Asymmetries, Structural Breaks, and Nonlinear Persistence: Evidence and Implications for Uncovering the Energy-Growth Nexus in Selected African Countries

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Abstract

The paper utilizes the nonparametric Triple test, the Bai-Perron test, and the KSS test to examine whether the paths of energy consumption and economic growth for 19 African countries are characterized by asymmetries, structural breaks, and nonlinear persistence over the period 1971-2011. We find evidence of deepness and steepness asymmetry, structural breaks, and nonlinear persistence in energy consumption and economic growth for these countries. The implications of these findings are that: (i) the findings of studies which examine the energy-growth nexus for these countries in linear settings may be doubtful; (ii) forecasts of energy consumption and economic growth which rely on linear models may contain sizeable forecasting errors. We recommend that future research on the energy-growth nexus should attempt to account for these nonlinearities in order to report more efficient estimates.

Keywords: Asymmetries, Persistence, Energy Consumption, Economic Growth
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1. Introduction

Recent empirical evidence suggests that most macroeconomic and financial variables may follow asymmetric paths over time. A particularly useful finding is the fact that some form of asymmetries may characterize business cycles. As has been argued elsewhere, extensive information about the nature of business cycles (and the dynamic paths of fundamental economic variables, thereof) enhances policy formulation and economic forecasting (see Pesaran and Potter, 1997; Narayan, 2009). Generally speaking, business cycles are said to be asymmetric whenever expansions and recessions are not mirror images of one another. Business cycles are, however, symmetric whenever expansions and recessions are mirror images of one another. In symmetric business cycles, the time propagation mechanisms (whether discrete or continuous), which transmit shocks into fluctuations, are invariant under positive or negative shocks (see Boldin, 1999). Asymmetries in business cycles are mostly attributed to: (i) the nature of the propagation mechanism or the types of shocks (see Boldin, 2001); and (ii) the sensitivity of the economy to the types of shocks (see Beaudry and Koop, 1993; Pesaran and Potter, 1997).

The nexus between energy consumption and economic growth has been one of the most studied relationships in the energy economics literature (see Iyke, 2015, for an outline). The conclusions drawn for the many studies on the nexus between these two variables have remained divergent (see Eggoh *et al.*, 2011). An understanding of the cyclical paths of energy consumption and economic growth may enhance the empirical model formulation, estimation and policy forecasting in this area of research. It may also bring univocal findings in the literature. For example, if asymmetric movements characterize these variables over time, symmetric or linear econometric techniques that have been utilized extensively to analyze these variables may be inappropriate. Indeed, a quick glance through the recent literature shows that the nexus between energy consumption and economic growth has been examined with linear models and techniques (see Huang *et al.*, 2008; Apergis and Payne, 2009a; Ozturk and Acaravci, 2011; Ozturk and Bilgili, 2015).

Even though some recent advances has been made to investigate the nexus between energy consumption and economic growth in nonlinear setting (see Esso, 2010; Eggoh *et al.*, 2011; Iyke, 2015), the existing studies investigating the asymmetries in macroeconomic variables have largely considered economic growth and closely related variables such as health expenditure, exchange rates, interest rates, inflation, unemployment, oil prices among others (see Neftci, 1984; DeLong and Summers, 1988; Beaudry and Koop, 1993; Potter, 1995; Ramsey and Rothman, 1996; Narayan, 2009).

Our aim is, therefore, to shed light on the potential asymmetries, structural breaks, and nonlinear persistence that may characterize the paths of these variables. In so doing, we contribute to the literature in various ways. First, we recognize that appropriate energy policies can only be formulated if policymakers have the idea of how energy consumption and other crucial variables move over time. Thus, we uncover the behaviour of energy consumption and economic growth in selected countries in Africa over time, highlighting potential asymmetries, structural breaks and nonlinear persistence in these variables. Second, by using much updated dataset, we report estimates that are based on desirable medium sample properties in this paper. Finally, we introduce into the energy literature a classic yet statistically powerful test for examining steepness and deepness asymmetries in the paths of variables. This test is the nonparametric Triple test developed by Randles *et al.* (1980). This test is known to be distribution free and performs well even in small samples. That it is distribution free implies that the Triple test is robust to outliers and to changes in the variance of the distribution. That aside, Monte Carlo exercises show that the Triple test is superior in detecting asymmetries in variables when compared to Gupta's (1967) G test (see Randles *et al.*, 1980).

To the best of our knowledge, this is the first paper to simultaneously analyze deepness and steepness asymmetries, nonlinear persistence, and structural breaks in the literature. The rest of the paper is organized as follows. In Section 2, we review the relevant literature. Then, in Section 3, we present the methodology. In Section 4, we document our empirical results. Then in Section 5, we present the conclusions and the implications for policy.

2. The Relevant Literature

The links between energy-related variables and economic growth first appeared in Kraft and Kraft (1978), who find unidirectional causal flow from economic growth to energy consumption in the US data. Since then, many papers are devoted to examining the relationships between economic growth and energy-related variables in the literature, generally emphasizing the direction of the causal flow between these variables. Strictly speaking, four strands of conclusions are documented in the literature. The first, which is the *growth hypothesis*, argues that energy consumption is important for economic growth. The second, the *conservative hypothesis*, argues that economic growth generates energy consumption. The third, the *neutrality hypothesis*, argues that energy consumption and economic growth are unrelated. The fourth, the *feedback hypothesis*, suggests that there exist feedback causal influence between energy consumption and economic growth.[2]

The aim of this section is not to classify the previous studies into these four strands based on their findings. Instead, we devote much space to emphasize the techniques utilized by these studies in order to motivate the existence of our paper. In addition, since our paper concentrates on selected African countries, we find it desirable to review relevant studies (i.e. studies on the energy-growth issues based on African countries or developing countries). Such studies include Ebohon (1996), Asafu-Adjaye (2000), Jumbe (2004), Lee (2005), Wolde-Rufael (2009), Ozturk and Bilgili (2015) among others (see Table 1).

The previous studies can be streamlined into time series and panel data studies with their common link being the assumption of linearity in the relationships characterizing energy consumption and economic growth. In the time series literature, linear residual based cointegration techniques of Engle and Granger (1987), and the linear maximum likelihood techniques of Johansen (1988) and Johansen and Juselius (1990) have dominated in the past studies. For instance, Ebohon (1996) utilize these techniques to examine the relationships between energy consumption and economic growth in Nigeria and Tanzania over different sample periods. Asafu-Adjaye (2000) investigates the nexus between energy consumption, electricity prices and economic growth in India, Indonesia, Phillipines and Thailand using the Johansen cointegration techniques and residual based causality tests. Jumbe (2004) use these techniques to examine the causal flow between electricity consumption and economic growth in Malawi. In a recent paper, Belloumi (2009) examine the direction of causality between energy consumption and economic

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[2] See Eggoh et al. (2011) for detailed explanation.

growth in Tunisia using the Johansen technique and vector error correction models.

In very recent papers, some authors have resorted to the linear autoregressive distributed lags (ARDL) bounds testing and the Toda-Yamamoto techniques due to Pesaran *et al.* (2001), and Tota and Yamamoto (1995), respectively, to examine the relationships between energy consumption and economic growth. For example, Wolde-Rufael (2005) utilizes the Toda-Yamamoto Granger causality test to examine the relationships between energy consumption and economic growth in 17 African countries. Similarly, Ouedraogo (2010), Akinlo (2008), Odhiambo (2009), and Ozturk and Acaravci (2011) utilize the ARDL bounds testing technique to examine the nexus between energy consumption and economic growth in some African countries.

There has been divergence in the conclusions presented in most of the studies on the energy-growth nexus in the literature. Some authors suggest that these may have been caused by limited time series data, especially for African countries (see Eggoh *et al.*, 2011), which can reduce the power and properties of linear cointegration tests. Thus, some studies have instead utilized linear panel data techniques to examine the links between energy consumption and economic growth. The popular of such linear panel data techniques are the Dynamic Ordinary Least Squares (DOLS) and the Fully Modified Ordinary Least Squares (FMOLS). Lee (2005), for instance, utilizes panel cointegration and error correction models to examine the links between energy consumption and economic growth in 18 developing countries. Similarly, Apergis and Payne (2009a) utilize these panel techniques to examine the links between energy consumption and economic growth in 6 Central American countries. Kedebe *et al.* (2010) utilize panel cointegration techniques to examine the relationships between energy consumption and economic growth in 20 sub-Saharan African countries. Eggoh *et al.* (2011) use panel cointegration tests with structural breaks to examine the cointegration relationships between energy consumption and economic growth in 21 African countries. However, they were unable to incorporate structural breaks in their error correction model. Finally, Ozturk and Bilgili (2015) use dynamic panel techniques to study the impact of biomass consumption on economic growth in 51 African countries.

The techniques utilized by these studies clearly elaborate our concern. These studies rely on linear econometric techniques. The question is: what happens then if the variables exhibit asymmetric movements over time? Obviously, if the paths of these variables are characterized by asymmetries, nonlinear persistence, and structural breaks, linear techniques may be inappropriate. Indeed recent studies accept the asymmetric phenomenon and attempt to resolve it using nonlinear techniques. As indicated above, Eggoh *et al.* (2011) recognize this issue and examine the relationships between energy consumption and economic growth in 21 African countries, using panel cointegration tests with structural breaks. In addition, studies such as Esso (2010) and Iyke (2015) utilize threshold cointegration techniques to examine the links between energy consumption and economic growth to overcome this challenge. Our paper aims to shed light on the asymmetries, structural breaks, and nonlinear persistence which characterize energy consumption and economic growth. This change in direction is in order to encourage future research to consider these irregular movements seriously.

Table 1: Relevant Studies on Energy Consumption and Economic Growth

Author(s)	Period	Country	Method(s)
Ebohon (1996)	1960–1984, 1960–1981	Nigeria, Tanzania	Granger Causality test
Asafu-Adjaye (2000)	1971–1995, 1973–1995	The Philippines, Thailand, India, Indonesia	Cointegration and Granger Causality based on ECM
Jumbe (2004)	1970–1999	Malawi	Cointegration and Granger Causality based on ECM
Lee (2005)	1975–2001	18 developing countries	Panel VECM
Wolde-Rufael (2005)	1971–2001	19 developing countries	Toda–Yamamoto's Granger causality
Wolde-Rufael (2006)	1971–2006	17 African countries	Toda-Yamamoto's Granger causality
Ouedraogo (2010)	1968–2003	Burkina Faso	ARDL Bounds tests
Al-Iriani (2006)	1960–2002	6 countries of GCC (Bahrain, Kuwait, UAE Oman, Qatar, Saudi Arabia)	Panel cointegration, GMM
Mahadevan and Asafu-Adjaye (2007)	1971–2002	20 energy importers and exporters	Panel error correction model
Akinlo (2008)	1980–2003	11 Sub-Saharan African Countries	ARDL Bounds tests
Huang et al. (2008)	1960–2001	82 Low, Middle, and High income countries	Panel VAR, GMM model
Odhiambo (2009)	1971–2006	Tanzania	ARDL Bounds test
Odhiambo (2010)	1971–2006	South Africa, Kenya and Congo Democratic Rep	ARDL Bounds tests
Apergis and Payne (2009a)	1991–2005	6 Countries (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama)	Panel cointegration, ECM
Apergis and Payne (2009b)	1980–2004	Armenia, Azerbadjan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Ukraine, Uzbekistan	Panel cointegration, ECM
Wolde-Rufael (2009)	1971–2004	17 African countries	Variance decomposition

			analysis and Toda-Yamamoto's Granger causality
Ozturk et al. (2010)	1971–2005	51 low and middle income countries	Panel cointegration and causality test
Ozturk and Acaravci (2011)	1971–2006	11 Middle East and North Africa (MENA) countries	ARDL Bounds test
Ozturk and Bilgili (2015)	1980–2009	51 Sub-Sahara African countries	Panel cointegration

Notes: ECM = Error correction model, VECM = Vector error correction model, ARDL = Autoregressive distributed lags, VAR = Vector autoregression, GMM = Generalized method of moments

3. Methodology

This section presents our empirical testing strategies. We discuss them briefly and underscore their relevance. To test for deepness and steepness asymmetries in energy consumption and economic growth, we employ the Triple test proposed by Randles *et al.* (1980). We analyze structural breaks using the Bai-Perron test which is originally advanced by Bai (1997), and Bai and Perron (1998; 2003a; 2003b). We end this section by discussing the test for nonlinear persistence developed in Kapetanios *et al.* (2003), and by describing our data.

3.1 Triple Test for Deepness and Steepness Asymmetries

We examine the asymmetric behaviour of energy consumption and economic growth using the Triple test developed by Randles *et al.* (1980). The rationale behind this test is quite straight forward. It builds on the idea that, given all possible triples of observations (Y_i, Y_j, Y_k) drawn from a sample of size T with most of these triples right skewed, a researcher can admit the behaviour of this sample as the true baseline distribution. Thus, given $1 \leq i, j, k \leq T$, we can say that the triples of observations Y_i, Y_j and Y_k are right triples, supposing that the middle observation is in the neighbourhood of the smallest observation relative to the largest observation.

A more formal way to define Randles *et al.* (1980) Triple test is as follows. Let $\{Y_t, t = 1, \dots T\}$ be a random draw from $F(Y - \varphi)$, where $F(\cdot)$ denotes a cumulative distribution function (CDF) for a continuous population such that $F(0) = 1/2$, and φ is the population (Y) median. Then, we can state the following

$$f(Y_i, Y_j, Y_k) = \{[sign(Y_i + Y_j - 2Y_k) + sign(Y_i + Y_k - 2Y_j) + sign(Y_j + Y_k - 2Y_i)]\}/3 \qquad (1)$$

where $sign(\nabla)$ is 0, 1 or -1 whenever ∇ is greater, less or equal to 0. Thus, $f(Y_i, Y_j, Y_k)$ can only admit the values $-1/3$, 0 and $1/3$, depending on $sign(\nabla)$. $f(Y_i, Y_j, Y_k) = -1/3$, 0 and $1/3$ denote left triple, non-skewed triple and right triple, respectively.

The test statistic for this test is constructed as

$$U = \frac{\hat{\mu} - \mu}{\left(\sigma_{\mu}^2/T\right)^{1/2}} \qquad (2)$$

where $\hat{\mu}$ is constructed such that

$$\hat{\mu} = \binom{T}{3}^{-1} \sum_{i<j<k} f(Y_i, Y_j, Y_k) \qquad (3)$$

Notice that $\binom{T}{3}$ denotes "T combination 3" so that $\hat{\mu}$ can be written alternatively as

$$\hat{\mu} = \frac{R - L}{3\binom{T}{3}} \tag{4}$$

where R and L denote the number of right and left triples, respectively. In addition, U is standard normal and its variance (σ_{μ}^{2}) is estimated as follows.

$$\sigma_{\mu}^{2} = \binom{T}{3}^{-1} \sum_{q=1}^{3} \binom{3}{q} \begin{pmatrix} T & -3 \\ 3 & q \end{pmatrix} \psi_q \tag{5}$$

where ψ_q takes the form:

$$\psi_q = var\left[f_q\left(Y_1, \dots, Y_q\right)\right] \tag{6}$$

So that, by definition, ψ_1, ψ_2 and ψ_3 are constructed as

$$\psi_1 = T^{-1} \sum_{i=1}^{T} (f_1(Y_i) - \hat{\mu})^2 \tag{7}$$

$$\psi_2 = \binom{T}{2}^{-1} \sum_{j<k}\sum \left(f_2\left(Y_j, Y_k\right) - \hat{\mu}\right)^2 \tag{8}$$

and

$$\psi_3 = \frac{1}{9} - \hat{\mu}^2 \tag{9}$$

where $f_1(Y_i)$ and $f_2\left(Y_j, Y_k\right)$ are defined as

$$f_1(Y_i) = \binom{T-1}{2}^{-1} \sum_{j<k}\sum f\left(Y_i, Y_j, Y_k\right) \qquad \forall\, j, k \neq i \tag{10}$$

and

$$f_2(Y_j, Y_k) = (T-2)^{-1} \sum_{i=1} f(Y_i, Y_j, Y_k) \qquad \forall\, i \neq j \neq k \quad (11)$$

Randles *et al.* (1980) test the null hypothesis that $\mu = 0$ and against the alternative that $\mu \neq 0$. By taking $\sigma_A^2 = 9\psi_1$ and $\sigma_T^2 = \sigma_A^2 + \sigma(1)$, Randles *et al.* (1980) demonstrate, using Slutsky Theorem, that $T^{1/2} = (\hat{\mu} - \mu)/\sigma_A$ is standard normal distributed. Thus, we can test the null hypothesis by using the idea that $\Gamma_1 = t^{1/2}\hat{\mu}/\sigma_T$ and $\Gamma_2 = t^{1/2}\hat{\mu}/\sigma_A$. Using these statistics, we can reject the null hypothesis that $\mu = 0$ if $|\Gamma_i| > Z_{\alpha/2}$ for $i = 1, 2$. $Z_{\alpha/2}$ denotes the upper percentile of the standard normal distribution (see Randles *et al.*, 1980).

The Triple test can be used to examine two kinds of asymmetries in macroeconomic series, namely: (i) deepness and (ii) steepness. The deepness asymmetry is tested on the cyclical component of the time series, whereas the steepness asymmetry is tested on the first differenced series. We can interpret a business cycle which exhibit both deepness and steepness asymmetries as follows. For deepness, we say the lengths of the troughs are deeper than the heights of the peaks. For steepness, we say contractions are steeper than expansions (see Sichel, 1993; Narayan, 2009). In addition, negative steepness suggests that the series decreases at a faster rate and increases at a slower rate; positive steepness suggests that the series increases at a faster rate and decreases at a slower rate (see Razzak, 2001; Narayan, 2009).

3.2 Testing for Structural Breaks

Testing for structural breaks forms an essential component of model formulation and forecasting. By not testing for structural breaks, the researcher is assuming that the parameter estimates remain unchanged over time. There are several reasons why such an assumption may not be economically meaningful. For example, the impact of the world wars, the Great Depression, the oil price shocks of the 1973 and 1979, the Gulf war in 1990, the civil wars that plague many African countries in the past, the Asian financial crisis of the 1997, and the recent global financial and economic crisis could have distorted the paths of most economic variables.

The test for structural breaks dates back to the seminal paper of Chow (1960). In his paper, Chow (1960) develops an F-test for regime shift in parameters by assuming that such break dates are known. This test has been extended by Quandt (1960), who derives a modified F-statistic based on the largest value over all possible break dates. The limiting distribution for the Quandt test are derived in Andrews (1993), and Andrews and Ploberger (1994).

The limitation of the Chow test and its descendants is that it is unable to incorporate multiple structural breaks. To emend this issue, Bai (1997), and Bai and Perron (1998; 2003a; 2003b) extend the Quandt-Andrews paper by deriving a test which is able to account for multiple structural breaks (see Perron, 2006, for an excellent survey of the literature). The Bai-Perron structural breaks test builds on the following regression

$$y_t = X_t'\gamma + Z_t'\theta_j + \varepsilon_t \qquad (12)$$

where the number of regimes, $j = 0, \dots, q$; y_t is the dependent variable; X are the variables whose coefficients do not change across regimes; Z are the variables whose coefficients are regime-specific; γ and θ are the coefficients; and ε is the random disturbance term.

According to Bai and Perron (1998), for a set of breakpoints, $\{T\}_q$, we can minimize the sum-of-squared residuals

$$S(\gamma, \theta | \{T\}) = \sum_{j=0}^{q} \left\{ \sum_{t=T_q}^{T_{q+1}-1} (y_t = X_t' \gamma + Z_t' \theta_j + \varepsilon_t) \right\} \tag{13}$$

by ordinary least squares (OLS) to obtain the estimates (γ, θ). The algorithms for estimating the global breakpoint optimizers are documented in Bai and Perron (2003a).

The Bai-Perron test evaluates the null hypothesis that there are no structural breaks, $\theta_0 = \theta_1 = \cdots \theta_{q+1}$, against an alternative of q structural breaks. The test follows a statistic of the form (see Bai and Perron, 2003a)

$$F(\hat{\theta}) = \frac{1}{T} \left(\frac{T - (q+1)p - r}{kp} \right) (R\hat{\theta})' (R\hat{V}(\hat{\theta})R')^{-1} R\hat{\theta} \tag{14}$$

where $(R\hat{\theta})' = (\theta_0' - \theta_1', \ldots, \theta_q' - \theta_{q+1}')$; $\hat{\theta}$ is the optimal q-break estimate of θ; and $\hat{V}(\hat{\theta})$ is the variance-covariance matrix of $\hat{\theta}$. The distribution of the test statistic is non-standard. Bai and Perron (2003b) derive the critical values and response surfaces for various trimming parameters, and the number of regressors and breaks for this test.

3.3 Testing for Nonlinear Persistence

Testing for persistence (or unit roots) is useful in time series analysis. Parameter estimates are often misleading if variables in a model are persistent (or contain unit roots). The commonly utilized tests for examining persistence in time series analysis are the *DF*, *ADF*, *PP*, and *KPSS* among others. These tests assume that the data generating process of the series under consideration is linear. Meaning that if the time series exhibits nonlinearities, these tests will frequently fail to reject the null hypothesis of unit root (see Kapetanios *et al.*, 2003).

To overcome this limitation, Kapetanios *et al.* (2003) develop an efficient test for unit roots (or persistence) which takes into account the potential nonlinear behaviour of time series variables. In this paper, we utilize this Kapetanios-Shin-Snell (KSS) nonlinear unit root test, since the variables we use are suspect of nonlinearities. The KSS test detects the presence of persistence or unit roots against a nonlinear globally stationary exponential smooth transition autoregressive (ESTAR) process of the form

$$\Delta x_t = \gamma x_{t-1}\{1 - \exp(-\theta x_{t-1}^2)\} + \varepsilon_t \qquad (15)$$

where Δ is the first difference operator, x_t is the time series variable being tested, γ is a parameter, $\theta \geq 0$ is the transition parameter of the ESTAR model, t is the time period, and ε_t is the white-noise error term.

We test the null hypothesis that $\theta = 0$ which implies x_t is a non-stationary linear process against the alternative of $\theta > 0$, which implies x_t is a stationary nonlinear ESTAR process. The parameter γ is unidentified under the null hypothesis. Therefore, Kapetanios *et al.* (2003) compute a first-order Taylor series approximation to the ESTAR model under the null hypothesis of $\theta = 0$ and derive a t-type test statistic, following Luukkonen *et al.* (1988). This means *Eq*. (15) will now be the following auxiliary regression

$$\Delta x_t = \delta x_{t-1}^3 + \varepsilon_t \tag{16}$$

For the general case of serially correlated errors, *Eq.* (15) can be extended to form the following general auxiliary regression for *Eq.* (16) as

$$\Delta x_t = \sum_{j=1}^{p} \rho_j \Delta x_{t-1} + \delta x_{t-1}^3 + \varepsilon_t \tag{17}$$

where p is the optimal lag to be included in the regression using AIC or BIC, and ρ_j and δ are coefficients to be estimated. In this form, we can formulate the null hypothesis of unit root, $\delta = 0$, against a nonlinear stationary ESTAR process, $\delta < 0$. The *t-type* statistic obtain for δ (i.e. $t_{NL} = \hat{\delta}/se(\hat{\delta})$) is compared to the simulated critical values for the three different cases tabulated by Kapetanios *et al.* (2003, Table 1, p. 364).

3.4 Data

The data for our empirical analysis is based on nineteen (19) countries in Africa. These countries are Algeria, Benin, Cameroon, Congo, Cote d'Ivoire, DRC, Egypt, Gabon, Ghana, Kenya, Morocco, Nigeria, Senegal, South Africa, Sudan, Togo, Tunisia, Zambia and Zimbabwe. We choose these countries due to data consideration. Majority of the countries in Africa do not have consistent data on energy consumption pre-1990s. To provide results that are based on a medium time span (and not a limited time span), we find it necessary to exclude most of these countries. Our data comes from the World Development Indicators (WDI) which is compiled by the World Bank. In particular, we access the 2015 version of the WDI for our empirical analysis. We extract two key variables: energy consumption and economic growth which are proxy, respectively by Energy use (kg of oil equivalent per capita) and GDP per capita growth (annual %) in the WDI dataset. Our data is annual, spanning from 1971 to 2011. The end date of our sample is purely due to lack of data for energy consumption after 2011 (see WDI, 2015).

4. Empirical Results

4.1 Evidence of Asymmetries in Energy Consumption

The results for the Triple test on deepness and steepness asymmetry in energy consumption for the 19 African countries are shown in Table 2a. The first part of the table shows the test for deepness asymmetry (i.e. the Triple test on the cyclical component of energy consumption); the second part of the table shows the results for the steepness asymmetry (i.e. the Triple test on first differenced energy consumption). We can interpret Table 2a as follows. Except for Algeria and Zimbabwe, we do not find evidence of deepness asymmetry in energy consumption. The *U-statistic* of 1.79 and 3.40 for Algeria and Zimbabwe, respectively, suggest that we can reject the null hypothesis of no deepness asymmetry in energy consumption at 8% and 1%. Thus, for these two countries, the cyclical component of energy consumption tends to exhibit asymmetric behaviour through time. In addition, we find steepness asymmetry in 6 out of the 19 African countries. These countries are Cote d'Ivoire, Kenya, Morocco, Nigeria, Sudan and Togo. Of the 6 countries that we find steepness asymmetry in energy consumption, only Nigeria exhibits negative steepness. The remaining 5 are significantly characterized by positive steepness over the business cycle (see Table 2a). This suggests that, for Nigeria, energy consumption tends to decline at a faster rate but rises at a slower rate. For the remaining 5 countries (i.e. Cote d'Ivoire, Kenya, Morocco, Sudan and Togo), energy consumption rises at a faster rate but declines at a slower rate.

Table 2a: Asymmetries in Energy Consumption

Country	Deepness [μ=0]		Steepness [μ=0]	
	U-statistic	P-value	U-statistic	P-value
Algeria	1.7941*	0.0728	0.3901	0.6964
Benin	-0.3979	0.6907	0.5304	0.5958
Cameroon	0.0032	0.9975	-0.8214	0.4114
Congo	0.4919	0.6228	0.6287	0.5295
Cote d'Ivoire	-0.3984	0.6904	1.9351*	0.053
DRC	0.2999	0.7643	-0.7067	0.4798
Egypt	-0.7734	0.4393	-0.0372	0.9703
Gabon	0.3545	0.7229	-0.5775	0.5636
Ghana	-0.3446	0.7304	-1.0156	0.3098
Kenya	-0.7897	0.4297	1.8482*	0.0646
Morocco	0.0695	0.9446	1.7343*	0.0829
Nigeria	0.7377	0.4607	-4.6364***	0.0000
Senegal	0.4822	0.6297	-0.6699	0.5029
South Africa	0.5452	0.5856	-0.2735	0.7844
Sudan	0.613	0.5399	1.9222*	0.0546
Togo	-0.3706	0.7109	1.9332*	0.0532
Tunisia	0.3175	0.7508	-1.3912	0.1642
Zambia	-0.1021	0.9186	0.0208	0.9834
Zimbabwe	3.4006***	0.0007	-0.1214	0.9034

Note: * and *** denote rejection of the null hypothesis at 10% and 1% significance level, respectively.

4.2 Evidence of Asymmetries in Productivity Growth

Table 2b reports the results for the Triple test on productivity growth for the 19 African countries. The results in Table 2b are organized in the same fashion as Table 2a. The first part of the table shows the results for the deepness asymmetry test (i.e. the Triple test on the cyclical component of productivity growth), whereas the second shows the results for the steepness asymmetry test (i.e. the Triple test on first differenced productivity growth). The key findings are summarized as follows. We find deepness asymmetry in productivity growth only in the case of Congo. The null hypothesis of no deepness asymmetry in productivity growth in the case of Congo is rejected at 7%, since the *U-statistic* is -1.85. This suggests that the lengths of troughs are deeper than the height of peaks in the case of Congo's business cycle. In addition to this, we find no evidence in favour of steepness asymmetry in productivity growth for the entire sample (see Table 2b).

Table 2b: Asymmetries in Productivity Growth

Country	Deepness [μ=0]		Steepness [μ=0]	
	U-statistic	P-value	U-statistic	P-value
Algeria	-0.1775	0.8591	0.1926	0.8473
Benin	-0.4481	0.654	0.9016	0.3673
Cameroon	-0.1828	0.855	0.0646	0.9485
Congo	-1.8482*	0.0646	-0.0237	0.9811
Cote d'Ivoire	0.5048	0.6137	-0.4333	0.6648
DRC	-1.16	0.246	1.228	0.2194
Egypt	-0.7627	0.4456	0.0476	0.962
Gabon	-0.8084	0.4189	-0.0186	0.9851
Ghana	-0.3672	0.7135	-0.1469	0.8832
Kenya	-0.9894	0.3225	-0.4054	0.6852
Morocco	0.7582	0.4483	-0.2216	0.8246
Nigeria	0.3462	0.7292	-0.0541	0.9569
Senegal	-1.129	0.2589	-0.5984	0.5496
South Africa	-1.1024	0.2703	-0.7026	0.4823
Sudan	-0.9791	0.3275	-0.7186	0.4724
Togo	0.1405	0.8883	0.5134	0.6076
Tunisia	-1.0512	0.2932	0.1457	0.8842
Zambia	0.4383	0.6612	-1.169	0.2424
Zimbabwe	-1.0765	0.2817	0.4425	0.6581

Note: * denotes rejection of the null hypothesis at 10% significance level.

4.3 Evidence of Structural Breaks in Energy Consumption and Economic Growth

Table 3a reports the evidence of structural breaks in energy consumption for the selected African countries. The maximum number of breaks recorded for the entire sample is 4.

The countries with the maximum number of structural breaks in energy consumption are Congo DR, Egypt, Morocco, and Tunisia. Countries, such as Ghana, Kenya and Togo recorded a single structural break in energy consumption. The last break date for most of these countries appear to occur around 2004 and 2006.

Table 3a: Structural Breaks in Energy Consumption

Country	No. of Breaks	F-statistics[Break Date]			
Algeria	2	143.8903[1982]	38.935[2005]		
Benin	3	18.371[1987]	42.138[2000]	24.293[2006]	
Cameroon	3	111.809[1979]	10.548[1991]	54.159[2006]	
Congo DR	4	225.218[1983]	30.399[1993]	32.177[2000]	26.739[2006]
Congo	3	31.569[1988]	23.984[1994]	31.057[2006]	
Cote D'ivoire	3	113.379[1982]	71.553[1996]	15.296[2004]	
Egypt	4	65.322[1979]	108.407[1985]	22.466[1997]	37.883[2005]
Gabon	2	180.096[1985]	15.840[1991]		
Ghana	1	71.207[1995]			
Kenya	1	26.829[2006]			
Morocco	4	88.567[1977]	32.493[1989]	42.208[1999]	29.069[2005]
Nigeria	1	126.357[1979]			
Senegal	3	62.236[1982]	22.687[1989]	48.687[2000]	
South Africa	1	96.908[1981]			
Sudan	3	71.165[1977]	18.760[1986]	30.269[2004]	
Togo	1	444.332[1996]			
Tunisia	4	106.012[1978]	45.600[1990]	28.921[1997]	21.507[2003]
Zambia	3	114.494[1979]	50.245[1990]	34.462[1996]	
Zimbabwe	2	63.359[1977]	65.614[2000]		

Unlike energy consumption which shows strong statistical significance of structural breaks for the entire sample, economic growth does not seem to show breaks for some of the countries (see Table 3b). For example, in countries such as Algeria, Egypt, Nigeria, and Tunisia, we find the structural breaks in economic growth to be statistically insignificant (see Table 3b). It is important to mention that although the structural breaks are not statistically significant they are economically meaningful. Plots (not shown here) of economic growth for the countries that we find no evidence of statistically significant structural breaks display jumps. Thus, the applied researcher may want to take such jumps into consideration when modelling economic growth. For the whole sample, the maximum number of structural breaks in economic growth is 4; this is reported for South Africa (see Table 3b).

Table 3b: Structural Breaks in Economic Growth

	No. of Breaks	F-statistics[Break Date]			
Algeria	0	3.457[None]			
Benin	0	1.984[None]			
Cameroon	2	12.777[1987]	20.187[1994]		
Congo DR	2	17.289[1990]	24.200[2002]		
Congo	2	11.149[1979]	11.295[1985]		
Cote D'ivoire	2	13.027[1979]	12.582[1985]		
Egypt	0	4.403[None]			
Gabon	1	32.371[1977]			
Ghana	1	22.047[1984]			
Kenya	0	8.553[None]			
Morocco	0	1.125[None]			
Nigeria	0	7.933[None]			
Senegal	0	4.131[None]			
South Africa	4	9.728[1988]	7.696[1992]	5.689[2000]	4.430[2006]
Sudan	0	4.020[None]			
Togo	0	2.286[None]			
Tunisia	0	8.071[None]			
Zambia	1	24.581[1999]			
Zimbabwe	1	3.242[None]			

Note: None implies that the structural breaks are not statistically significant.

4.4 Evidence of Nonlinear Persistence in Energy Consumption and Economic Growth

Table 4 presents the results for the nonlinear persistence testing. Recall that the KSS test evaluates the hypothesis that the series under consideration is nonstationary against the alternative that the series is a nonlinear stationary ESTAR process. From Table 4, it is evident that energy consumption in majority of the countries in the sample has a unit root or is persistent. There are four cases where energy consumption appears to be a stationary ESTAR process. These are Gabon, Sudan, Zambia and Zimbabwe. We find economic growth to follow a stationary ESTAR process in most cases. The variable appears persistent only in few cases such as Cameroon, Egypt, Ghana, Nigeria, and Zambia. These results suggest that the applied researcher may want to transform energy consumption and economic growth in cases where they appear to be persistent. The results also means that for cases where these variables follow a stationary ESTAR process, the usual linear models and estimation techniques which are often used to examine these variables are flawed.

Table 4: Nonlinear Persistence in Energy Consumption and Economic Growth

	KSS statistic	
	Energy Consumption	GDP
Algeria	1.061	-2.499**
Benin	-0.255	-3.851***
Cameroon	-0.929	-1.049
Congo DR	0.8939	-1.636
Congo	-0.042	-2.820**
Cote D'ivoire	0.545	-2.823***
Egypt	1.190	-1.728
Gabon	-2.450**	-3.724***
Ghana	0.636	-1.487
Kenya	0.442	-2.709**
Morocco	3.436	-0.783
Nigeria	0.532	-1.909
Senegal	-0.811	-2.543**
South Africa	0.414	-2.558**
Sudan	-3.146***	-3.173***
Togo	1.032	-5.003***
Tunisia	1.336	-1.406
Zambia	-4.113***	-0.572
Zimbabwe	-2.503**	-3.202***

Note: The values in the table are the KSS statistics. These values are compared to Table 1 [Case 1] in Kapetanios *et al.* (2003, p. 364). ** and *** denote significance at 5% and 1%, respectively.

5. Conclusions and Policy Implications

Energy consumption and economic growth nexus has remained a dominant topic in the energy economics literature. This is perhaps due to the fact that the conclusions drawn in the many studies on the nexus between these two variables have remained divergent. This paper does not pretend to shed new light on the energy-growth nexus but instead reveals the characteristics of the paths of these two variables that may change the way researchers model and forecast them. The paper examines the possibility of asymmetries, structural breaks, and nonlinear persistence in energy consumption and economic growth for 19 African countries using the techniques proposed in Randles *et al.* (1980), Bai and

Perron (1998; 2003a; 2003b), and Kapetanios *et al.* (2003) over the period 1971-2011. Two issues motivate the existence of this paper. First, majority of the studies that examine the nexus between energy consumption and economic growth either in bivariate or multivariate settings have assume symmetry or linearity in the nexus featuring these variables. Such a limiting assumption, we believe, may have contributed to the divergence in the findings we see in the literature. Second, forecasting is an essential element of policymaking and implementation. Thus, the need to understand whether energy consumption and economic growth relate symmetrically comes invaluable, since wrong choices of forecasting techniques may prove far-fetching, in terms of policy formulation.

The key findings of the paper can be summarized as follows. There is evidence of deepness and steepness asymmetry, structural breaks, and nonlinear persistence in energy consumption and economic growth. The implications of these asymmetries, structural breaks, and nonlinear persistence in energy consumption and economic growth are that: (i) the findings of studies which examine the energy-growth nexus for these countries (see, for example, Ebohon, 1996; Lee, 2005; Wolde-Rufael, 2006; Akinlo, 2008; Huang *et al.*, 2008; Eggoh *et al.*, 2011; Ozturk and Bilgili, 2015) in linear settings may be doubtful; (ii) forecasters who employ linear models to forecast energy consumption and economic growth for these countries may be committing sizeable forecasting errors. In light of these implications, the paper recommends that future studies on the energy-growth nexus should consider testing whether these variables are characterized by asymmetries, structural breaks, and nonlinear persistence. If they are, appropriate asymmetric models should be used to examine the relationships between these two variables. The current research seems to move towards this direction. For example, studies such as Esso (2010) and Iyke (2015) have utilized threshold cointegration models to examine the links between energy consumption and productivity growth. This change in direction, we believe, will enhance the results and findings in the literature. It will also enhance forecasting and decision-making.

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