS-LM) unit root test with structural breaks. Although for most countries our evidence suggests stochastic conditional convergence, we find divergence for four countries including DR Congo, Senegal, Egypt and Botswana. Consistent with the neoclassical growth models we also examine the catch-up rate between energy consumption levels of African economies and that one of China and investigate its convergence properties. As African economies continue to grow, regional energy consumption disparity narrows, African energy consumption levels will catch up to the ones in China.

KEYWORDS
Africa; catch-up rate; convergence; unit root; structural breaks

JEL CLASSIFICATION
C50; Q40

I. Introduction

Over the past 60 years, the African continent enjoyed poor income growth together with high and persistent population growth (Khan 2014). Lack of economic performance can be attributed to the colonial past, poor governance and corruption, insufficient investment in human capital, civil wars and regional conflicts. Many African economies recognised the need for a change and, due to prudential macroeconomic policies and favourable external factors between 2000 and the Global Financial Crisis (hereafter GFC), African countries were growing on average at 5% or more per year (African Development Bank (ADB) 2009). Since many African economies rely heavily on agriculture, apparel, limited manufacturing and extractive industries (Anorou and DiPietro 2014), they would require industrialization which is impossible without an increase in energy consumption. Do energy consumption per capita levels among African nations converge towards a common level? Do energy consumption levels in low income, lower- and upper-middle-income African countries catch up with those in China, an economy that grew from an agrarian state with limited manufacturing in the 1960s to a rapidly growing middle-income economy? What are the important events (i.e. structural breaks) that affected the energy consumption path of African economies? This paper strives to answer these questions for 26 countries from North Africa and South Africa from 1971 to 2014 using advanced recent panel and univariate tests for stochastic conditional convergence which is consistent with conditional convergence hypothesis (Strazicich, Lee, and Day 2004) allows understanding the impact of shocks on the trajectory of energy consumption. In addition, we analyse the catch-up rate or the rate with which African nations can be potentially converging to the energy consumption level of a rapidly developing country (China). This allows for an understanding of how a nation's demand for energy will change over time as it moves from low-income status to relatively higher income.

Studying stochastic convergence in energy consumption and its catch-up rate is important for several reasons. *First*, because per capita energy consumption in addition to GDP per capita is one of the most commonly used measures of

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welfare (Mohammadi and Ram 2012; Meng, Payne, and Lee 2013), studying stochastic convergence allows an understanding of the impact of shocks to energy consumption. If a country's per capita energy consumption relative to the group average is stationary, this is interpreted as the sign of convergence towards the group average (Fallahi 2017), implying that the impact of various shocks to energy consumption would be temporary in nature. Otherwise, the impact of shocks to energy consumption would have permanent effects. Since the current structure of African economies makes them very vulnerable to external and internal shocks, this has important implications from economic and environmental policy standpoints for each sample country. *Second*, in addition to being a vital input in the production of goods and services, energy consumption is the major contributor to human development. *Third*, when formulating realistic targets for regional growth and greenhouse gas emissions, both domestic and global policymakers need to understand the path of convergence between less and more developed countries. Given the energy availability constraints, poor access to essential energy services and infrastructure, limited involvement of renewables into the current energy mix in Africa, and uncertain geopolitical situations, catching up with other developing nations, such as China and potentially developed nations, could be even more difficult for African countries.

Studying convergence is not new and was investigated mostly for developed countries and some emerging nations. Recent trends in the literature include analysing large panels of data containing both developing and developed countries (Fallahi 2017), analysis of states within the same country (Mohammadi and Ram 2017; Payne, Vizek, and Lee 2017) or specific sectors of individual countries (Lean, Mishra, and Smyth 2016; Mishra and Smyth 2017). The consensus among such studies is convergence in energy consumption per capita. However, convergence levels of the developed and developing countries are not directly comparable and depend on the choice of the reference time frame with different initial conditions, prior history and previous economic successes (Sy 2016).

The fact that literature has largely ignored the issue of energy consumption for African nations denotes a significant gap because Africa represents an important case from the economic development perspective. Despite the efforts of regional integration, there is significant variation in per capita energy consumption among countries, access to essential energy infrastructure as well as the cost of energy. Following Oyuke, Penang and Howard (2016), two major problems that affect these nations are rolling blackouts (North Africa) and lack of essential electricity infrastructure (Sub-Saharan Africa). At the same time, the African continent has vast energy endowments of renewable and non-renewable energy which are not evenly distributed among countries (International Energy Agency (IEA) 2014). This creates significant energy poverty for some countries. For example, in Sub-Saharan Africa, as a whole, of the 915 million people only 290 million (or 31.69%) have access to electricity (IEA 2014, 13). This is different from North Africa where more than 90% of the population has access to electricity but suffers from blackouts and irregularities in supply (Oyuke, Penar, and Howard 2016).

This paper makes the following contributions to the literature. First, it focuses on Sub-Saharan and North Africa from 1971 to 2014. Focusing solely on Africa allows us to obtain more robust results as compared to previous panel studies which investigated both developed and developing countries together. We split the sample into low income, lower middle-income and upper middle-income levels based on the World Bank[1] income classification.

Second, due to the convergence findings in the majority of the existing studies for developed and other developing nations, the implications for potential divergence in energy consumption largely have been ignored in the literature. Given substantial heterogeneities between countries in the sample, including significant spread in access to energy resources, disparities in energy infrastructure, historical conditions, corruption, civil

[1]World Bank categorizes countries into four groups based on their income levels. For the current 2018 fiscal year, low-income economies are those with a GNI per capita, calculated using the World Bank Atlas method, of $1,005 or less in 2016; lower-middle-income economies are those countries with a GNI per capita between $1,006 and $3,955; upper middle-income economies are those with a GNI per capita between $3,956 and $12,235; high-income economies are those with a GNI per capita of $12,236 or more.

wars, and terms of trade shocks, we should expect to find divergence in energy consumption for some countries. The present study fills this gap by providing policy implications for divergence in energy consumption which are ignored in the previous studies.

Third, we investigate stochastic convergence among per capita energy consumption by adopting the Pesaran (2007) cross-sectionally augmented IPS (CIPS) panel unit root tests as well as the Carrion-i-Silvestre, Barrio-Castro, and Lopez-Bazo (2005) panel KPSS unit root tests that allow multiple (up to five) structural breaks (hereafter panel KPSS with breaks) which are endogenously determined in the data. This enables us to reject a false unit root null hypothesis unambiguously. The advantage of CIPS is that it controls for cross-sectional dependence of the errors. Advantages of the panel KPSS test with breaks are: first, it includes individual fixed effects and/or an individual-specific time-trend, and second, the test allows for multiple breaks that may potentially appear at different unknown dates in addition to varying numbers of breaks for each individual series. While panel tests allow us to check whether a country converges to a panel average, univariate tests allow us to understand individual energy consumption convergence paths for every country in the sample. Therefore, we also utilise time series versions of CIPS and panel KPSS tests with breaks. In case of obtaining conflicting results between panel and univariate tests and as the robustness check we utilize the recently developed Meng et al. (2014) Residual Augmented Least Squares-Lagrange multiplier (RALS-LM) unit root test. RALS-LM tests allow for trend breaks under the null hypothesis and utilize information on non-normal error terms making them superior to non-linear tests which tend to perform poorly when faced with non-normal errors (Meng, Payne, and Lee 2013).

Fourth, in addition to investigating convergence, we estimate the catch-up rate between per capita energy consumption in African countries with per capita energy consumption in China. China was chosen for this analysis for two reasons: First, based on the Rostow's (1960) five stages development model, in its development, a country typically transitions from traditional society to the age of mass consumption and post-industrial society. China represents a development path from an agrarian economy with limited manufacturing and significant extractive resources (the situation that many of the poorest lower income African countries are in currently) to a post-industrial society achieved over the course of three decades. Second, in line with the Environmental Kuznets Curve (EKC) theory, at the early development stages with large-scale primary production and further industrialization, achievement of higher economic welfare requires the increased use of energy potentially leading to environmental degradation. However, 'further economic growth can improve environmental degradation after an economy has reached an adequate level of economic growth' (Kaika and Zervas 2013, 1393) when further improvements in technology, use of different types of energy (e.g. shift from fossil fuels to renewable energy sources) and other factors would result in more growth accompanied by more efficient energy use and lower level of environmental degradation (Panayotou 2003). Since the start of economic reforms in 1978, China has experienced the average growth rate of 9% in real per capita GDP from 1978 to 2012 (Li, Wang, and Zhao 2016), which is the fastest sustained economic expansion by a major economy in history, and has helped more than 800 million people out of poverty (World Bank 2018). This growth was accompanied by the increase in energy consumption and a rapid rise in pollution. To overcome its over-reliance on fossil fuels and promote greener growth, only recently has China started changing its energy mix towards renewables. In the twenty-fifth 'Five-year Plan' (2011–2015) the Chinese government has introduced limits to fossil fuel-based energy consumption to 40 million tons of standard coal. Just like China earlier, current energy consumption mix for the African economies in the sample is biased towards fossil fuels. At the same time, African economies have enormous green energy potential meaning they can reach higher development levels at the cost of lower energy and resource use leading to lower environmental degradation.

Foreshadowing the main results, stochastic conditional convergence was found for African countries in the sample meaning that energy consumption levels do converge to the respective panel average (panel tests) and their individual energy consumption paths tend to exhibit stationary properties (RALS-LM test). We find evidence of divergence for four countries (DR Congo, Senegal, Egypt and Botswana). In addition, since the regional energy consumption disparity narrows as countries continue to grow, the per capita energy consumption in African countries will catch up with China in the future.

The remainder of the paper is organized as follows. Section II presents a brief review of related studies. In Section III, we discuss the data. Section IV is devoted to the framework used for catch-up rate. Section V presents the empirical methodology used in this study. Section VI reports findings, Section VII interprets the break dates. Section VIII provides a discussion of results and policy implications, and Section IX concludes the paper. Summary of recent studies, descriptive statistics, conventional tests results, and a detailed break dates description are reported in the Online Appendix.

II. Literature review

The work on examining stationarity and integration properties of energy variables is pioneered by Narayan and Smyth (2007). Since then, the literature has flourished. Based on the methodologies used, the existing studies on conditional stochastic convergence in per capita energy consumption can be classified into four broad sets. The first one consists of studies applying univariate unit root tests such as conventional Augmented Dickey-Fuller (ADF) and Phillips Perron (PP) unit root tests. These classical univariate unit root tests have several limitations which make them not sufficiently reliable. First, the ADF test is likely to provide a biased result in the presence of structural breaks. Second, the ADF and PP test series are linear; hence, they have low power to reject the unit root null if the data process is non-linear. For these reasons, the literature on stochastic conditional convergence has moved to unit root tests with structural breaks (second set), panel stationarity tests (third set) and non-linear stationarity tests (fourth set).

The second set of literature (Lee and Strazicich 2003; Narayan and Popp 2010) employed univariate unit root tests with breaks to address non-rejection of unit root null hypothesis due to failure to consider structural breaks in the data. Most studies found energy consumption is stationary around a broken trend (Apergis and Payne 2010; Narayan, Narayan, and Popp 2010). While earlier studies utilised country-level data at low frequency, more recent studies concentrate on examining the convergence issue at the sector or organization level (Lean, Mishra, and Smyth 2016; Mishra and Smyth 2017). For example, using annual energy consumption per capita data at the sector level in Australia over the period 1973–74 to 2013–14, Mishra and Smyth (2017) found evidence of convergence in energy consumption in six of seven industry sectors in Australia.

While earlier studies focused on individual countries, studies utilising panel data (either large panels of countries or state-level) with or without breaks have emerged to overcome shortcomings of conventional univariate unit root tests. Studies that employed panel unit root tests without breaks provide mixed results (Agnolucci and Venn 2011; Shahbaz, Tiwari, and Khan 2016), while studies that applied panel stationarity tests with breaks are unanimous in supporting stochastic convergence in energy consumption (Mishra and Smyth 2014; Acaravci and Erdogan 2016).

The fourth set applied non-linear stationarity tests to avoid the drawbacks of the ADF and PP tests discussed earlier. As shown by Hasanov and Telatar (2011) and Alper and Hakan (2011), energy variables can be potentially non-linear in mean. For example, Öztürk and Aslan (2015) studied stationary properties of per capita electricity consumption by employing a non-linear unit root Lagrange Multiplier and Kruse's (2011) test for 23 OECD countries from 1960 to 2005. Although they found non-linear behaviour in electricity consumption for 70% of the OECD countries, it was found to be a non-stationary process for 12 countries. A summary of recent literature is presented in Table A1 in Appendix.

In relation to Africa, despite Anorou and DiPietro (2014) and Fallahi (2017), there was very limited work on per capita energy consumption convergence. To the best of our knowledge, no literature had previously examined the catch-up rate between energy consumption of African countries and that of China. Using conventional panel stationarity tests for 22 African countries, Anorou and DiPietro (2014) found that per capita panel energy consumption series have converged. Once they introduced Sequential Panel Selection Methods (SPSMS) methodology, for some countries (Tunisia, Cote d'Ivoire, Sudan, Gabon, Zimbabwe, Morocco and Togo) energy consumption paths appeared to be diverging from the group average. However, when examining the reliability of SPSMS, Costanti and Claudio (2014) showed that SPSMS does not perform better than the traditional univariate stationarity tests. Fallahi (2017) considered African energy consumption convergence but only as a part of the larger panel. Using interval estimation methods, Fallahi (2017) suggested that regional-specific characteristics are important when analysing stochastic convergence and argued in favour of stochastic convergence for Africa.

In summary, although recent studies examined the existence of convergence, research on convergence in energy consumption in Africa was very limited. Moreover, the implications for potential divergence, as well as the existence of structural breaks and potential cross-sectional dependence in energy consumption largely have been ignored in the literature. Hence, estimation results that did not consider these issues may be unreliable and not robust. The present study attempts to fill the research gaps addressed above.

III. Data

The empirical analysis is based on relative per capita energy consumption for country i, which is calculated using Equation (1):

$$Relative\ energy\ consumption_{it} = \ln\left(\frac{G_{i,t}}{AG_t}\right) \qquad (1)$$

where $G_{i,t}$ denotes the per capita energy consumption for country i in year t and AG_t is the average energy consumption per capita for each economy in year t. The main purpose of transforming the data is to ensure cross-sectional independence by removing common shocks that can influence all countries in the sample. Any negative shock to energy consumption across all countries will reduce the average consumption amount by the same proportion, making relative energy consumption constant and structural breaks identified in the transformed series will be country specific.

Data on per capita energy consumption (in kg of oil per capita) are from the World Development Indicators (WDI) Database of the World Bank. Our sample consists of 26 African countries from North Africa and Sub-Saharan Africa, which were split into low income, lower middle-income and upper-middle-income panels (see Table 1 for country description). To examine the catch-up rate for the African economies, we collected per capita Chinese energy consumption. Descriptive statistics of the series (Table A2 in Appendix) reveal a great disparity between energy consumption levels between poorer and relatively richer African nations.

The time period of analysis is from 1971 to 2014 which corresponds to the postcolonial development of the African nations. Exceptions are Botswana (1981–2014), Zambia and Zimbabwe (1971–2013). Figure 1 plots the trends in energy consumption per capita for each income panel and shows that except for Panel A (low income) energy consumption per capita for other economies converges to the average

Table 1. Country classifications based on income levels.

Country	World Bank country code	Geographic Region
Panel A: *Low income economies*		
Benin	BEN	Sub-Saharan Africa
Congo, Dem. Rep.	COD	Sub-Saharan Africa
Ethiopia	ETH	Sub-Saharan Africa
Mozambique	MOZ	Sub-Saharan Africa
Senegal	SEN	Sub-Saharan Africa
Togo	TGO	Sub-Saharan Africa
Tanzania	TZA	Sub-Saharan Africa
Zimbabwe	ZWE	Sub-Saharan Africa
Panel B: *Lower middle-income economies*		
Angola	AGO	Sub-Saharan Africa
Cote d'Ivoire	CIV	Sub-Saharan Africa
Cameroon	CMR	Sub-Saharan Africa
Congo, Rep.	COG	Sub-Saharan Africa
Egypt	EGY	Middle East & North Africa
Ghana	GHA	Sub-Saharan Africa
Kenya	KEN	Sub-Saharan Africa
Morocco	MAR	Middle East & North Africa
Nigeria	NGA	Sub-Saharan Africa
Sudan	SDN	Sub-Saharan Africa
Tunisia	TUN	Middle East & North Africa
Zambia	ZMB	Sub-Saharan Africa
Panel C: *Upper middle-income economies*		
Algeria	DZA	Middle East & North Africa
Botswana	BWA	Sub-Saharan Africa
Gabon	GAB	Sub-Saharan Africa
Libya	LBY	Middle East & North Africa
Mauritius	MUS	Sub-Saharan Africa
South Africa	ZAF	Sub-Saharan Africa

Notes: Regions in this table are based on the classification criteria from the World Bank.

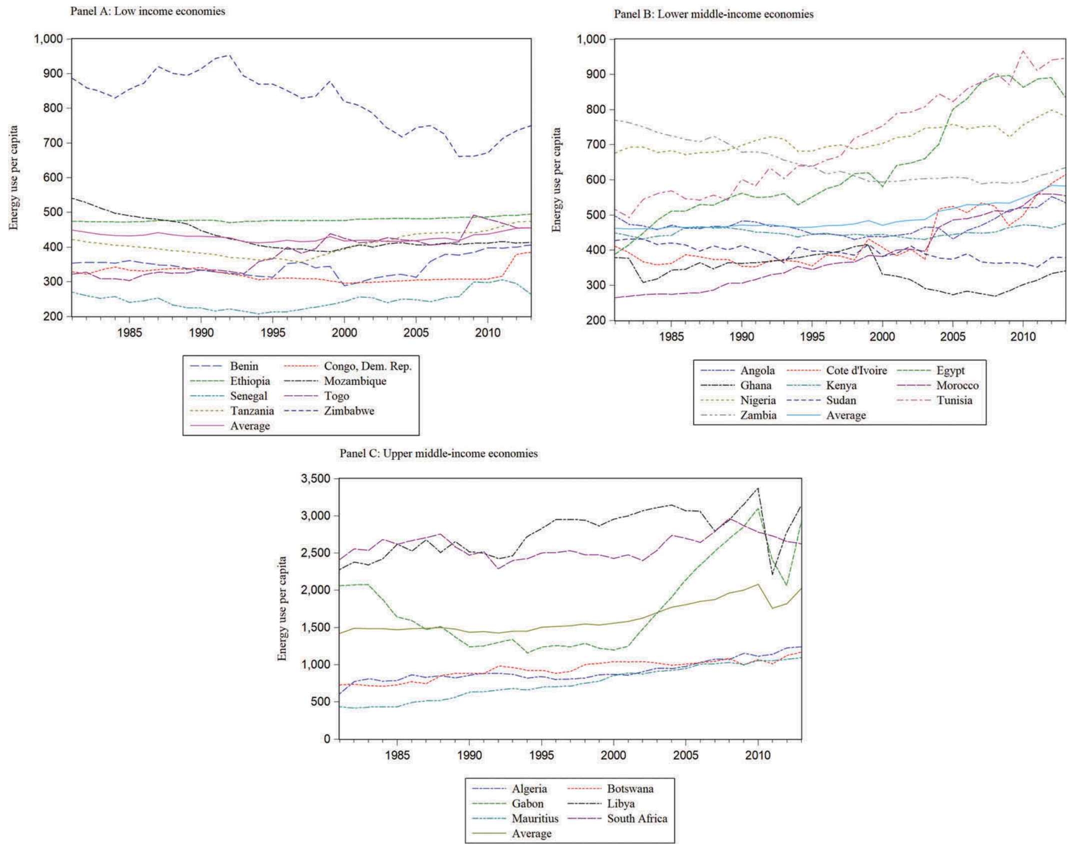

Figure 1. Energy consumption per caption in different economies relative to the mean energy use (1981–2013).
Notes: Average is the mean energy consumption in each panel.

value of its panel. Figure 2 illustrates the energy use in each African country as a percentage of China's per capita energy consumption and shows that this percentage decreases over time.

IV. Catch-up rate framework

The theoretical foundation of the catch-up hypothesis can be traced to the neoclassical Solow-Swan model. Following Solow (1956) and Barro and Sala-i-Martin (1991), real per capita incomes are inversely related to the initial income levels corresponding to the early stages of development. This implies poorer countries tend to grow faster than the richer countries and can potentially over time catch-up with the income levels of richer nations. Since energy use is an important factor in growing income, the hypothesis of catch-up in energy consumption (consistent with the neoclassical growth models) would imply that African nations that have low per capita energy consumption levels should grow their energy consumption faster (i.e. catch-up) than China, which is not yet a developed country but until recently has been growing rapidly.

As a framework for calculating the energy consumption catch-up rate we use following Barro and Sala-i-Martin (2004) approximation:

$$D(logG_t - logG_t^*) = \lambda(log\ G_t - logG_t^*) \qquad (2)$$

where G_t is per capita energy consumption, G_t^* denotes the steady-state value of G_t (proxied by the per capita energy consumption in China), $D(logG_t - logG_t^*)$ refers to the growth rate of $logG_t - logG_t^*$ and λ is a negative parameter. If $logG_t - logG_t^* < 0$ current per capita energy consumption is less than its steady-state value, resulting in $D(logG_t - logG_t^*) > 0$ since $\lambda < 0$. $X_{i,t} = log(G_{i,t}/G_{china,t})$ where $G_{china,t}$

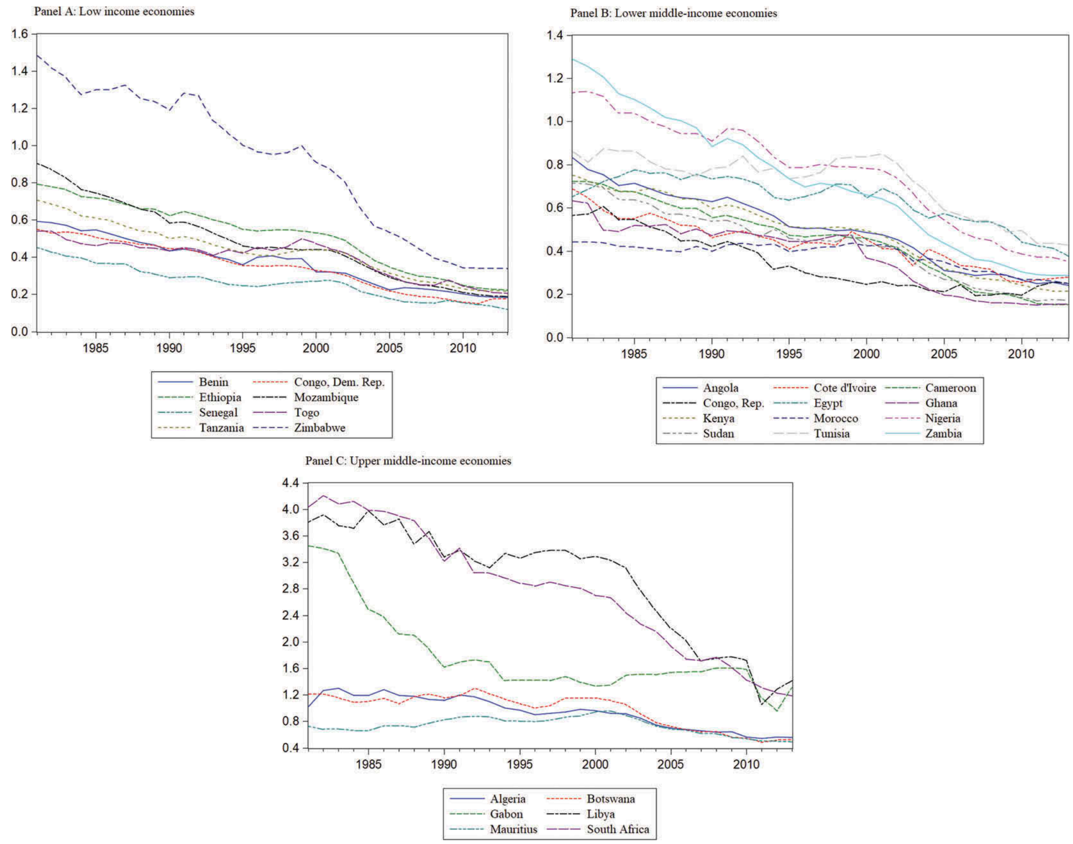

Figure 2. Energy consumption per capita in African country as a percentage of China's per captia energy consumption (1981–2013).

represents Chinese per capita energy consumption in year t. Equation (2) shows that $X_{i,t}$ should be stationary, possibly with a broken trend.

Figures 3 and 4 show the evolution of the catch-up rate and the catch-up growth rate, respectively. Over time the difference between the per capita energy consumption in African countries has been reducing as compared to that one in China (i.e catching up) (Figure 3). For low and lower-middle-income catch-up growth rates were very volatile over the sample period (Figure 4). For some low-income economies, the growth rates became larger towards the end of the sample period. For the upper-middle-income countries, catch-up growth rates were relatively stable over time and less volatile as compared to the low and lower-middle-income nations. The exception was Libya where growth rates have tanked post 2010 due to the ongoing war.

V. Econometric methodology

In this paper, we use a wide range of recent panel unit root tests that allow for cross-sectional dependence and structural breaks to investigate the stochastic convergence of per capita energy consumption and its catch-up rate. Panel unit root tests are considered to be more powerful

than time series tests because they combine information from both time series and cross-sectional dimensions. As a benchmark for panel analysis, we utilise conventional panel tests without structural breaks (Levin, Lin, and Chu 2002) (LLC hereafter), Hadri (2000) panel LM unit root tests. Results of these tests are presented in Appendix. These conventional tests have large size distortions in the presence of cross-sectional dependence in the data (Maddala and Wu 1999; Banerjee, Marcellino, and Osbat 2005). To examine whether the transformation has removed the cross-sectional dependence in our panel, following

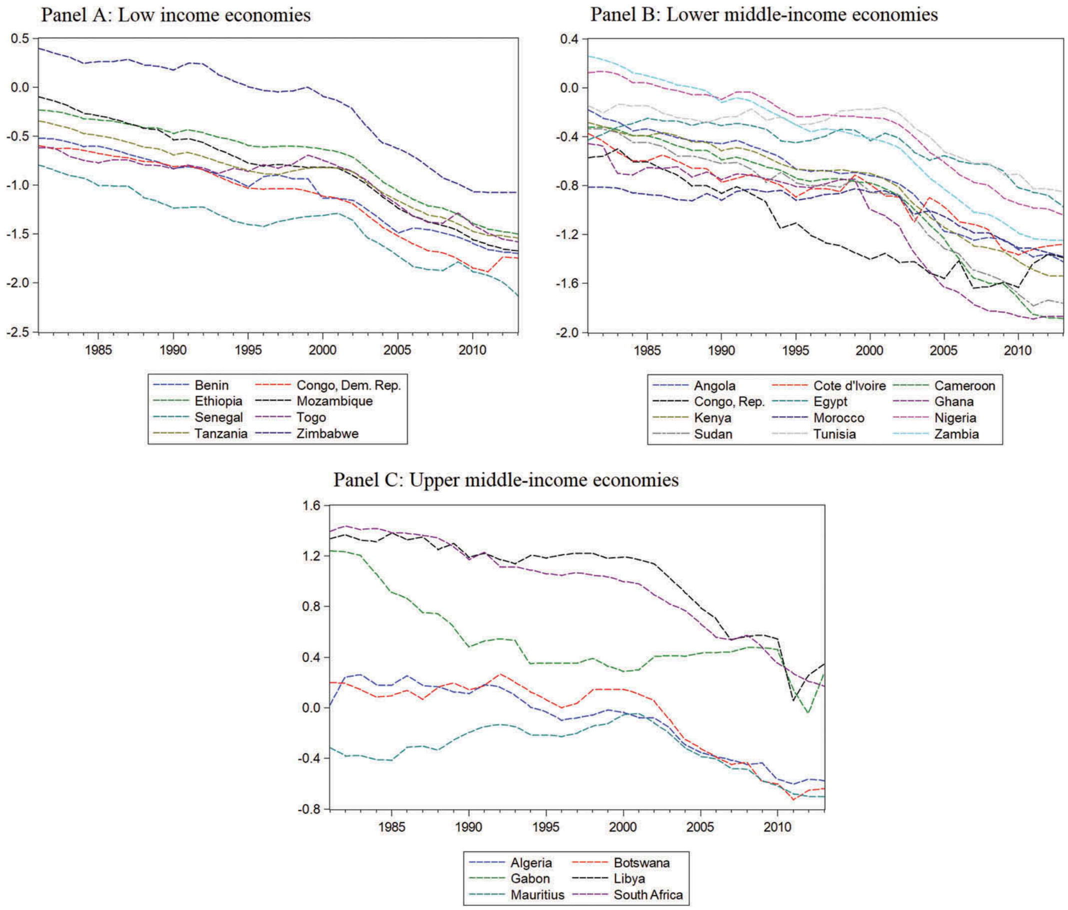

Figure 3. Catch-up rate in African economies (1981–2103).

Pesaran (2004) we estimate individual ADF(p) regressions for lag length (p) = 1, 2, 3 and 4 and calculate pair-wise cross-section correlation coefficients of the residuals from these regressions (namely $\hat{\rho}_{ij}$). If the cross-sectional dependence is found in the data, we employ the Pesaran (2007) CIPS panel unit test. Another potential problem of the conventional panel tests is that these tests do not consider potential structural breaks in the data, leading to erroneous results. According to Bacon and Mattar (2005), African countries are particularly sensitive to shocks due to inefficient energy supply mix and dependence on imported oil as the primary energy source for many countries. To avoid such a result in this paper, we use panel KPSS unit root test with multiple structural breaks for each income panel.

Since convergence among the countries in the panel does not necessarily indicate that each individual country is converging towards the group's average we adopt time series versions of the CIPS test and panel KPSS test with breaks that allow us to study convergence properties of

energy consumption of individual countries in the sample. As a robustness check, we adopt he recently developed univariate Meng, Payne, and Lee 2013) RALS-LM test. The test is robust to some forms of non-linearity and allows removing the dependency of the test statistic on nuisance parameters that many endogenous break unit root tests have.

Panel KPSS unit root test with multiple breaks

The panel KPSS unit root test with multiple breaks has the null hypothesis of stationarity. It allows the most general specification in which each country's energy series can be modelled

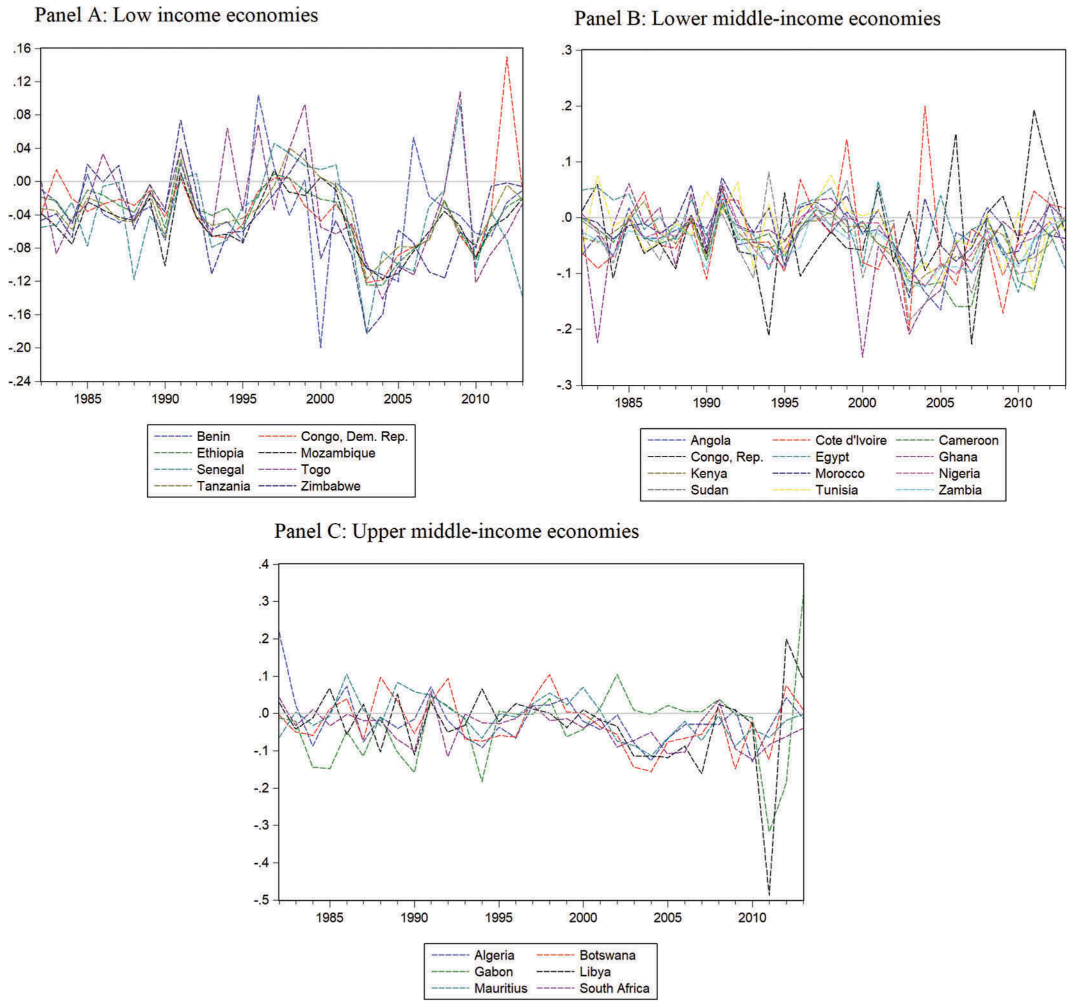

Figure 4. Growth rate of catch-up in African economies (1982–2013).

independently with structural breaks caused by country-specific shocks. Apart from the panel test statistic, this test also provides results for individual countries in the panel and allows different countries to have a different number of structural breaks. Another attractive feature of this test is that it only reports statistically significant breaks. To perform the test, Carrion-i-Silvestre, Barrio-Castro, and Lopez-Bazo (2005) employed Bai and Perron (1998) technique to detect break dates. Since trimming is necessary when estimating break dates, we set the trimming region $T[0.1, 0.9]$. The breaks are restricted to be at least 0.1 of the sample apart to ensure data points before and after breaks are enough for estimation. Once all potential breaks are identified, the optimal break dates are selected using the modified Schwartz information criterion (SIC) for trending regressors which involves sequential computation and the estimation of breaks using a pseudo-F-type test statistic. Following the suggestions of Carrion-i-Silvestre, Barrio-Castro, and Lopez-Bazo (2005), we allowed five as the maximum number of breaks.

RALS-LM unit root tests with structural breaks

Before implementing the RALS-LM tests, we first identify whether breaks exist in the data, and if so, by applying the procedure developed by Perron and Yabu (2009) and Kejriwal and Perron (2010) we identify one or two breaks. If the series under consideration contains no breaks, RALS-LM has lower power due to accounting for extraneous break dummies, leading to the model misspecification issue. The Perron and Yabu (2009) method is implemented first to test the null of no breaks against the alternative of one break. For those countries where Perron and Yabu (2009) identified one break, the Kejriwal and Perron (2010) procedure is used to test the null of one break against the alternative of two breaks. This method helps us to verify the number of breaks for each country and makes our findings more reliable over the existing convergence literature that employed tests for endogenous breaks in the trend function under the trend stationary alternative.

Assume the following data generating process:

$$y_t = \psi + \xi t + x_t, \; x_t = \beta x_{t-1} + e_t \quad (3)$$

The null hypothesis is $\beta = 1$ against the alternative of $\beta < 1$. The parameters ψ and ξ are the deterministic components of intercept and trend, respectively. The model can be written in a general form as follows:

$$y_t + z_t^{'}\delta + x_t, \; x_t = \beta x_{t-1} + e_t \quad (4)$$

where $z_t^{'}$ is the deterministic terms including potential structural changes. With an intercept, trend and R breaks, $z_t^{'}$ can be represented as [1, t, $D_{1t}, \ldots, D_{Rt}$], where $D_{jt} = 1$ for $t \geq T_{Bj} + 1$, $j = 1, \ldots, R$; 0 otherwise. The LM test statistic can be obtained by conducting the regression below:

$$\Delta y_t = \delta' \Delta z_t + \phi \tilde{y}_{t-1} + \sum\nolimits_{j=1}^{p} g_i \Delta \tilde{y}_{t-1} + e_t \quad (5)$$

where $\tilde{y}_t = y_t - \tilde{\psi} - z_t\tilde{\delta}$, $t = 2, \ldots, T$; $\tilde{\delta}$ denotes the coefficient vectors of Δz_t, $\tilde{\psi}$ is the restricted maximum likelihood estimate of ψ, which equals $y_1 - z_1\tilde{\delta}$; y_1 and z_1 refer to the first observation of y_t and z_t, respectively. The term $\Delta\tilde{y}_{t-j}$ represents the lagged differences which re-included in the regression to control for auto-correlated errors. The LM test statistic $\tilde{\tau}_{LM}$ is the t-statistic testing the null of $\phi = 0$ in Equation (5).

Meng et al. (2014) improved this procedure by utilizing information in the higher moments of non-normal errors to infer the nature and functional form of non-linearity. They defined the items below by following an approach proposed by Im and Schmidt (2008): $h(\hat{e}_t^2, \hat{e}_t^3)'$, $\hat{K} = \frac{1}{T}\sum_{t=1}^{T} h(\hat{e}_t)$, $\hat{D}_2 = \frac{1}{T}\sum_{t=1}^{T} h'(\hat{e}_t)$ and $m_j = T^{-1}\sum_{t=1}^{T} \hat{e}_t^j$ and Equation (5) with the term below:

$$\hat{w}_t = \left[\hat{e}_t^2 - m_2, \; \hat{e}_t^3 - m_3 - 3m_2\hat{e}_t\right]' \quad (6)$$

The final specification of the RALS-LM unit root test is as follows:

$$\Delta y_t + \delta' \Delta z_t + \phi \tilde{y}_{t-1} + \sum\nolimits_{j=1}^{p} g_j \Delta \tilde{y}_{t-j} + \hat{w}_t^{'}\gamma + u_t \quad (7)$$

The RALS-LM test statistic is generated via least squares estimations and the t-statistic used to test the null of $\phi = 0$ is $\tau^*_{RALS-LM}$. The asymptotic distribution of $\tau^*_{RALS-LM}$ and the asymptotic critical values for the test are provided in Meng et al. (2014). Notice that the RALS-LM test statistic does not depend on the parameters of break points, thus the same critical values can be applied regardless of the number of structural breaks identified in the data series.

The locations of the breaks, the significance of break dummies and the optimal number of lags for the RALS-LM tests are all determined using a *maxF* test. The optimal lag length is selected by employing a Hull's general to specific procedure, with eight being the maximum number of lags allowed.

VI. Results and discussion of findings

Used as a benchmark (see Appendix for tabulated results), the results of the conventional panel unit root tests reveal that there is strong evidence of divergence in both per capita energy consumption and catch-up rate with China in African economies.

Table 2 presents the simple average of the pair-wise cross-section correlation coefficients across all pairs ($\bar{\rho}$) together with the cross-section dependence (*CD*) test statistic for both untransformed and transformed series (i.e. relative energy consumption series) are reported under each panel. For the untransformed series, the Pesaran CD statistic is not significant at all four lags for both Panel A and B, implying non-rejection of the null hypothesis of cross-sectional independence. After transforming the series, the null hypothesis is rejected at the 1% level for all three panels. Similarly, cross-sectional dependence is also

Table 2. Cross-section correlation of the errors in the ADF(p) regression.

Economies	p = 1	p = 2	p = 3	p = 4
Panel A: *Low income economies*				
Actual energy consumption per capita				
$\bar{\hat{\rho}}$	0.028	0.028	0.027	0.025
CD	0.920	0.933	0.898	0.825
Relative energy consumption per capita				
$\bar{\hat{\rho}}$	−0.083	−0.080	−0.080	−0.078
CD	−2.741***	−2.648***	−2.627***	−2.589***
Panel B: *Lower middle-income economies*				
Actual energy consumption per capita				
$\bar{\hat{\rho}}$	0.028	0.011	0.020	0.021
CD	1.440	0.534	1.018	1.081
Relative energy consumption per capita				
$\bar{\hat{\rho}}$	−0.066	−0.063	−0.060	−0.058
CD	−3.374***	−3.192***	−3.038***	−2.921***
Panel C: *Upper middle-income economies*				
Actual energy consumption per capita				
$\bar{\hat{\rho}}$	0.131	0.160	0.154	0.150
CD	3.284***	4.005***	3.864***	3.771***
Relative energy consumption per capita				
$\bar{\hat{\rho}}$	−0.122	−0.115	−0.107	−0.103
CD	−3.052***	−2.875***	−2.687***	−2.575***
Panel D: *Catch-up rate: low income economies*				
$\bar{\hat{\rho}}$	0.587	0.510	0.508	0.509
CD	19.405***	16.843***	16.802***	16.822***
Panel E: *Catch-up rate: lower middle-income economies*				
$\bar{\hat{\rho}}$	0.425	0.417	0.409	0.399
CD	21.586***	21.144***	20.776***	20.224***
Panel F: *Catch-up rate: upper middle-income economies*				
$\bar{\hat{\rho}}$	0.289	0.245	0.242	0.238
CD	6.123***	5.208***	5.131***	5.057***

Notes: The cross-sectional dependence (CD) test is developed by Pesaran (2004) for testing cross-sectional dependence in panels. All statistics are based on univariate AR(p) specifications in the level and trend of the variables with $p \leq 4$. The null hypothesis is that output innovations are cross-sectionally independent. The CD test statistic follows a $N(0,1)$ distributions. The 10%, 5% and 1% critical values for the CD statistic are 1.64, 1.96 and 2.57, respectively. *** denotes statistical significance at the 1% level.

found in the catch-up rate series. Since the transformed energy consumption series and the catch-up rate contain cross-sectional dependence, there is a need to apply CIPS unit root test methodology that takes this issue into account.

Table 3 reports the results of the CIPS test for the three income panels as well as the panel catch-up rate. These results show that neither energy consumption per capita nor the catch-up rate contain a panel unit root at all four lags at the 1% level of significance. The null hypothesis of panel non-stationarity is rejected at one lag for lower-middle-income economies only. This result implies that after considering cross-sectional dependence in the data, both per capita energy consumption and its catch-up rate converge towards their long-run levels.

Table 3. Pesaran (2007) CIPS panel unit root test results.

Economies	p = 1	p = 2	p = 3	p = 4
Panel A: *Energy consumption per capita*				
Low income economies	−2.158	−2.314	−2.336	−2.418
Lower middle-income economies	−2.515	−2.322	−2.372	−2.535
Upper middle-income economies	−2.554	−2.225	−1.595	−1.473
Panel B: *Catch-up rate*				
Low income economies	−1.809	−1.780	−1.363	−1.106
Lower middle-income economies	−3.083***	−2.515	−2.348	−2.175
Upper middle-income economies	−2.246	−1.95	−1.443	−1.448

Notes: The test is performed under the assumption that there is an intercept and linear trend in the series (Case 3 in Pesaran 2007). For the low-income economies and upper-middle-income economies, the 10%, 5% and 1% critical values for Case 3 with T= 50, N = 10 from Pesaran (2007) are −2.73, −2.84 and −3.06, respectively. For the lower middle-income economies, the 10%, 5% and 1% critical values for Case 3 with T= 50, N = 15 from Pesaran (2007) are −2.66, −2.76 and −2.93, respectively. *** denotes statistical significance at the 1% level.

Table 4 presents the results of the panel KPSS test with multiple structural breaks in the data. Similar to Table 3, the null hypothesis of stationarity cannot be rejected at the 5% level or better for both per capita energy consumption and its catch-up rate. The results confirm that after taking into account both cross-sectional dependence and structural breaks, the energy consumption per capita and the catch-up rate stochastically converge for all income panels. The difference in findings between the conventional panel unit root test (divergence) and panel CIPS and KPSS tests (convergence) suggest that ignoring cross-sectional dependence and structural breaks can result in imprecise inference.

Although we find evidence of convergence in all income panels, as argued in Anorou and DiPietro (2014), this does not necessarily indicate the existence of convergence for each individual country. Therefore to investigate the stochastic convergence properties of energy consumption in each country we further employ both conventional time series unit root tests (ADF, PP and KPSS), univariate version of Pesaran (2007) CIPS and the Carrion-i-Silvestre, Barrio-Castro, and Lopez-Bazo (2005) univariate KPSS tests with structural breaks. Using the conventional tests (see Appendix for tabulated results), we find that per capita energy consumption for five countries (Panel A: Togo; Panel B: Morocco, Sudan, Zambia; Panel C: Mauritius) are converging towards their respective mean values. The catch-up rates of five countries (Panel D: Mozambique,

Table 4. Panel KPSS test with multiple structural breaks.

Economies	KPSS test statistic (using Bartlett kernel)	Bootstrap critical values			
		90%	95%	97.5%	99%
Panel A: *Low income economies*					
Breaks (Homogeneous)	5.251	7.495	8.692	9.667	11.207
Breaks (Heterogeneous)	22.136	20.891	24.065	27.615	31.689
Panel B: *Lower middle-income economies*					
Breaks (Homogeneous)	6.730	15.039	16.022	17.135	18.183
Breaks (Heterogeneous)	7.901	17.519	18.698	19.667	20.775
Panel C: *Upper middle-income economies*					
Breaks (Homogeneous)	11.268	12.616	16.204	20.710	26.913
Breaks (Heterogeneous)	33.385	31.006	35.275	40.456	46.393
Panel D: *Catch-up rate: low income economies*					
Breaks (Homogeneous)	3.665	13.010	15.502	17.662	20.967
Breaks (Heterogeneous)	25.690	35.447	41.550	47.151	55.783
Panel E: *Catch-up rate: lower middle-income economies*					
Breaks (Homogeneous)	4.302	12.380	13.296	14.167	15.147
Breaks (Heterogeneous)	9.582	17.055	18.686	20.025	21.163
Panel F: *Catch-up rate: upper middle-income economies*					
Breaks (Homogeneous)	2.739	7.930	9.476	13.003	17.329
Breaks (Heterogeneous)	5.537	20.073	24.011	26.939	30.746

Notes: The long-run variance is estimated using the Bartlett kernel with automatic spectral window bandwidth selection. Bootstrap critical values are based on a Monte Carlo simulation with 2000 replications and allow for cross-sectional dependence. The results are generated by a model with an intercept and trend.

Senegal, Tanzania; Panel E: Cote d'Ivoire, DR Congo) stochastically converge to the level of China during 1971–2014.

Results of the univariate CIPS unit root test (Table 5) demonstrate a failure to reject the null of non-stationarity (i.e. energy consumption is diverging) for most nations, which further confirms Anorou and DiPietro (2014) argument. The null hypothesis can be rejected at the 5% level or better for only two countries at lag 1 and 2, and for none at lag 3. In addition, the null hypothesis is rejected for three countries at lag 4 at the 10% level or better. For the catch-up rate, the null of unit root is rejected at the 10% level or better for seven countries at lag 1, is rejected for only three countries at lags 2 and 3, and for none at lag 4. Based on these test results we conclude that the per capita energy consumption and its catch-up rate diverge for most African nations in the sample from their respective long-run energy consumption paths.

Table 6 presents the results of the Carrion-i-Silvestre, Barrio-Castro, and Lopez-Bazo (2005) KPSS univariate unit root tests together with statistically significant breaks while critical values are presented in Appendix. Three to four structural breaks are found to be significant for most of the African countries. Similar to the Pesaran (2007) CIPS univariate tests results, after taking into account structural breaks, the null hypothesis of stationarity was rejected in 18 and 20 countries for the relative per capita energy consumption and its catch-up rate, respectively, at the 10% level or better.

The diverge in findings between univariate and panel tests results highlight the fact that failure to verify the optimal number of breaks in the series can lead to biased results. Therefore, we perform the Perron and Yabu (2009) and Kejriwal and Perron (2010) tests for identifying the optimal number of breaks in relative energy consumption per capita and its catch-up rate. Results are presented in Table 7. More than half of the African countries have two structural breaks in per capita energy consumption. For six countries (Low income: DR Congo, Zimbabwe; Lower middle income: Angola, Morocco, Zambia; Upper middle income: Botswana) there are no breaks, for six countries (Low income: Mozambique, Togo; Lower middle income: Egypt, Tunisia; Upper middle income: Algeria, Libya) there is one break and for 14 countries (Low income: Benin, Ethiopia, Senegal, Tanzania; Lower middle income: Cote d'Ivoire, Cameroon, DR Congo, Ghana, Kenya, Nigeria, Sudan; Upper middle income: Gabon, Mauritius, South Africa) there are two breaks. In terms of the catch-up rate, there are no breaks for seven countries (Low income: DR Congo, Mozambique, Tanzania; Lower middle income: Angola, Zambia; Upper middle income: Gabon, South Africa), one break for 16 countries (Low

Table 5. Pesaran (2007) time series CIPS unit root test results.

Economies	p = 1	p = 2	p = 3	p = 4
Panel A: *Low income economies*				
Benin	−2.612	−2.647	−2.649	−2.539
Congo, Dem. Rep.	−0.428	−1.139	−1.590	−1.180
Ethiopia	−2.056	−1.466	−0.817	−1.198
Mozambique	−2.291	−2.022	−1.794	−2.329
Senegal	−2.987	−3.528	−3.722	−4.103*
Togo	−2.421	−2.971	−3.641	−3.545
Tanzania	−1.377	−1.397	−1.587	−1.588
Zimbabwe	−3.092	−3.339	−3.068	−2.860
Panel B: *Lower middle-income economies*				
Angola	−3.192	−4.247**	−2.764	−3.375
Cote d'Ivoire	−2.668	−2.784	−3.135	−4.135*
Cameroon	−1.075	−1.369	−2.214	−2.001
Congo, Rep.	−1.205	−0.364	−0.992	−1.539
Egypt	−0.684	−1.319	−1.551	−0.958
Ghana	−2.043	−2.078	−1.875	−1.938
Kenya	−2.615	−2.288	−2.752	−2.763
Morocco	−2.649	−2.702	−2.511	−2.772
Nigeria	−3.215	−2.751	−2.550	−3.005
Sudan	−2.543	−1.648	−1.424	−0.916
Tunisia	−3.443	−2.731	−3.381	−3.722*
Zambia	−4.848**	−3.579	−3.310	−3.293
Panel C: *Upper middle-income economies*				
Algeria	−1.506	−0.591	0.071	−0.088
Botswana	−1.999	−1.863	−1.630	−1.386
Gabon	−2.326	−1.876	−2.098	−2.318
Libya	−3.185	−2.202	−2.005	−1.785
Mauritius	−1.042	−0.711	−0.726	−0.818
South Africa	−5.267**	−6.109**	−3.183	−2.446
Panel D: *Catch-up rate: low income economies*				
Benin	−4.198*	−4.540*	−4.247*	−3.198
Congo, Dem. Rep.	−1.033	−1.183	−1.232	−0.716
Ethiopia	−1.316	−0.726	0.025	−0.330
Mozambique	−2.002	−1.062	0.647	0.399
Senegal	−1.306	−1.601	−1.697	−2.165
Togo	−2.495	−2.646	−2.405	−1.614
Tanzania	−1.033	−0.626	−0.522	−0.307
Zimbabwe	−1.091	−1.854	−1.475	−0.921
Panel E: *Catch-up rate: lower middle-income economies*				
Angola	−3.676*	−4.102*	−4.126*	−3.457
Cote d'Ivoire	−2.550	−1.948	−1.238	−1.420
Cameroon	−5.255**	−3.653*	−3.661*	−2.788
Congo, Rep.	−2.004	−1.014	−1.085	−1.708
Egypt	−1.426	−1.512	−2.043	−2.013
Ghana	−1.329	−1.716	−1.573	−1.797
Kenya	−3.149	−2.891	−3.356	−3.170
Morocco	−1.878	−1.974	−1.576	−1.649
Nigeria	−4.039*	−3.388	−2.763	−2.462
Sudan	−3.975*	−3.037	−2.582	−2.059
Tunisia	−3.043	−1.979	−2.180	−1.879
Zambia	−4.669**	−2.968	−1.994	−1.691
Panel F: *Catch-up rate: upper middle-income economies*				
Algeria	−2.741	−2.362	−2.173	−2.073
Botswana	−1.255	−1.074	−0.712	−0.287
Gabon	−0.461	−0.150	0.324	0.629
Libya	−4.049*	−3.375	−3.044	−3.277
Mauritius	−1.485	−1.551	−1.008	−1.361
South Africa	−3.487	−3.189	−2.045	−2.320

Notes: The test is performed under the assumption that there is an intercept and linear trend in the series (Case 3 in Pesaran 2007). For the low-income economies and upper-middle-income economies, the 10%, 5% and 1% critical values for Case 3 with $T = 50$, $N = 10$ from Pesaran (2007) are −4.02, −4.91 and −7.69, respectively. For the lower middle-income economies, the 10%, 5% and 1% critical values for Case 3 with $T = 50$, $N = 15$ from Pesaran (2007) are −3.63, −4.17 and −5.48, respectively. *, ** denote statistical significance at the 10% and 5% level, respectively.

income: Benin, Ethiopia, Senegal, Togo, Zimbabwe; Lower middle income: Cote d'Ivoire, Cameroon, DR Congo, Egypt, Kenya, Morocco, Nigeria, Sudan, Tunisia; Upper middle income: Botswana, Mauritius) and there are two breaks for three countries (Lower middle income: Ghana; Upper middle income: Algeria, Libya).

We further conduct RALS-LM unit root tests as robustness check and report results in Table 8. The null hypothesis of a unit root in relative energy consumption per capita is rejected at the 10% level or better for six of the eight countries for Low-income panel, for eleven of the twelve countries for Lower middle-income panel and for five of the six countries for Upper middle-income panel. Similarly, the null of non-stationarity in catch-up rate is rejected at the 10% level or better for almost half of the African countries. The catch-up rate converges for three out of the eight countries for Low-income panel, for six out of the twelve countries for Lower middle-income panel and for three out of the six countries for Upper middle-income panel.

Based on the results of the panel tests we conclude that there is convergence in per capita energy consumption for the majority of countries in the sample, and the catch-up rates stochastically converge to the level of China for almost half of the African countries. The results of RALS-LM unit root tests with structural breaks confirm the findings of panel CIPS and KPSS tests. That is, there is convergence in per capita energy consumption and catch-up rate for most of the countries in the sample except for DR Congo, Senegal (lower income), Egypt (lower middle-income) and Botswana (upper middle-income).

VII. Discussion of estimated break dates

In this section, we provide plausible reasons for the structural breaks identified by the RALS-LM unit root tests (see Table A7 in Appendix for a detailed discussion of the estimated break dates). These events can only be regarded as possible events associated with breaks but not as evidence of a statistical linkage with the proposed events or with the time periods of structural breaks. This is a limitation of our study which requires further investigation.

Four countries (Ghana (1982), Ethiopia (1983), Senegal (1983) and Congo (1985)) experienced a structural break in the 1980s. With much of

Table 6. KPSS time series tests with multiple breaks.

Economies	KPSS test statistic (using Bartlett kernel)	mi	Break dates TB_1	TB_2	TB_3	TB_4	TB_5
Panel A: *Low income economies*							
Benin	0.248***	4	1985	1995	1999	2005	-
Congo, Dem. Rep.	0.037*	3	1982	1998	2009	-	-
Ethiopia	0.025	4	1982	1992	1999	2008	-
Mozambique	0.078	2	1999	2003	-	-	-
Senegal	0.315***	4	1979	1994	2002	2008	-
Togo	0.030**	5	1976	1982	1993	1998	2008
Tanzania	0.033	5	1980	1986	1996	2003	2008
Zimbabwe	0.139***	5	1984	1992	1998	2004	2008
Panel B: *Lower middle-income economies*							
Angola	0.131***	5	1975	1981	1994	2004	2008
Cote d'Ivoire	0.039*	5	1978	1982	1998	2003	2008
Cameroon	0.073***	3	1981	2003	2008	-	-
Congo, Rep.	0.033	4	1982	1990	2000	2006	-
Egypt	0.101***	4	1974	1983	2004	2008	-
Ghana	0.027	5	1982	1987	1999	2004	2008
Kenya	0.042	3	1985	2001	2008	-	-
Morocco	0.054***	4	1979	1987	1993	2003	-
Nigeria	0.028	5	1981	1986	1993	1997	2003
Sudan	0.068***	3	1979	1993	2003	-	-
Tunisia	0.045**	3	1981	1985	1999	-	-
Zambia	0.108***	1	1977	-	-	-	-
Panel C: *Upper middle-income economies*							
Algeria	0.131***	3	1983	1993	2010	-	-
Botswana	0.118***	4	1987	1991	1997	2010	-
Gabon	0.045	3	1990	2001	2010	-	-
Libya	0.092***	5	1984	1993	2001	2006	2010
Mauritius	0.638***	4	1983	1989	1999	2010	-
South Africa	0.083***	3	1988	2007	2010	-	-
Panel D: *Catch-up rate: low income economies*							
Benin	0.023	4	1980	1995	1999	2003	-
Congo, Dem. Rep.	0.032	4	1980	1992	2002	2009	-
Ethiopia	0.151***	5	1974	1979	1994	2001	2005
Mozambique	0.321***	5	1974	1979	1994	2001	2005
Senegal	0.083***	4	1979	1996	2002	2008	-
Togo	0.085***	5	1978	1993	1998	2003	2008
Tanzania	0.200***	4	1979	1997	2001	2006	-
Zimbabwe	0.054***	5	1976	1990	1997	2002	2009
Panel E: *Catch-up rate: lower middle-income economies*							
Angola	0.029	5	1974	1990	1994	2001	2005
Cote d'Ivoire	0.095***	4	1982	1998	2003	2008	-
Cameroon	0.065***	4	1980	1994	2001	2006	-
Congo, Rep.	0.039***	3	1980	1993	2008	-	-
Egypt	0.071***	5	1977	1983	1993	2002	2009
Ghana	0.049***	4	1977	1985	1999	2006	-
Kenya	0.034**	4	1979	1993	2000	2005	-
Morocco	0.054***	3	1974	1983	2002	-	-
Nigeria	0.194***	5	1980	1990	1994	2001	2006
Sudan	0.049***	4	1979	1992	2002	2009	-
Tunisia	0.030	4	1985	1994	2000	2004	-
Zambia	0.150***	5	1974	1979	1994	2001	2006
Panel F: *Catch-up rate: upper middle-income economies*							
Algeria	0.088***	3	1983	1993	2003	-	-
Botswana	0.030	5	1987	1991	1997	2002	2010
Gabon	0.048***	3	1989	1993	2010	-	-
Libya	0.040***	5	1984	1993	2001	2006	2010
Mauritius	0.147***	5	1985	1990	1996	2000	2003
South Africa	0.04	4	1988	1991	2000	2007	-

Notes: All results are generated by a model with an intercept and trend. The maximum number of breaks (m_i) allowed is 5. *,**,*** denoted statistical significance at the 10%, 5% and 1% level, respectively.

Table 7. Perron and Yabu (2009) and Kejriwal and Perron (2010) tests results.

Economies	Model	ExpW(1|0) Test	Break date	ExpW(2|1) Test	Break date
Panel A: *Low income economies*					
Benin	III	11.906**	1999	3.762**	1977
Congo, Dem. Rep.	III	2.255	-	-	-
Ethiopia	III	4.927**	1993	22.574***	1984
Mozambique	III	24.257***	1999	1.973	-
Senegal	III	6.969***	1987	5.048***	1992
Togo	III	8.154***	1993	1.739	-
Tanzania	III	9.132***	1999	3.493**	1992
Zimbabwe	III	1.805	-	-	-
Panel B: *Lower middle-income economies*					
Angola	III	2.519	-	-	-
Cote d'Ivoire	III	14.710***	1990	5.499***	1981
Cameroon	III	13.997***	2001	8.580***	1975
Congo, Rep.	III	4.471**	1998	5.577***	1983
Egypt	III	3.671**	1983	0.776	-
Ghana	III	6.942***	2000	6.454***	1982
Kenya	III	2.948*	1985	6.237***	1982
Morocco	III	2.472	-	-	-
Nigeria	III	3.320**	1993	4.350**	1977
Sudan	III	6.774***	1993	3.112*	1979
Tunisia	III	4.348**	1981	1.091	-
Zambia	III	1.462	-	-	-
Panel C: *Upper middle-income economies*					
Algeria	III	3.120*	1993	1.392	-
Botswana	III	1.408	-	-	-
Gabon	III	2.762*	2001	8.761***	1987
Libya	III	24.308***	2002	1.457	-
Mauritius	III	2.859*	1991	9.551***	1989
South Africa	III	5.146***	1991	3.437**	2000
Panel D: *Catch-up rate: low income economies*					
Benin	III	11.406***	1985	2.106	-
Congo, Dem. Rep.	III	0.712	-	-	-
Ethiopia	III	10.733***	2002	1.703	-
Mozambique	III	1.150	-	-	-
Senegal	III	3.262**	1997	0.973	-
Togo	III	4.955***	1997	2.088	-
Tanzania	III	1.695	-	-	-
Zimbabwe	III	2.868*	2002	1.194	-
Panel E: *Catch-up rate: lower middle-income economies*					
Angola	III	1.561	-	-	-
Cote d'Ivoire	III	3.702**	1996	1.194	-
Cameroon	III	9.257***	2002	1.066	-
Congo, Rep.	III	3.969**	2006	1.562	-
Egypt	III	4.867***	1988	1.015	-
Ghana	III	7.205***	2002	3.145*	1997
Kenya	III	6.161***	2002	0.696	-
Morocco	III	30.466***	2002	0.967	-
Nigeria	III	4.552**	2002	1.658	-
Sudan	III	4.132**	2003	1.368	-
Tunisia	III	5.560***	2002	1.058	-
Zambia	III	1.318	-	-	-
Panel F: *Catch-up rate: upper middle-income economies*					
Algeria	III	5.194***	2003	2.963*	1993
Botswana	III	5.302***	2002	1.008	-
Gabon	III	1.867	-	-	-
Libya	III	21.156***	2003	4.805**	1995
Mauritius	III	5.122***	2002	1.811	-
South Africa	III	1.881	-	-	-

Notes: Model III refers to structural change in both intercept and slope. We follow a sequential procedure that first test the null of on breaks against one break. For the countries that the null is rejected, we test the null of one break against two breaks. The Gauss codes for these tests are available from Pierre Perron's website at http://people.bu.edu/perron/code/breakcode.zip. *,**,*** denoted statistical significance at the 10%, 5% and 1% level, respectively.

Table 8. Results for RALS-LM unit root tests with no breaks, one break or two breaks.

	RALS-LM				
Economies	$\tau^*_{RALS-LM}$	$\hat{\rho}^2$	$\hat{T}_B$		$\hat{k}$
Panel A: *Low income economies*					
Benin	−4.338**	0.874	1996	2004	3
Congo, Dem. Rep.	0.441	0.459	-	-	0
Ethiopia	−3.760**	0.521	1983	2007	0
Mozambique	−5.818***	0.641	1998	-	8
Senegal	−2.328	0.698	1983	1994	6
Togo	−3.576**	0.751	1994	-	1
Tanzania	−4.514**	0.910	1996	2004	0
Zimbabwe	−4.499***	0.584	-	-	7
Panel B: *Lower middle-income economies*					
Angola	−2.974*	0.895	-	-	3
Cote d'Ivoire	−6.236***	0.758	2002	2006	3
Cameroon	−5.341***	0.995	1997	2002	5
Congo, Rep.	−5.413***	0.909	2004	2007	0
Egypt	−1.692	0.906	2008	-	0
Ghana	−6.201***	0.171	1982	1998	8
Kenya	−4.760***	0.989	1991	2002	8
Morocco	−2.782*	0.923	-	-	7
Nigeria	−5.865***	0.761	1992	2002	5
Sudan	−5.756***	0.720	1992	2005	8
Tunisia	−3.825**	0.844	2007	-	0
Zambia	−3.631***	0.814	-	-	0
Panel C: *Upper middle-income economies*					
Algeria	−4.724***	0.645	2001	-	4
Botswana	−0.545	0.520	-	-	7
Gabon	−3.846**	0.667	1996	2010	7
Libya	−6.233***	0.713	1993	-	0
Mauritius	−12.843***	0.295	1998	2009	5
South Africa	−5.151***	0.866	1992	1998	1
Panel D: *Catch-up rate: low income economies*					
Benin	−4.726***	0.702	1998	-	5
Congo, Dem. Rep.	−0.215	0.737	-	-	1
Ethiopia	−3.062	0.988	2001	-	1
Mozambique	−2.112	0.989	-	-	1
Senegal	−6.142***	0.590	2007	-	3
Togo	−2.932	0.611	2001	-	5
Tanzania	−1.868	0.975	-	-	1
Zimbabwe	−4.465***	0.725	2001	-	7
Panel E: *Catch-up rate: lower middle-income economies*					
Angola	−2.759*	0.706	-	-	2
Cote d'Ivoire	−3.852***	0.415	2007	-	5
Cameroon	−2.627	0.778	2000	-	1
Congo, Rep.	−1.747	0.918	2008	-	1
Egypt	−4.686***	0.971	1998	-	7
Ghana	−6.885***	0.419	1982	1998	5
Kenya	−3.368	0.956	2001	-	5
Morocco	−3.464*	0.926	2001	-	0
Nigeria	−3.882**	0.958	2004	-	7
Sudan	−3.289	0.871	2002	-	3
Tunisia	−2.400	0.918	2000	-	2
Zambia	−1.816	0.875	-	-	0
Panel F: *Catch-up rate: upper middle-income economies*					
Algeria	−3.975***	0.188	1990	2000	6
Botswana	−2.881	0.592	1998	-	1
Gabon	−1.295	0.367	-	-	2
Libya	−14.193***	0.320	1992	1999	8
Mauritius	−3.694**	0.967	1998	-	8
South Africa	−1.881	0.891	-	-	2

Notes: The term $\hat{T}_B$ stands for the locations of the structural breaks, $\hat{k}$ represents the optimal lag length decided by a general to specific procedure. Test statistic for the RALS-LM unit root tests are invariant to the break locations. Critical values for the tests are provided in Meng, Payne, and Lee (2013). *,**,*** denoted statistical significance at the 10%, 5% and 1% level, respectively.

the world's attention focused on the debt crisis in Latin America during this period, another debt servicing crisis was developing in Sub-Saharan Africa. Although the total international debt of African countries was far smaller than that of the Latin American region, the African economic crisis was much deeper than failing on the short-term financial obligations (Lancaster 1983). On the political front, the most important events were related to civil unrest. For example, in 1985, Mahele Lieko Bokoungo fought back Congo's Laurent Kabila, who set up a rebel republic on the shores of Lake Tanganyika near Moba.

For the majority of countries, the break appeared between the mid-1990s to late 1990s. This period was characterised by the Asian Financial Crisis (AFC) which had influenced the African economies in a number of ways. In particular, it resulted in a period of highly volatile commodity prices, which reduced commodity demand and consequently decreased imports of commodities from Africa. For example, the drop in the gold price had seriously affected African gold producers (Ghana, South Africa and Zimbabwe); Botswana and South Africa were hurt by the decline in demand for diamonds; the fall in cotton prices had a major impact on Togo (International Monetary Fund (IMF) 1998). The sharp decline in world oil prices had a severe negative influence on African net exporters of petroleum products (Angola, Cameroon, Gabon and Nigeria) for whom the loss in export earnings was substantial. In addition, on average, the economic growth in Africa was low in both the 1980s and 1990s, a phenomenon referred to as 'lost decades' of African development. The slower growth produced set-backs, especially via cuts to education and health expenditures, which have severe long-run consequences for future economic growth.

Between the early 2000s and 2010, 18 countries experienced structural break/s. The most important break can be attributed to the 2008 GFC which led to a vicious cycle of falling trade flows and investments. The food and fuel price shocks in mid-2008 left food-importing and oil-importing African countries under serious pressure, pushing down their foreign exchange reserves and creating an obstacle to sustain economic growth.

These results show that African nations are vulnerable to both internal and external shocks.

As African countries continue their integration into the global economy (for example, through China's activities in Africa), this vulnerability is likely to increase in the future.

VIII. Policy implications

Results of the RALS-LM unit root tests show that relative energy consumption per capita is found to be divergent for four African countries (DR Congo, Senegal, Egypt and Botswana) meaning that a negative shock to energy (e.g. an adverse oil price shock) has the potential to have a permanent effect on these African nations and will lead to a persistent decline in productivity, output and a surge in unemployment that may worsen the existing poverty levels. Furthermore, a divergence in energy consumption per capita poses additional problems to the environment through the impossibility of converging to a common developing nation's greenhouse gas emissions levels, such as outlined by the Kyoto protocol. As a result, sound economic policies that promote equity in energy consumption are necessary to prevent adverse supply shocks and their detrimental macroeconomic and environmental consequences.

For the remaining African countries, energy consumption appears to be stationary indicating convergence in energy consumption levels. These countries increasingly rely on large levels of energy consumption to achieve economic growth. The energy control targets and greenhouse gas emissions targets should be different in different panels depending on the level of income. Specifically, the energy control target should not be too tight for both low income and lower-middle-income economies. Otherwise, the economic growth in these countries can be adversely affected due to not satisfying the necessary demand for energy. By contrast, it is reasonable to set stricter goals for upper-middle-income economies since these countries have the potential to control their energy consumption levels based on the rules of convergence.

In terms of catching up with China, the spread between African and Chinese energy consumption has been declining, indicating that, over time, African economies were increasing their energy consumption levels (i.e. catching up with China). But since these levels are still small compared to those of China, as African countries will continue to grow, this spread will be diminished further.

IX. Conclusions

Since 1971 the performance of African nations has been uneven and depended on many factors, in particular, energy consumption. Although the countries differ by industrial structure (e.g. Togo, DR Congo and Ethiopia rely on agriculture while South Africa is one of the world's leading mining economies), all African countries in the sample have a challenge of achieving higher level of economic development for which they need energy.

Due to the importance of energy consumption in achieving economic growth, this paper investigates stochastic conditional convergence in per capita energy consumption and the catch-up rate for 26 African countries using the latest advances in panel and univariate stationarity tests including the Pesaran (2007) CIPS panel and univariate tests, Carrion-i-Silvestre, Barrio-Castro, and Lopez-Bazo (2005) KPSS panel and univariate tests as well as RALS-LM test with breaks by Meng et al. (2014).

Our main findings are as follows. *First*, the results from the conventional panel unit root tests suggest there is divergence in both relative energy consumption per capita and catch-up rates for all panels. Nevertheless, panel stationarity tests that take into account cross-sectional dependence and structural breaks provide strong evidence of convergence. Results of panel tests imply that ignoring the issue of cross-sectional dependence and structural breaks can give imprecise statistical inference. *Second*, based on the results of panel KPSS test with multiple breaks we conclude that the impact of shocks on per capita energy consumption levels is likely to be temporary, which serves as evidence in favour of convergence. This has implications for formulating regional economic policies. *Third*, results of univariate RALS-LM tests with structural breaks confirm the findings of CIPS panel tests and panel KPSS tests with breaks. That is, there is convergence in per capita energy consumption and catch-up rate for most of the countries in the sample. *Fourth*, depending on a country, RALS-LM tests suggest up to two structural breaks in the series. These breaks included events external to Africa (e.g. AFC and GFC) as well as the internal shocks linked to specific economies (e.g. civil unrests). *Fifth*, for four countries we found divergence in relative energy consumption per capita. Therefore, the presence of poverty and income inequality in these nations does not only cause per capita energy consumption divergence, but affects the per capita energy consumption disparity in the region. *Sixth*, almost half of the African countries are found to share a common, steady energy consumption path with the energy consumption level of China. This shows that African countries are likely to follow in China's footsteps by increasing energy use to achieve economic growth and reduce energy poverty. In particular, the African continent faces major electrification challenges. Due to immense financial constraints, individual country efforts should be accompanied by international efforts, such as the World Bank's Lighting Africa off-grid solar project as well as the financial or technical investments of other countries including China. Through its state-owned enterprises, China has invested substantially in Africa as a strategy to expand international investments and gain access to foreign markets.

Our finding of stochastic convergence for most countries in the sample implies that joint policies with respect to energy are likely to contribute towards the common level. For most countries, the impact of shocks is likely to be temporary, meaning that Africa will rebound from economic hardships, although this might take time.

There are several avenues for future research. This paper focused on stochastic convergence in per capita energy consumption among African nations. It would be interesting to study other forms of convergence such as absolute and club convergence because they would highlight other properties of convergence in energy consumption in Africa. In addition, events proposed in the paper as potential causes of breaks need to be investigated further in terms of their magnitude, direction and duration of impact. This will allow classifying the impact of different events (domestic vs external, terms of trade shocks vs production or financial shocks). Future research could investigate energy convergence at the state level within countries. Following Apergis and Christou (2016), future research could examine convergence in energy productivity or energy intensity. As an extension of the work presented in this article, it would be interesting to model the catch-up rate, the speed of convergence with Chinese energy consumption and the factors that could affect this convergence.

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Online Appendix

'Stochastic convergence in per capita energy consumption and its catch-up rate: Evidence from 26 African countries' by Lei Pan and Svetlana Maslyuk-Escobedo

Table A1. Recent studies on convergence in energy consumption.

Study	Methodology	Period	Country	Energy Type	Findings
Meng, Payne, and Lee (2013)	LM, RALS-LM	1960–2010	25 OECD countries	Energy consumption per capita	Convergence
Mishra and Smyth (2014)	Carrion-i-Silvestre, Barrio-Castro, and Lopez-Bazo (2005) panel KPSS	1971–2011	ASEAN-5	Energy consumption per capita	Convergence
Anoruo and DiPietro (2014)	Conventional panel unit root, SPSM	1971–2011	22 African countries	Energy consumption per capita	Convergence Convergence
Shahbaz, Tiwari, and Khan (2016)	Conventional panel unit root	1971–2010	103 countries	Energy consumption per capita	Convergence
Lean, Mishra, and Smyth (2016)	GRACH unit root test with breaks	1973–2014	5 sectors in US	Petroleum consumption	Mixed Evidence
Fallahi (2017)	Subsampling confidence intervals	1971–2013	109 countries	Energy consumption per capita	Regional Convergence
Mishra and Smyth (2017)	LM, RALS-LM	1973–74 to 2013–14	Industry sectors in Australia	Energy consumption	Convergence across sectors
Mohammadi and Ram (2017)	Maddala and Wu (1999), Pesaran (2007) CIPS test	1970–2013	48 US states	Energy consumption per capita	No stochastic convergence
Payne, Vizek, and Lee (2017)	LM, RALS-LM	1970–2013	All US states	Fossil fuel consumption per capita	Convergence

Table A2. Descriptive statistics of relative per capita energy consumption (kg of oil equivalent per capita) for different economies in Africa.

Country	Obs.	Mean	Std.Dev	Min	Max	Skewness	Kurtosis
Panel A: *Low income economies*							
Benin	44	−0.221	0.073	−0.368	−0.007	0.665	3.383
Congo, Dem. Rep.	44	−0.312	0.071	−0.451	−0.074	0.745	4.732
Ethiopia	44	0.082	0.063	−0.069	0.169	−1.050	3.113
Mozambique	44	0.067	0.139	−0.108	0.367	0.665	2.108
Senegal	44	−0.553	0.080	−0.693	−0.373	0.271	2.810
Togo	44	−0.180	0.178	−0.444	0.123	0.084	1.480
Tanzania	44	−0.040	0.071	−0.153	0.125	0.122	1.970
Zimbabwe	43	0.652	0.098	0.419	0.803	−0.946	2.948
Panel B: *Lower middle-income economies*							
Angola	44	0.006	0.111	−0.185	0.279	0.910	3.153
Cote d'Ivoire	44	−0.117	0.116	−0.288	0.065	0.047	1.416
Cameroon	44	−0.185	0.159	−0.576	−0.043	−1.377	3.440
Cong, Rep.	44	−0.382	0.192	−0.760	−0.052	−0.368	2.288
Egypt	44	0.067	0361	−0.729	0.519	−0.866	2.610
Ghana	44	−0.341	0.173	−0.687	−0.146	−0.721	1.959
Kenya	44	−0.066	0.071	−0.234	0.049	−0.540	2.355
Morocco	44	−0.359	0.244	−0.872	−0.009	−0.220	2.022
Nigeria	44	0.361	0.042	0.280	0.427	−0.388	2.051
Sudan	44	−0.171	0.154	−0.476	0.128	−0.168	2.394
Tunisia	44	0.246	0.244	−0.300	0.565	−0.637	2.374
Zambia	43	0.356	0.193	0.060	0.685	0.119	1.831
Panel C: *Upper middle-income economies*							
Algeria	44	−0.723	0.299	−1.486	−0.397	−1.425	3.673
Botswana	34	−0.552	0.106	−0.740	−0.371	−0.206	1.915
Gabon	44	0.153	0.270	−0.264	0.655	−0.014	1.747
Libya	44	0.415	0.253	−0.373	0.666	−1.421	4.209
Mauritius	44	−0.850	0.227	−1.277	−0.512	−0.361	1.816
South Africa	44	0.478	0.090	0.256	0.653	−0.388	2.757

Table A3. The catch-up rate and growth rate of catch-up in African economies.

	Catch-up rate			Catch-up Growth rate
Country	Mean	Min	Max	Mean
Panel A: *Low income economies*				
Benin	−0.913	−1.695	−0.225	−0.034
Congo, Dem. Rep.	−1.004	−1.888	−0.359	−0.032
Ethiopia	−0.609	−1.505	0.023	−0.036
Mozambique	−0.625	−1.678	0.459	−0.049
Senegal	−1.245	−2.131	−0.497	−0.037
Togo	−0.872	−1.589	−0.335	−0.029
Tanzania	−0.732	−1.549	0.149	−0.039
Zimbabwe	−0.017	−1.083	0.782	−0.044
Panel B: *Lower middle-income economies*				
Angola	−0.593	−1.422	0.203	−0.037
Cote d'Ivoire	−0.716	−1.367	−0.037	−0.029
Cameroon	−0.784	−1.885	−0.144	−0.040
Cong, Rep.	−0.981	−1.638	−0.252	−0.027
Egypt	−0.532	−1.010	−0.252	−0.006
Ghana	−0.940	−1.898	−0.279	−0.037
Kenya	−0.665	−1.540	−0.024	−0.034
Morocco	−0.958	−1.397	−0.796	−0.011
Nigeria	−0.238	−1.075	0.220	−0.030
Sudan	−0.770	−1.782	0.055	−0.042
Tunisia	−0.353	−0.863	−0.134	−0.011
Zambia	−0.226	−1.248	0.596	−0.044
Panel C: *Upper middle-income economies*				
Algeria	−0.169	−0.697	0.262	0.004
Botswana	−0.084	−0.727	0.266	−0.017
Gabon	0.707	−0.043	1.626	−0.027
Libya	0.968	0.057	1.380	−0.004
Mauritius	−0.297	−0.704	−0.046	−0.015
South Africa	1.031	0.169	1.442	−0.029

Table A4. Conventional panel unit root tests results.

Economies	LLC	Hadri Z
Panel A: *Energy consumption per capita*		
Low income economies	1.039	7.331***
Lower middle-income economies	0.197	8.542***
Upper middle-income economies	−0.943	7.145***
Panel B: *Catch-up rate*		
Low income economies	18.235	6.039***
Lower middle-income economies	15.263	9.624***
Upper middle-income economies	6.958	7.475***

Notes: The test statistics for the two panel unit root tests are LLC adjusted t statistic and Hadri Z statistic, respectively. The maximum lag length chosen for LLC test is 12. Both tests are generated by a model with time and trend. Two tests use the automatic bandwidth selection technique of Newey-West and Bartlett Kernel for computing the spectrum. *** denotes statistical significance at the 1% level.

Table A4 presents the results of Levin, Lin and Chu (LLC, 2002) and Hadri (2000) panel unit root tests, where the former has the null hypothesis that panels contain unit roots while the latter with the null that all panels are stationary. We apply two panel stationarity tests with opposite null because jointly testing of both null hypotheses can ascertain stationarity results. Table A1 shows that the LLC test statistic cannot reject the null hypothesis for all panels, which indicates that the per capita energy consumption for the three economies in Africa does not converge to its mean value. The Hadri Z statistic rejects the null hypothesis of stationarity at the 1% level which confirms the divergence finding of energy consumption per capita. Similarly, both test statistics provide strong evidence of divergence in catch-up rate for the three economies.

The results of conventional time series unit root tests for per capita energy consumption and its catch-up rate are provided in Table A5. As evident in Table A5, the results for the ADF and PP tests suggest that the null hypothesis of unit root cannot be rejected in any African counties except for Zambia. In the KPSS test, the null of stationarity is rejected for 22 out of 26 series. Therefore, we conclude that 5 countries are converging towards the average per capita energy consumption of their belonged economies. In terms of the catch-up rate, both ADF and PP test statistics show that the null hypothesis cannot be rejected in all the African countries. Yet, the result for KPSS test indicates the null hypothesis that the series under consideration does not contain a unit root is rejected among 21 countries. Conventional time series stationarity test suggest that the catch-up rates of 5 countries stochastically converge around the level of China during 1971–2014.

Table A5. Conventional time series unit root tests results.

	Test Statistic					
Economies	ADF	Lag length	PP	Bandwidth	KPSS	Bandwidth
Panel A: *Low income economies*						
Benin	−1.699	0	−1.851	1	0.134*	4
Congo, Dem. Rep.	−0.787	0	−1.217	2	0.139*	4
Ethiopia	−2.225	0	−2.201	2	0.205**	5
Mozambique	−0.290	0	−0.232	1	0.213**	5
Senegal	−1.716	0	−1.683	2	0.167**	5
Togo	−2.661	0	−2.675	6	0.100	4
Tanzania	−0.830	0	−0.877	2	0.209**	5
Zimbabwe	−1.753	1	−1.481	2	0.185**	5
Panel B: *Lower middle-income economies*						
Angola	−1.711	0	−1.589	3	0.196**	4
Cote d'Ivoire	−1.673	0	−1.547	1	0.213**	5
Cameroon	−0.964	0	−0.973	7	0.197**	5
Congo, Rep.	−0.343	0	−0.248	4	0.157**	5
Egypt	−0.522	0	−0.560	1	0.183**	5
Ghana	−1.773	0	−1.980	3	0.128*	5
Kenya	−2.563	0	−2.517	4	0.146**	4
Morocco	−2.681	0	−2.679	2	0.075	4
Nigeria	−1.150	0	−0.806	5	0.204**	5
Sudan	−3.120	0	−3.062	3	0.102	5
Tunisia	−1.330	1	−1.692	4	0.171**	5
Zambia	−4.272***	0	−4.441***	3	0.129*	3
Panel C: *Upper middle-income economies*						
Algeria	−2.083	0	−2.088	2	0.183**	5
Botswana	−1.698	0	−1.698	0	0.154**	4
Gabon	−0.941	0	−0.941	0	0.201**	5
Libya	−2.478	0	−2.478	0	0.211**	5
Mauritius	−2.579	0	−2.613	2	0.108	5
South Africa	−1.602	4	−3.091	3	0.172**	4
Panel D: *Catch-up rate: low-income economies*						
Benin	−2.268	0	−2.359	1	0.171**	4
Congo, Dem. Rep.	−1.954	1	−1.770	3	0.174**	5
Ethiopia	−1.430	1	−0.982	3	0.183**	5
Mozambique	−2.652	1	−2.817	3	0.102	5
Senegal	−2.758	1	−2.337	2	0.085	4
Togo	−0.899	0	−1.272	3	0.138*	5
Tanzania	−2.612	1	−2.151	3	0.093	5
Zimbabwe	−1.438	1	−1.130	2	0.173**	5
Panel E: *Catch-up rate: lower middle-income economies*						
Angola	−1.768	0	−1.768	0	0.135*	5
Cote d'Ivoire	−3.140	0	−3.083	2	0.113	4
Cameroon	−1.473	1	−0.878	3	0.192**	5
Congo, Rep.	−1.461	0	−1.527	3	0.118	4
Egypt	−0.277	0	−0.117	4	0.211**	5
Ghana	−1.397	0	−1.594	3	0.169**	5
Kenya	−1.857	1	−1.405	2	0.183**	5
Morocco	−1.217	0	−1.169	4	0.192**	5
Nigeria	−1.230	1	−0.803	1	0.196**	5
Sudan	−1.212	0	−1.476	4	0.159**	5
Tunisia	−0.963	0	−0.963	0	0.193**	5
Zambia	−1.468	1	−1.728	3	0.171**	5
Panel F: *Catch-up rate: upper middle-income economies*						
Algeria	−2.426	0	−2.403	2	0.203**	5
Botswana	−1.677	1	−1.516	1	0.178**	4
Gabon	−2.102	0	−1.998	3	0.167**	5
Libya	−2.272	0	−2.320	3	0.210**	5
Mauritius	−1.271	1	−1.160	4	0.136*	5
South Africa	−0.846	0	−0.846	0	0.203**	5

Notes: The lag length for ADF test is decided by using Schwartz Information Criterion (SIC). For PP and KPSS tests, the optimal bandwidth is selected by Newey–West method using Bartlett kernel. All stationarity tests are performed under the assumption of constant term and linear trend in the series. The maximum length selected in all cases is 9. *, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively.

Table A6. Critical values for the panel KPSS test with multiple breaks.

Critical values	10%	5%	2.5%	1%
Panel A: *Low income economies*				
Benin	0.023	0.025	0.027	0.029
Congo, Dem. Rep.	0.032	0.038	0.044	0.051
Ethiopia	0.045	0.055	0.063	0.072
Mozambique	0.081	0.104	0.124	0.161
Senegal	0.034	0.041	0.048	0.057
Togo	0.024	0.027	0.029	0.031
Tanzania	0.035	0.042	0.047	0.056
Zimbabwe	0.055	0.071	0.086	0.103
Panel B: *Lower middle-income economies*				
Angola	0.026	0.029	0.031	0.034
Cote d'Ivoire	0.035	0.040	0.045	0.051
Cameroon	0.022	0.024	0.025	0.027
Congo, Rep.	0.044	0.054	0.063	0.076
Egypt	0.039	0.045	0.054	0.062
Ghana	0.048	0.058	0.067	0.080
Kenya	0.061	0.076	0.091	0.115
Morocco	0.032	0.038	0.045	0.050
Nigeria	0.040	0.049	0.056	0.065
Sudan	0.031	0.036	0.041	0.046
Tunisia	0.029	0.034	0.039	0.045
Zambia	0.025	0.028	0.031	0.034
Panel C: *Upper middle-income economies*				
Algeria	0.030	0.034	0.036	0.041
Botswana	0.034	0.039	0.045	0.055
Gabon	0.055	0.068	0.080	0.106
Libya	0.026	0.028	0.030	0.032
Mauritius	0.025	0.027	0.030	0.035
South Africa	0.043	0.051	0.057	0.069
Panel D: *Catch-up rate for low-income economies*				
Benin	0.024	0.027	0.029	0.032
Congo, Dem. Rep.	0.038	0.045	0.050	0.063
Ethiopia	0.027	0.032	0.036	0.043
Mozambique	0.026	0.030	0.034	0.040
Senegal	0.040	0.047	0.052	0.062
Togo	0.033	0.038	0.042	0.048
Tanzania	0.043	0.049	0.054	0.062
Zimbabwe	0.027	0.030	0.034	0.037
Panel E: *Catch-up rate: lower middle-income economies*				
Angola	0.029	0.034	0.038	0.043
Cote d'Ivoire	0.047	0.058	0.070	0.084
Cameroon	0.028	0.031	0.035	0.040
Congo, Rep.	0.024	0.027	0.030	0.036
Egypt	0.025	0.028	0.031	0.037
Ghana	0.026	0.029	0.032	0.036
Kenya	0.025	0.028	0.032	0.037
Morocco	0.022	0.024	0.026	0.030
Nigeria	0.034	0.041	0.049	0.058
Sudan	0.024	0.027	0.030	0.034
Tunisia	0.031	0.037	0.042	0.047
Zambia	0.026	0.029	0.033	0.040
Panel F: *Catch-up rate: upper middle-income economies*				
Algeria	0.021	0.023	0.024	0.026
Botswana	0.034	0.042	0.046	0.056
Gabon	0.025	0.027	0.030	0.032
Libya	0.026	0.029	0.031	0.034
Mauritius	0.029	0.032	0.035	0.039
South Africa	0.043	0.05	0.057	0.065

Notes: Bootstrap critical values are based on a Monte Carlo simulation with 2000 replications.

Table A7. Major events in African countries around the break dates.

Economies	Break dates	Major events around the break dates
Panel A: *Low income economies*		
Benin	1996, 1998, 2004	1996: Mathieu Kerekou, former Benin dictator, was elected over incumbent Nicephore Soglo 2000: The Cotonou Agreement[2], a treaty between the European Union and the group of African, Caribbean and Pacific States (ACP countries). The agreement ceased to be legal under the WTO rules. 2004: Eight French speaking African countries[3] began retiring over 1 billion in decaying currency with new CFA francs.
Congo, Dem. Rep.	-	
Ethiopia	1983, 2001, 2007	1985: Mahele Lieko Bokoungo fought back Congo's Laurent Kabila, who set up a rebel republic on the shores of Lake Tanganyika near Moba. 2000: Congo civil war 2007: Fortunat Lumu, the head of Congo's atomic energy commission, was arrested along with an aide of suspicion of illegally selling uranium.
Mozambique	1998	1999: Creditors cancelled over $4 billion worth of debt. The annual debt service of over $100 million had flowed to creditors in wealthy nations.
Senegal	1983, 1994, 2007	1983: Rebel fighters with the Movement of the Democratic Forces (MFDC) began a low level insurgency against the government. 1994: Gambian soldiers proclaimed military government in Dakar, Senegal. 2007: The president Abdoulaye Wade, hosted the Islamic Development Bank's annual meeting, and spoke on behalf of the bank to launch a $10 billion fund to combat poverty in developing Muslim countries in Africa and other parts of the world.
Togo	1994, 2001	1994: Legislative election were marked by army violence and intimidation. 2000: 36 African heads of state signed a draft treaty which regarded as a step forward an African Union.
Tanzania	1996, 2004	1997: The worst drought in 40 years happened in Tanzania. 2002: The US government has forgiven all the remaining $21.3 million debt owned by the Tanzania government.
Zimbabwe	2001	2000: After the IMF announced it would nor resume financial aids, the Zimbabwe stock exchange made a record of 500 points gain. Moreover, the official inflation was 53.6% and local cash cannot be moved out of the country.
Panel B: *Lower middle-income economies*		
Angola	-	-
Cote d'Ivoire	2002, 2006, 2007	2002: Rebels seized control in north of country, military munity in Abidjan. 2006: Political and rebel leaders failed to reach an agreement on main issues of voter registration and disarmament. 2007: The president Gbagbo and rebel leader Guilaume Soro signed peace accord.
Cameroon	1997, 2000, 2002	1998: Business organization, Transparency International labelled Cameroon as the "most corrupt country in the world". 2000: The World Bank approved funding for oil and pipeline project in Cameroon and Chad. 2003: Chad began pumping oil to Cameroon in project funded by the World Bank.
Congo, Rep.	2004, 2007, 2008	2003: Outbreak of the deadly Ebola virus in Congo, Rep. 2007: Congo and the London Club of private creditors reached a deal of cancelling 80% of the Central African country's $2.5 billion debt. 2008: Leaders of the six Central African states[4], met to discuss closer economic ties. The Economic and Monetary Union of Central Africa (CEMAC), planned discussions on such issues as monetary reform and the free movement of citizens.
Egypt	1998, 2008	1997: Terrorism issue in Egypt. 58 tourists are killed by the Egypt's Islamic Group. 2011: Egyptians staged nationwide demonstrations against the President Mubarak. The parliament is dissolved and the constitution is suspended.
Ghana	1982, 1998	1981: The president Hilla Limann is ousted following two years of a weak government and stagnant economy. 2001: The government removed fuel subsidies which led to a 60% increase in petrol prices.
Kenya	1991, 2001, 2002	1992: Ethnic violence erupted in western Kenya. 2001: The head of government Leaky charged with abuse of power and perverting the course of justice. 2002: Mwai Kibaki won landslide victory ending Moi's 24-year long rule and KANU[5]'s four decades in power.
Morocco	2001	1998: The first opposition-led government came into power.
Nigeria	1992, 2002, 2004	1992: Commercial creditors forgave most of Nigeria's debt. 2002: Nigeria's parliament approved changes to an oil revenue-sharing law which gives state governments a share of revenues from offshore oil and gas production. 2004: The oil giant Royal Dutch/Shell declared it plans to streamline its operations in Nigeria. An estimated 30 percent of its workforce will be laid off.

(*Continued*)

[2]Cotonou is the largest city in Benin. The agreement was signed by 79 ACP nations and 15 members of EU. It is the latest agreement in the history of ACP-EU development cooperation.
[3]They are Benin, Burkina Faso, Guinea-Bissau, Ivory Coast, Mali, Niger, Senegal and Togo.
[4]Specifically, they are Cameroon, Chad, Gabon, CAR, Congo, Rep. and Equatorial Guinea.
[5]KANU is the abbreviation of Kenya African National Union. It is a political party that ruled for almost 40 years after Kenya's independence from British colonial rule in 1963 until its electoral loss in 2002.

Table A7. (Continued).

Economies	Break dates	Major events around the break dates
Sudan	1992, 2002, 2005	1991: UNICEF reported fighting and crop failures in southern Sudan had forced an unexpected exodus of 200,000 people. 2002: Sudan's government signed an agreement with rebels to suspend fighting to end their 20-year war. 2004: China invested nearly $150 million in Sudan this year.
Tunisia	2000, 2007	1999: Algeria, Libya and Tunisia agreed to share the northwest Sahara aquifer system. 2007: Tunisia blocked access to the popular video sharing websites YouTube and DailyMotion, which both contain materials about Tunisian political prisoners.
Zambia	-	
Panel C: *Upper middle-income economies*		
Algeria	1990, 2000, 2001	1991: Islamic Salvation Front (FIS) called general strike after ban placed on political campaigning in mosques, state of emergency declared. 1999: The president Bouteflika ordered release of 5,000 political and religious detainees Berber protest in Kabylie region turned violent.
Botswana	1998	1997: Constitutional amendment approved that presidency limited to two five-year terms and 2001: According to UNAIDS, Botswana was reported to have the world's highest HIV infection rate at 38.3% of the population.
Gabon	1996, 2010	1993: The president Omar Bongo Ondimba declared that president following elections under the multiparty system. 2012: The Africa cup co-hosted by Gabon and Equatorial Guinea.
Libya	1992, 1993, 1999	1989: Libya, Algeria, Morocco, Mauritania and Tunisia joined together to form the Arab Maghreb Union. 2003: Libya was elected chairman of the UN Human Rights Commission despite opposition.
Mauritius	1998, 2009	2002: Both the president and vice-president resigned after refusing to sign a controversial anti-terrorism bill. 2012: The president Anerood Jugnauth has been in open conflict with the prime minister Navinchandra Ramgoolam, said he was resigning to join the opposition.
South Africa	1992, 1998	1993: The US president Clinton signed legislation lifting remaining US sanctions against South Africa, and announced an initiative to spur investment in South Africa's black private sector. 1998: The US president Clinton visited South Africa, stood with president Nelson Mandela in a racially integrated South African parliament to salute a country that was 'truly free and democratic at last'.

Notes: The break dates reported in this table are based on the significant breaks identified by the RALS-LM unit root tests.

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