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Energy consumption and economic growth in Sub-Saharan African countries: Further evidence

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Abstract

This article examines the causal relationship between energy consumption and economic growth within a multivariate approach which incorporates physical capital, land, trade openness and financial development in 13 Sub-Saharan African countries. The autoregressive distributed lag bounds approach to cointegration and a modified version of the Granger non-causality test are applied to investigate the short-term and the long-term properties. The results show the existence of a long-term relationship in eight out of the 13 countries and evidence of growth hypothesis is reported in Gabon, Kenya and Nigeria. We also observe the existence of the conservation hypothesis in Sudan and Zambia, feedback hypothesis in Cameroon, and a neutrality nexus in Benin, Cote d'Ivoire, Congo, Ghana, Senegal, South Africa and Togo. These findings provide useful reference in designing appropriate country specific environmental and energy policies.

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1. Introduction

The economic growth and energy consumption relationship has been extensively studied in recent years since the seminal work carried out by Kraft and Kraft (1978). This growth in popularity may be due to the role of economic growth and energy consumption in explaining the carbon pollution level. A survey of Ozturk (2010) and Payne (2010) on the energy-growth nexus outlined four main hypotheses which are addressed, namely the growth hypothesis, the conservation hypothesis, the neutrality hypothesis and the feedback hypothesis.[1] These hypotheses are related to two theoretical views in the literature concerning the relationship between energy consumption and economic growth. Some authors consider energy as a primary production factor complementing the conventional classical production factors (capital, labor and land) and an essential means in reaching economic, social and technological progress (Dunkerley, 1982; Ebohon, 1996; Templet, 1999). Accordingly, there should be a causality running from energy consumption to growth meaning that the country is dependent on energy so that an environmental policy that reduces energy consumption (namely a "conservation policy") could affect negatively the growth path. Therefore, a policy which increases the accessibility and the usage of energy (i.e. "growth policy") in the production system should be prioritized. Others minimize the role of energy and postulate that energy consumption represents a too "small cost share" in total output (Okun, 1974, 1975) and consequently plays a minor role in a country's GDP evolution (Ebohon, 1996; Squalli, 2007). In this sense, technological progress and economic growth would tend to reduce the demand for energy per unit of production in the production sector (industry and construction or agriculture) while a rising energy consumption would be enhanced by the household sector. Hence, a causality from income to energy or a no-causality relationship would imply that an energy conservation policy would have little or no impact on economic growth as a perfect substitution is assumed between energy and the other production factors.

However, it is noteworthy that despite the considerable number of studies on the issue, the results are inconclusive and there is a need of further examination of the causal relationship between economic growth and energy consumption. Since previous studies have focused essentially on the bivariate case, the conflicting results of the causality between economic growth and energy consumption were attributed to the omission of relevant variables, the differences in causality approaches, the time periods considered and the country characteristics (Tang *et al.*, 2016; Ozturk, 2010; Payne, 2010). Indeed, it is well known that the exclusion of relevant variables not only makes the estimates biased and inconsistent but also an erroneous no-causality relationship could arise from a bivariate system due to the omitted variables (Lütkepohl, 1982). Hence, the result from a bivariate analysis may be invalid as important variables affecting both economic growth and energy consumption are ignored and the inclusion of more information through supplementary variables in the estimation can provide more reliable results (Loizides and Vamvoukas, 2005; Wolde-Rufael, 2009). Following Ozturk (2010) and in order to fix the inconsistency and the variable omission bias, future work should consider a multivariate framework by including supplementary variables. A relevant strategy to handle this is to use a production function approach. Thus, there is a growing attention to the role of various variables

[1] A growth hypothesis implies a unidirectional causality from energy consumption to growth. It suggests that economic growth is dependent on energy and consequently involves an expansionary economic policy. A conservation hypothesis implies that causality runs from growth to energy consumption and an energy conservation policy would not have an adverse effect on growth. A feedback hypothesis means that both factors are mutually dependent while the neutrality hypothesis assumes the opposite.

such as physical capital, labor, human capital, energy price, government spending, trade, financial development, etc. (see for instance Asafu-Adjaye, 2000; Shahbaz *et al.*, 2013; Nasreen and Anwar, 2014; Komal and Abbas, 2015; Fang and Chang, 2016; Tang *et al.*, 2016).[2]

However, when regarding SSA countries there is a lack of studies investigating the energy-growth nexus based on a multivariate approach, since previous studies have been based essentially on the bivariate model and those which have incorporated additional variables, are concerned with only one single country. Table 1 summarizes the results of research on SSA countries. Clearly, the table reveals that there is no departure between the four hypotheses, even when looking at each country. Among these studies, Akinlo (2008) used consumer price index and government expenditure as control variables, Odhiambo (2010) incorporated consumer price index, Odhiambo (2009a) and Lin and Wesseh Jr (2014) considered employment in South Africa and Iyke (2015) was concerned with the inflation rate in Nigeria. To the best of our knowledge, Wolde-Rufael (2009) is the only study which investigated the energy-growth causality using a production function approach and which focused on different SSA countries. The author investigated the causality between energy consumption and economic growth by including labor and capital as additional variables. His result supported the growth hypothesis in Benin and South Africa, the conservation hypothesis in Cote d'Ivoire, Nigeria, Senegal, Sudan and Zambia, the bidirectional relationship in Gabon, Ghana, Togo, Zimbabwe, and the independence relationship in Cameroon and Kenya.

The present paper contributes to the existing literature by incorporating land into the production function in addition to physical capital and labor and by setting the technological factor to be a function of trade openness and financial development. It is well known that empirical models that are grounded in sound theory produce better outcomes (Shahbaz *et al.*, 2013) and the inclusion of relevant variables that may affect economic growth and energy consumption should deal with the variable omission bias reported in previous studies. It is essential to consider the most relevant production factors (the neoclassical production factors, i.e. physical capital, labor and land are used in this study) when focusing on energy as complementary (or substitutable) to the standard factors through a causality analysis. Actually, it is standard in most analyses to ignore the land factor but regarding that the economic structure of SSA countries is largely based on the agricultural sector, considering this factor could provide compelling evidence on the energy-growth nexus. Previous work has not paid attention to this aspect as Lin and Wesseh Jr (2014) focused only on the non-agricultural sector and Jumbe (2004) reported the causality result between electricity consumption and the non-agricultural GDP. Kebede *et al.* (2010) pointed out the significant role of the agricultural sector in explaining energy demand in Sub-Saharan Africa. Furthermore, researchers have pointed out the economically important role of trade openness and financial development in the production function (see Shahbaz *et al.*, 2013; Kumar *et al.*, 2015).[3] More specifically,

[2]Another group of studies which is an extension of studies on the environmental Kuznets curve hypothesis, examines the relationship between economic growth, energy consumption and carbon emission. The results are inconclusive and recent developments tend also to incorporate additional variables. This paper does not address this kind of issue and for a review of studies which are concerned with SSA countries, refer to Menyah and Wolde-Rufael (2010), Kohler (2013) and Mensah (2014).

[3]More precisely, Grossman and Helpman (1991) and Romer (1990) reported that foreign trade enhances technological progress. The work of Schumpeter (1974) and Levine (1997) pointed out that an efficient financial sector encourages technological innovation by increasing savings and funding innovative investors. Some empirical studies have also focused on the interactions between trade openness and

some authors have reported that trade openness is closely correlated with the growth cycles in SSA countries as they found that trade shocks account for almost half of the volatility in aggregate output (Kose and Riezman, 2001; Iqbal and Khan, 1998; Brückner and Lederman, 2012; Azam *et al.*, 2002). Accordingly, it is essential to consider openness to international trade when focusing on economic growth in SSA countries and energy consumption. For instance, openness to international trade could affect energy consumption in the production sector through a trade structure which is oriented towards the export (or import) of an energy intensive commodity or through better technology transfers. Likewise, financial development can improve the economic efficiency of a country and give access to better technology that may reduce the role of energy during the production and hence could influence the direction of causality between energy consumption and production growth. This study believes that the inclusion of such variables related to energy consumption and essential to the production function may enable valid causality results between economic growth and energy consumption in the selected SSA countries.

Hence, this study investigates the dynamic relationship between economic growth and energy consumption in a multivariate framework which incorporates physical capital, labor, land, trade openness and financial development. Since there is a strong heterogeneity between SSA countries, the policy implications should be specific to each country. So, time series approaches of cointegration and causality analysis should be used to examine the long-run and short-run dynamics.[4] Payne (2010) reported standard methods used in the literature such as the approaches of Johansen and Juselius (1990), Engle and Granger (1987), Pesaran *et al.* (2001), and Toda and Yamamoto (1995). This study makes use of the autoregressive distributed lag (ARDL) approach of Pesaran *et al.* (2001) and the Toda and Yamamoto (1995)[T-Y hereafter] causality test procedure as it has been demonstrated that they are suitable especially for small sample sizes (Payne, 2010; Narayan, 2005; Kofi Adom *et al.*, 2012). The T-Y approach augments a vector autoregressive (VAR) model with d_{max} extra lags, where d_{max} is the maximum order of integration of the series. Consequently, unit root tests are implemented as well to examine the non-stationary properties of each variable. Following Omri (2014) and since SSA countries have implemented structural reforms which have affected the economic activity, the long-run estimations allow for the presence of structural breaks in the model. Recent developments in time series enable the testing for a stable time trend against an alternative of unknown number of abrupt ruptures in the series (Bai and Perron, 1998, 2003)[BP] and unit root tests that allow for symmetric treatment of breaks under both the null and alternative hypotheses have been developed (Carrion-i Silvestre *et al.*, 2009).

This study contributes to the energy-growth literature in the following main ways: First, we re-examine the energy-growth nexus using a multivariate framework and focus on a range of countries which was not sufficiently studied; Second, we explore the role of additional variables like land which was not yet used in the literature; Third, we allow for the presence of breaks in the series and use appropriate testing procedures; Finally, we provide compelling new evidence on the relationship between energy consumption and economic growth in selected SSA countries. Recent growth performance and the dynamic

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financial development with economic growth and/or energy consumption (see for e.g. Sadorsky, 2010; Shahbaz, 2012; Rousseau and D'Onofrio, 2013; Islam *et al.*, 2013; Shahbaz *et al.*, 2013; Kumar *et al.*, 2015).

[4]There are studies using panel method to investigate the causal relationship between economic growth and energy consumption in selected SSA countries. For a review, refer to Eggoh *et al.* (2011), Fowowe (2012) and Ouedraogo (2013)

population growth in most SSA countries have stressed the demand for modern energy services so that understanding the energy-growth nexus has important policy implications as it supplies a reference in designing appropriate environmental and energy policies.

The rest of the paper is structured as follows: Section 2 introduces the econometric specification and the estimation methods; Section 3 presents the empirical results; Section 4 discusses the results and the policy implications; and Section 5 concludes the study.

2. Methods

2.1. Model specification

The paper assumes an extended Cobb-Douglas production as follows:

$$Y_t = A_t K_t^{\alpha_1} C_t^{\alpha_2} N_t^{\alpha_3} L_t^{\alpha_4} e^{u_t} \tag{1}$$

where Y is the real production, K the stock of physical capital, C energy consumption, N arable land, L the labor force, A_t the measure of technological progress and u_t is the error terms assumed N(iid). When the production function is restricted to ($\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1$), it shows a constant return to scale in K_t, C_t, N_t and L_t, and an increasing return to scale in A_t, K_t, C_t, N_t together. The technological function is set to be determined by unknown trended variables proxied with time t, trade openness and financial development. The idea of considering additional variables in the production function through the technological factor was suggested by Rao (2007). Accordingly, the technological function is expressed as follows:

$$A_t = A_0 e^{gt} T_t^{\delta} F_t^{\gamma} \tag{2}$$

where T_t is openness to international trade and F_t financial development.
Substituting equation (2) in (1), dividing and multiplying both sides by labor and the ratio of labor to population, respectively, and considering finally the natural logarithm of the function, we get:

$$ln(y_t) = ln(A_0) + gt + \delta ln(T_t) + \gamma ln(F_t) + \alpha_1 ln(k_t) + \alpha_2 ln(c_t) + \alpha_3 ln(n_t) + u_t \tag{3}$$

where y_t, T_t, F_t, k_t, c_t and n_t are respectively real GDP per capita, trade openness proxied as total trade to GDP, financial development, physical capital per capita, energy consumption per capita and arable land per capita.
Considering the first differences of the variables in equation (3) gives:

$$\Delta ln(y_t) = \lambda_0 + \lambda_1 \Delta ln(T_t) + \lambda_2 \Delta ln(F_t) + \lambda_3 \Delta ln(k_t) + \lambda_4 \Delta ln(c_t) + \lambda_4 \Delta ln(n_t) + \epsilon_t \tag{4}$$

Some features of these specifications are noticeable. The equation (3) is the long-run relationship of the real production function explained by the independent variables and the equation (4) represents the short-run dynamic. Hence, the energy consumption and economic growth relationship is investigated based on the estimation of these equations.

2.2. ARDL cointegration approach

The autoregressive distributed lag (ARDL) bounds testing approach to cointegration proposed by Pesaran *et al.* (2001) is used to investigate the long-term relationship between the selected variables. It has been demonstrated that this approach is suitable as the long-run and short-run parameters are considered simultaneously. Furthermore, it avoids the endogeneity problems associated with the Engle-Granger method as all the variables are assumed to be endogenous in testing for a long-run relationship and can be used whether the time series data have a unit root or not. According to Narayan (2005), it is more appropriate for small sample sizes than the traditional cointegration method of Johansen and Juselius (1990). The empirical representation of the ARDL bounds testing approach to cointegration when income per capita is the dependent variable is formulated following the aforementioned specifications (3) and (4):

$$\Delta ln(y_t) = \alpha_0 + \sum_{i=1}^{l} \alpha_{DU_i} DU_{it} + \alpha_t t + \alpha_y ln(y_{t-1}) + \alpha_k ln(k_{t-1}) + \alpha_c ln(c_{t-1}) + \alpha_n ln(n_{t-1})$$
$$+\alpha_T ln(T_{t-1}) + \alpha_F ln(F_{t-1}) + \sum_{i=1}^{p_1} \psi_{1i} \Delta ln(y_{t-i}) + \sum_{i=0}^{p_2} \psi_{2i} \Delta ln(k_{t-i}) + \sum_{i=0}^{p_3} \psi_{3i} \Delta ln(c_{t-i})$$
$$+ \sum_{i=0}^{p_4} \psi_{4i} \Delta ln(n_t) + \sum_{i=0}^{p_5} \psi_{5i} \Delta ln(T_{t-i)} + \sum_{i=0}^{p_6} \psi_{6i} \Delta ln(F_{t-i}) + v_t \quad (5)$$

where $DU_i = I(t > \tau_i)$, $i = 1, \ldots, l$, l is the number of breaks, with τ_i the corresponding break date.[5]

The null hypothesis of the test is $H_0 : \alpha_y = \alpha_k = \alpha_c = \alpha_n = \alpha_T = \alpha_F = 0$ against an alternative hypothesis of cointegration (i.e. $H_1 : \alpha_y \neq \alpha_k \neq \alpha_c \neq \alpha_n \neq \alpha_T \neq \alpha_F \neq 0$). The F-test does not have a standard distribution. Consequently, the upper and the lower critical bounds computed in Narayan (2005) are used as they are more appropriate for small sample sizes. Before computing the F-test, the autoregressive order $(p_1, p_2, p_3, p_4, p_5, p_6)$ was selected based on the Bayesian information criterion (BIC) and the Akaike's information criterion (AIC). A long-run relationship and an error correction model are estimated in case of rejection of the null hypothesis.

2.3. Toda and Yamamoto causality test

The causal relationship between economic growth and energy consumption is investigated using the modified version of the Granger non-causality test developed by Toda and Yamamoto (1995). The advantage of this method is that it is valid regardless of whether the series are I(0), I(1) or I(2), cointegrated or not. The T-Y Granger causality test augments a VAR model in level with d extra lags (d is the maximum order of integration of the series). This ensures that the Wald statistics possess the necessary power properties. Then, the augmented VAR model with a total of $(m + d_{max})$ lags is estimated on levels of the selected variables and restricting the first m-lags to zero. Thus, using this approach, the augmented VAR model is represented as follows:

$$\begin{bmatrix} ln(y_t) \\ ln(k_t) \\ ln(c_t) \\ ln(n_t) \\ ln(T_t) \\ ln(F_t) \end{bmatrix} = \begin{bmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \\ \pi_4 \\ \pi_5 \\ \pi_6 \end{bmatrix} + \sum_{i=1}^{m+d_{max}} \begin{bmatrix} \zeta_{1i} & \kappa_{1i} & \xi_{1i} & \eta_{1i} & \phi_{1i} & \rho_{1i} \\ \zeta_{2i} & \kappa_{2i} & \xi_{2i} & \eta_{2i} & \phi_{2i} & \rho_{2i} \\ \zeta_{3i} & \kappa_{3i} & \xi_{3i} & \eta_{3i} & \phi_{3i} & \rho_{3i} \\ \zeta_{4i} & \kappa_{4i} & \xi_{4i} & \eta_{4i} & \phi_{4i} & \rho_{4i} \\ \zeta_{5i} & \kappa_{5i} & \xi_{5i} & \eta_{5i} & \phi_{5i} & \rho_{5i} \\ \zeta_{6i} & \kappa_{6i} & \xi_{6i} & \eta_{6i} & \phi_{6i} & \rho_{6i} \end{bmatrix} \times \begin{bmatrix} ln(y_{t-i}) \\ ln(k_{t-i}) \\ ln(c_{t-i}) \\ ln(n_{t-i}) \\ ln(T_{t-i}) \\ ln(F_{t-i}) \end{bmatrix} + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \\ \mu_{3t} \\ \mu_{4t} \\ \mu_{5t} \\ \mu_{6t} \end{bmatrix} \quad (6)$$

[5]The number of breaks l is determined using the sequential procedure of Bai and Perron (1998, 2003) and the corresponding breaks are dated based on the unit root tests of Carrion-i Silvestre *et al.* (2009).

The optimal m order of the vector autoregressive model is selected based on the FPE, AIC, HQIC and BIC criteria. After estimating the above systems of equations, the T-Y approach is based on the Wald statistic test for the significance of the first m lags by restricting the coefficients to zero, under a null hypothesis of no causality.

2.4. Data

Based on the above econometric specifications, this study employs annual time series data of 13 SSA countries and covers the period 1971-2013 to examine the dynamic relationship between economic growth and energy consumption. The countries are selected based on data availability during the covered period and are Benin, Cameroon, Cote d'Ivoire, Congo, Gabon, Ghana, Kenya, Nigeria, Senegal, South Africa, Sudan, Togo and Zambia. Data on GDP per capita (constant 2010 $ US), energy use (kgs of oil equivalent per capita), arable land (hectare per capita), total trade (sum of imports and exports at constant 2010 $ US) to GDP and financial development are collected from World development indicators provided by World Bank (2016). Financial development is constructed through a composite indicator of financial deepening. Physical capital per capita (re-expressed at constant of 2010 $ US per capita) are from the Penn World Table (Feenstra *et al.*, 2015).[6]

Some descriptive statistics (mean value, standard deviation and coefficient of variation (*standard deviation/mean*)) of the aforementioned variables are presented in Table 2 and are displayed by country. We note that the highest means of GDP per capita during the covered period are reported in Gabon ($ US 11,095.68) and South Africa ($ US 6,592.45). South Africa is considered as one of the most industrialized economies in Africa (Mohamed, 2011) and the high level of GDP per capita in Gabon is essentially linked to its economic and trade structures oriented towards the export of oil products. Moreover, these countries exhibit better than average access to energy services with 1,545.07 kg of oil equivalent per capita for Gabon and 2,556.36 for South Africa, and are more endowed in physical capital than the other countries. Regarding the structure of international trade and the financial sector, the descriptive statistics show that the proportion of international trade to GDP is high in Congo, Gabon or Togo in comparison to Cameroon or Sudan. Similarly, South Africa displays a more developed financial sector during the covered period. The highest average levels of arable land available for agricultural production are exhibited in Togo and Sudan in contrast to Ghana and Kenya where the lowest values are reported. Sudan tends to have a more dispersed distribution i.e. high values of the coefficient of variation for the different variables. The relative high volatility of the Sudanese economy may be explained by the recurrent social and political crisis that damage its growth path.

3. Results

3.1. Unit root test

Before applying the ARDL and T-Y procedures, we examine first the non-stationarity properties of the selected variables. The sequential procedure of Bai and Perron (1998, 2003) is used to check if the series are independently and identically distributed with a constant mean and a finite variance against the alternative hypothesis of l time changes at unknown dates. Accordingly, the unit root tests with structural breaks proposed by Carrion-i Silvestre *et al.* (2009)[henceforth CKP] are employed. The null hypothesis of

[6] More details on the financial development index, physical capital and arable land measurements are provided in Appendix A.

these tests is that the series has a unit root process versus an alternative hypothesis of stationarity. These tests are suitable contrary to the standard tests (e.g. Dickey and Fuller, 1979, 1981; Perron, 1989; Elliot *et al.*, 1996; Ng and Perron, 2001; Zivot and Andrews, 1992) as they allow for an arbitrary number of changes in both the level and slope of the trend function under the null and alternative hypotheses.

The results of the BP and the CKP tests are presented in Table 3. The tests are applied at the nominal asymptotic 5% significance level with the appropriate lag selected by the MAIC criterion. The BP test provides useful evidence on the presence or not of ruptures in the series and this evidence is used in carrying out the unit root investigation. Overall, the ADF_{gls} statistic, the feasible optimal statistic (P_T) and the M-class statistics (MP_T, MZ_α and MZ_T) indicate that our sample is made of a mix of I(0) and I(1) series therefore validating the use of the ARDL and the T-Y approaches. The CKP procedure enables the determination of the corresponding break dates as well. The breaks occurred in general in the mid of 1970s to the late of 1980s, a period which is associated to the first and second oil shocks and also to significant fluctuations on primary commodity market which have affected SSA economies. Furthermore, the implementation of structural adjustment programs in some countries during the 1990s has also affected the trend function of some variables.

3.2. ARDL cointegration test result

The F-test results for the presence of a long-term relationship between income growth, physical capital, energy use, arable land, trade openness and financial development are presented in Table 4. The results reject the null hypothesis in Cameroon, Cote d'Ivoire, Kenya and Sudan suggesting the presence of a long-term relationship for income per capita. In contrast, the test fails to reject the null of cointegration in Benin, Congo, Nigeria and Zambia, and is inconclusive in Ghana, Senegal, and Togo. Following the F-test results, the long-run parameters are estimated and the results are displayed in Table 5.

The findings show that investment in physical capital has a positive and significant effect on income growth in Cameroon, Gabon, Ghana, Kenya, Senegal, South Africa and Sudan.[7] This result is consistent with the standard economic growth theories which consider physical capital as one of the main factors explaining output level and hence consolidates the insight so that ignoring this factor in the energy-growth nexus investigation could lead to erroneous causality results. Energy consumption is involved in enhancing long-run economic growth in Cameroon and Kenya. Notably, we find a negative effect of energy use on economic growth in Gabon at a 1% level of significance and in South Africa at 10%. This situation may be explained by an inefficient energy sector due to the use of energy in unproductive sectors (Zhang and Xu, 2012; Shahbaz *et al.*, 2013; Squalli, 2007) or to the energy quality used in energy intensive sectors (Liddle, 2012). This kind of mixed effect is also found for arable land in Gabon and South Africa. Additional surface of arable land contributes to the increase of income per capita in Gabon whilst the opposite effect is observed in South Africa due to a possible inefficient allocation of

[7] The results fail to exhibit a significant effect of physical capital on economic growth in Cote d'Ivoire and Togo. Regarding the first country, this result could indicate a minimal role of the classical factors (physical capital and land) in explaining the long-run growth in Cote d'Ivoire and a leading role of trade openness and financial development as that country's economy tends to be dependent on the export of primary commodities such as cocoa and coffee. For the latter one (Togo), a none significant relationship is established between income growth and the selected independent variables in accordance with the inconclusive F-test result as the F-statistic falls between the lower and the upper bounds.

land in the production process. Regarding the effect of international trade and financial development, the estimations give a positive effect of trade openness on income per capita in Cameroon, Cote d'Ivoire and South Africa, and income growth is positively associated to financial development in Cote d'Ivoire. This result is consistent with the view of Grossman and Helpman (1991), Romer (1990) and the empirical findings of Kumar *et al.* (2015) that trade openness affects economic growth positively. However, openness to international trade and financial development is found to have a limited impact on long-run growth in the other countries. Except for Cote d'Ivoire (supposing a 10% level of significance), the estimations suggest a non-significant influence of financial development on economic growth. Saxegaard (2006) and Nketcha Nana and Samson (2014) pointed out that in many African countries, particularly in SSA countries, banks practice credit rationing and hold large amounts of liquid assets preventing capital accumulation and technological progress promotion through the financial sector. Sachs and Warner (1997) and Collier and Gunning (1999) reported that SSA countries lack of openness to international trade (among various factors) has been a major obstacle to better economic performance. Gries *et al.* (2009) and Menyah *et al.* (2014) were concerned with the recent effort of SSA countries in the liberalization of the financial sector and the openness to trade and found that it is still not enough to spur economic growth in many countries.

Diagnostic tests are also performed on the ARDL models to ensure the validity of the F-test results and the corresponding estimated long-run parameters. Specifically, we carry out the Lagrange multiplier test of residual serial correlation (χ^2_{sc}), the Breusch-Pagan test for heteroskedasticity (χ^2_{hc}), the normality test based on the test of skewness and kurtosis of residuals (χ^2_n) and the Ramsey reset test for variable omission using powers of the fitted values (F_{ff}). The diagnostic tests (presented in Table 4) fail to reject the null hypotheses of no serial correlation, of no heteroskedasticity, of normality and no variable omission for virtually all the countries. The estimation of the error correction term (ECT_{t-1}) also validates the existence of a long-term relationship in these countries as the error correction term has the right sign, i.e. negative and is significant.

3.3. Granger causality analysis result

The modified version of the Granger non causality test proposed by Toda and Yamamoto (1995) is applied to investigate the causal dynamic between economic growth and energy consumption. Since this study focuses on the causal relationship between energy consumption and economic growth, we therefore present the results of the "energy does not Granger cause income" and "income does not Granger cause energy" tests in Table 6.

The test statistic rejects the null of "energy does not lead to income growth" in Cameroon, Gabon, Kenya and Nigeria while the opposite evidence is indicated in Benin, Cote d'Ivoire, Congo, Ghana, Senegal, South Africa, Sudan, Togo and Zambia. Regarding the income per capita does not Granger cause energy hypothesis, the test is in line with the null hypothesis in Benin, Cote d'Ivoire, Congo, Gabon, Ghana, Kenya, Nigeria, Senegal, South Africa and Togo. In contrast, the causality analysis suggests that income growth leads to energy consumption in Cameroon, Sudan and Zambia. These results are consistent with the long-run parameters presented previously, especially in Cameroon, Gabon and Kenya.

To sum up, our investigation supports the growth hypothesis in Gabon, Kenya and Nigeria, the conservation hypothesis in Sudan and Zambia, the feedback hypothesis in Cameroon, and the neutrality hypothesis in Benin, Cote d'Ivoire, Congo, Ghana, Senegal, South Africa and Togo. With respect to previous studies, these results contradict those of

Akinlo (2008), Wolde-Rufael (2009) and Lin and Wesseh Jr (2014) but are consistent with Iyke (2015). The main policy implication following these results is that a "growth policy" should be implemented in Cameroon, Gabon, Kenya and Nigeria and that a "conservative policy" may be implemented in Benin, Cote d'Ivoire, Congo, Ghana, Senegal, South Africa, Sudan, Togo and Zambia without adverse effect on economic growth.

4. Results discussion and policy implications

Numerous investigations have addressed the energy-growth nexus in the literature. However, the results are still inconclusive and there is no clear departure between the four hypotheses (growth, conservative, feedback and neutrality). Previous studies have been criticized for severe methodological concerns and relevant variables omissions which may be the sources of the inconsistencies. Consequently, current investigations consider additional variables other than the energy factor in the production function and employ appropriate investigation approaches. This study used the suitable cointegration and causality approaches proposed by Pesaran *et al.* (2001) and Toda and Yamamoto (1995) and incorporated physical capital, labor and arable land in the production function in complement to energy consumption and set the technology factor to be determined by the openness to international trade and financial development. We then paid attention to the relationship between energy consumption and economic growth in 13 selected SSA countries (namely Benin, Cameroon, Congo, Cote d'Ivoire, Gabon, Ghana, Kenya, Nigeria, Senegal, Sudan, South Africa, Togo and Zambia).

The results showed that there is a bidirectional relationship between energy consumption and income growth in Cameroon. A unidirectional relationship from income growth to energy was supported in Sudan and Zambia whilst the reverse-type relation was reported in Gabon, Kenya, Nigeria. A neutral relationship was found in Benin, Cote d'Ivoire, Congo, Ghana, Senegal, South Africa and Togo. These differences in the results across the countries may be explained by substantial underlying factors and also call for specific policy implications.

The first point raised by the findings is that seven out of the 13 countries (namely Benin, Cote d'Ivoire, Congo, Ghana, Senegal, South Africa and Togo) exhibited a neutral relationship between energy consumption and economic growth. This result indicates that energy is not the crucial factor in the production process in these countries in comparison to Physical capital and labor. Wolde-Rufael (2009) and Mensah (2014) found similar results when using capital and labor, as they reported a minimal role of energy and a primary role of labor factor in contributing to income growth in African countries. African economies have an abundant endowment in labor factor as the continent has a young population structure and in many countries, the population lacks access to energy for production and consumption processes so that its role is minimal with respect to the labor force. According to (IEA, 2014) more than 68% of the population in SSA remain without access to electricity and nearly 80% rely on traditional biomass for cooking.

Regarding the countries where at least a causal relationship (regardless of the direction of the causality) between energy consumption and economic growth was supported (Cameroon, Gabon, Kenya, Nigeria, Sudan and Zambia), it is noteworthy that except for Kenya, these countries are oil producing countries. Indeed, according to the Statistical Review of World Energy[8], Nigeria, Gabon and Sudan are among the top ten oil producers and exporters in the continent. Moreover, the significant relationship between energy

[8]British Petroleum Group, BP Statistical Review of World Energy, June 2016, 65th Edition, London, UK.

and growth in these economies contrasts with other oil producing countries such as Cote d'Ivoire, Congo, Ghana or South Africa where the economic and the trade structure is not essentially oriented towards the exploitation and the export of energy products.[9] For instance, Cote d'Ivoire is specialized in the production and the export of cocoa and coffee, Congo in lumber, plywood and sugar, Ghana in cocoa and bauxite, and South Africa in gold, diamond, platinum, machinery and equipment.[10] However, the direction of the causal relationship is not identical across the countries, as a bidirectional relationship is found in Cameroon, a leading relation from income growth to energy consumption in Sudan and Zambia, and a causal nexus from energy to production in Gabon, Kenya, and Nigeria. Following the direction of the causality, the effect of a energy conservation policy would not have the same effect on growth. In countries where income growth spurs energy consumption, it would not have an adverse effect on growth while the opposite may happen in the energy causing growth situation.

Furthermore, the stability of the social-political institutions could explain the differences in the nature of the relationship between income and energy across the countries. For instance, when focusing on oil producing countries, a causal relationship is exhibited in Cameroon, Nigeria and Sudan where one can point out the lack of strong institutions. However, regarding their counterparts Ghana and South Africa the neutrality hypothesis was supported.[11]

Since the results vary according to each country specificities, the policy implication should respect these specificities. Theoretically, in countries where a neutral causality is found between energy consumption and income growth (Benin, Cote d'Ivoire, Congo, Ghana, Senegal, South Africa and Togo) an environmental policy by means of a regulation of energy consumption level could be designed as energy is supposed to represent a small proportion of the country GDP. Moreover, in countries where a leading role of energy was found i.e. in Gabon, Nigeria, Kenya and in countries where a complementarity role between energy and growth was reported such as in Cameroon, an environmental policy through energy consumption could jeopardize the objective of economic growth. Hence, a "growth policy" i.e. a policy which does not restrict energy factor but on the contrary increases accessibility to energy resources in the countries should be implemented. Since energy use is associated with pollution emission level, these countries should improve their energy efficiency and also adopt cleaner production technologies.

However, as pointed out by Wolde-Rufael (2009), an energy conservation measure in a country where a minimal role of the energy factor was supported by the causality analysis in comparison to physical capital or labor, may not be a viable option since energy infrastructures are lacking in many SSA countries and a majority of the population still does not have access to modern energy services. Additionally, despite the strong heterogeneity between SSA countries, it is noticeable that among the first 10 economies intensive in energy use in 2014 measured by the total primary energy use by GDP PPP

[9] Note that the paper does postulate that in oil producing countries where at least a causal relationship is established regardless of the direction, oil is the only one export commodity but is about its proportion in GDP or export revenues. For example, the contribution of oil is estimated to 20% of GDP and 95% of export earnings in Nigeria (Squalli, 2007) while it has been evaluated to 3.3% of GDP in South Africa (Fofana *et al.*, 2009).

[10] CIA (2017), The World Factbook. Accessible at `https://www.cia.gov/library/publications/resources/the-world-factbook/` (retrieved on March 28, 2017).

[11] There is an on-going debate in the literature about the interactions of social and political institutions with resource allocation (energy resource for example) and economic progress. See for a review Acemoglu *et al.* (2005) and Engerman and Sokoloff (1997).

(ton of oil equivalent/thousand 2005 $ US), five are SSA countries (IEA, 2016a,b).[12] This could indicate that many SSA countries have inefficient production sector in energy resource use. Hence, these countries should invest more in clean and efficient production technologies while expanding accessibility of the population to energy services. An interesting channel would be through international trade and financial development since a positive effect of these variables on growth was supported specifically in Cameroon, Cote d'Ivoire and South Africa. Note that trade openness is supposed to enhance technological progress through exchange of better production practices between local agents and foreign agents while financial development is assumed to encourage investment in more innovative technologies (Grossman and Helpman, 1991; Romer, 1990; Schumpeter, 1974; Levine, 1997).

5. Conclusion

This study examined the dynamic relationship between economic growth and energy consumption based on a multivariate production function approach. In contrast with previous studies on the growth-energy nexus in SSA countries, this paper dealt with the variable omission bias and is the first attempt in literature to incorporate arable land, trade openness and financial development. Additionally, this paper also addressed the presence of structural changes in the analysis while covering more than one SSA country. Consequently, appropriate time series approaches of cointegration and causality were applied to data collected on 13 SSA countries over the period 1971-2013.

The results gave evidence of the growth hypothesis in Gabon, Kenya and Nigeria, the conservation hypothesis in Sudan and Zambia, the feedback hypothesis in Cameroon, and the neutrality hypothesis in Benin, Cote d'Ivoire, Congo, Ghana, Senegal, South Africa and Togo. Based on the afore-mentioned outcomes, investment in physical capital accumulation should be encouraged in order to sustain long-term growth performances. Regarding the SSA low integration rate to international trade and its potential positive effect on growth, SSA countries should implement policy that promotes international trade and generates positive externalities and technological exchange. Policy makers should also pay attention to the financial sector and facilitate access to financial services. More importantly, the present finding provides a useful reference in designing country specific and appropriate energy and environmental policies.

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[12]More precisely and following the IEA Energy Atlas, these countries are the Democratic Republic of Congo, Zimbabwe, Mozambique, Ethiopia and Togo and the corresponding energy intensities (ton of oil equivalent/thousand 2005 $ US) reported in 2014 are 0.55, 0.43, 0.41, 0.36 and 0.35, respectively. In comparison, the average level of energy use per GDP is estimated to 0.11 in OECD countries, 0.15 for the Africa continent and 0.14 for the world (IEA Energy Atlas, Available at `http://energyatlas.iea.org/#!/tellmap/-297203538/3`, retrieved on June 7, 2017).

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Table 1: Overview of main energy-growth nexus studies on SSA countries

Authors	Methods	Time period	Additional variables	Countries	Results
Ebohon (1996)	Granger test	1960-1984	–	Nigeria	EC↔GDP
		1960-1981		Tanzania	EC↔GDP
Jumbe (2004)	Granger test	1970-1999	–	Malawi	ELC↔GDP
					NAGDP→GDP
Wolde-Rufael (2005)	ARDL & T-Y	1971-2001	–	Cameroon, Nigeria	EC→GDPPC
				Congo (DR), Cote d'Ivoire, Ghana	GDPPC→EC
				Gabon, Zambia,	EC↔GDPPC
				Benin, Congo, Kenya, Senegal, South Africa, Sudan, Togo, Zimbabwe	EC↮GDPPC
Wolde-Rufael (2006)	ARDL & T-Y	1971-2001	–	Benin, Congo(DR)	ELC→GDPPC
				Cameroon,Ghana,Nigeria, Senegal,Zambia,Zimbabwe	GDPPC→ELC
				Gabon	ELC↔GDPPC
				Congo,Kenya, South Africa, Sudan	ELC↮GDPPC
Akinlo (2008)	ARDL & VECM	1980-2003	Consumer price index, government expenditure	Congo, Zimbabwe	GDPPC→EC
				Gambia, Ghana, Senegal	EC↔GDPPC
				Cameroon, Cote d'Ivoire, Kenya, Nigeria, Sudan, Togo	EC↮GDPPC
Akinlo (2009)	Granger & Hodrick-Prescott filter	1980-2006	–	Nigeria	ELC→GDP
Wolde-Rufael (2009)	ARDL & T-Y	1971-2004	Labor and Capital	Benin, South Africa	EC→GDP
				Cote d'Ivoire, Nigeria, Senegal, Sudan, Zambia	GDP→EC
				Gabon, Ghana Togo, Zimbabwe	EC↔GDP
				Cameroon, Kenya	EC↮GDP
Odhiambo (2009a)	Granger test	1971-2006	Employment	South Africa	EC↔GDPPC
Odhiambo (2009b)	ARDL & Granger test	1971-2006	–	Tanzania	EC→GDPPC
					ELC→GDPPC
Odhiambo (2010)	ARDL	1972-2006	Consumer price index	Kenya, South Africa	EC→GDPPC
				Congo (DRC)	GDPPC→EC
Ouédraogo (2010)	ARDL & VECM	1968-2003	Gross capital formation	Burkina Faso	EC↔GDP
Tamba *et al.* (2012)	VECM	1975-2008	–	Cameroon	Diesel↮GDP
Wesseh Jr and Zoumara (2012)	Bootstrap LR test	1980-2008	Employment	Liberia	EC↔GDPPC
Fondja Wandji (2013)	Granger test	1971-2009	–	Cameroon	Oil→GDPPC
					ELC↮GDPPC
					Biofuels↮GDPPC
Solarin and Shahbaz (2013)	Gregory-Hansen, ARDL & VECM	1971-2009	Urbanization	Angola	ELC↔GDPPC
Lin and Wesseh Jr (2014)	ARDL & Bootstrap Granger test	1971-2010	Employment in the non-agricultural sector	South Africa	EC→GDPPC
					ELC→GDPPC
Iyke (2015)	VECM	1971-2011	Inflation rate	Nigeria	ELC→GDPPC

Notes: EC and ELC stand for per capita (or total) energy and electricity consumption.
GDP, GDPPC and NAGDP indicate real GDP, real GDP per capita and non-agricultural GDP, respectively.
→, ↔ and ↮ denotes unidirectional causality, bidirectional causality and no causality relationship, respectively.

Table 2: Summary statistics of the variables for the individual countries

Country	Summary statistic	GDP	Energy Use	Arable land	Physical capital	Total trade	Financial deepening
Benin	Mean	643.17	348.53	0.35	6003.66	52.79	16.84
	Std. Dev.	64.26	27.87	0.05	945.05	7.21	7.64
	CV	0.10	0.08	0.15	0.16	0.14	0.45
Cameroon	Mean	1164.47	390.00	0.49	5311.76	45.25	17.63
	Std. Dev.	204.78	30.20	0.16	347.13	8.02	5.80
	CV	0.18	0.08	0.32	0.07	0.18	0.33
Cote d'Ivoire	Mean	1573.83	433.81	0.21	11078.15	75.64	28.26
	Std. Dev.	359.39	68.80	0.05	2782.97	10.85	8.99
	CV	0.23	0.16	0.23	0.25	0.14	0.32
Congo	Mean	2567.13	342.00	0.21	10949.65	114.14	14.20
	Std. Dev.	410.87	73.33	0.08	2676.32	26.01	5.06
	CV	0.16	0.21	0.36	0.24	0.23	0.36
Gabon	Mean	11095.68	1545.07	0.30	56001.58	94.82	15.86
	Std. Dev.	2090.29	364.96	0.06	14953.18	13.11	4.82
	CV	0.19	0.24	0.21	0.27	0.14	0.30
Ghana	Mean	992.14	346.57	0.19	7706.73	55.61	16.53
	Std. Dev.	215.00	38.13	0.01	1445.85	30.00	5.83
	CV	0.22	0.11	0.06	0.19	0.54	0.35
Kenya	Mean	879.33	453.35	0.20	5069.69	58.23	29.02
	Std. Dev.	68.02	14.19	0.05	413.42	6.78	4.43
	CV	0.08	0.03	0.25	0.08	0.12	0.15
Nigeria	Mean	1660.83	690.19	0.29	6093.51	49.34	19.01
	Std. Dev.	390.06	52.42	0.08	1612.43	15.64	7.25
	CV	0.23	0.08	0.26	0.26	0.32	0.38
Senegal	Mean	910.64	254.78	0.43	6722.24	65.77	26.35
	Std. Dev.	62.17	26.82	0.15	943.06	9.57	6.80
	CV	0.07	0.11	0.36	0.14	0.15	0.26
South Africa	Mean	6592.45	2556.36	0.37	30394.32	52.67	95.29
	Std. Dev.	508.47	250.10	0.09	2976.17	7.51	25.93
	CV	0.08	0.10	0.25	0.10	0.14	0.27
Sudan	Mean	981.99	408.51	0.55	2525.25	27.25	15.44
	Std. Dev.	262.69	35.70	0.12	1930.08	9.85	6.42
	CV	0.27	0.09	0.22	0.76	0.36	0.42
Togo	Mean	541.90	372.31	0.56	3992.38	90.88	24.86
	Std. Dev.	56.53	58.81	0.14	716.60	17.28	6.45
	CV	0.10	0.16	0.24	0.18	0.19	0.26
Zambia	Mean	1197.63	687.55	0.36	27688.50	71.30	21.85
	Std. Dev.	231.90	94.23	0.13	13238.27	10.46	12.76
	CV	0.19	0.14	0.37	0.48	0.15	0.58

Notes: Std. Dev. stands for Standard deviation and *CV* for Coefficient of variation.
GDP per capita real GDP (in constant 2010 $ US), *Energy use* (kgs of oil equivalent per capita), *Arable land* (hectare per capita), *Physical capital* (constant 2010 $ US), *Total trade* (sum of exports and imports at constant 2010 $ US) to GDP and *Financial deepening* (to GDP) is composed of broad money, total domestic credit to the private sector and total domestic credit provided by the banking sector.

Table 3: Unit root test results

Country	Variable	BP test	CKP (2009) test					
		# Breaks	ADF^{gls}	P_T	MP_T	MZ_α	MZ_T	Break Dates
Benin	ln(y)	2	-4.34*	13.14	12.65	-17.62	-2.96	1978; 1986
	ln(k)	1	-1.52	50.03	37.62	-3.52	-1.08	1990
	ln(c)	0	-1.53	5.86	5.6	-4.49	-1.42	
	ln(n)	0	-0.08	21.88	16.4	-0.17	-0.08	
	ln(T)	0	-2.28	4.25	3.54	-9.48	-1.92	
	ln(F)	0	-1.10	12.18	9.8	-2.34	-0.97	
Cameroon	ln(y)	0	-1.41	9.83	6.57	-3.75	-1.30	
	ln(k)	0	-0.89	11.43	7.27	-3.32	-1.16	
	ln(c)	1	-1.71	32.98	30.14	-3.86	-1.31	2004
	ln(n)	0	0.16	5.43	3.83	-7.89	-1.78	
	ln(T)	0	-2.31	3.11	2.97	-8.30	-2.03	
	ln(F)	0	-1.48	5.59	5.4	-4.54	-1.50	
C. d'Ivoire	ln(y)	0	-0.85	19.49	15.46	-1.30	-0.68	
	ln(k)	0	-3.19*	7.76	6.34	-14.46	-2.68	
	ln(c)	1	-2.58	12.17	12.7	-10.00	-2.22	2003
	ln(n)	0	-2.14	13.84	13.15	-6.93	-1.86	
	ln(T)	1	-2.89	19.93	16.6	-9.34	-2.13	1993
	ln(F)	1	-1.12	55.69	42.44	-2.89	-0.98	1992
Congo	ln(y)	1	-1.78	26.64	27.24	-5.90	-1.63	1985
	ln(k)	1	-0.44	44.11	44.24	-1.32	-0.41	1981
	ln(c)	0	-0.40	36.69	37.36	-0.91	-0.35	
	ln(n)	0	-0.34	17.86	11.94	-1.42	-0.59	
	ln(T)	0	-1.78	5.63	4.6	-5.73	-1.58	
	ln(F)	0	-1.13	9.64	9.58	-2.51	-1.08	
Gabon	ln(y)	0	-2.34	20.49	14.99	-6.08	-1.74	
	ln(k)	0	-2.72	12.19	9.08	-10.08	-2.24	
	ln(c)	1	-1.07	99.1	80.28	-1.38	-0.68	1986
	ln(n)	0	-1.50	80.24	57.27	-1.16	-0.62	
	ln(T)	1	-2.94	17.21	17.55	-9.50	-2.16	1976
	ln(F)	0	-2.27	2.96	3.01	-8.14	-2.02	
Ghana	ln(y)	0	-0.68	33.2	28.27	-2.22	-0.76	
	ln(k)	0	-0.66	1.51*	1.47*	-97.38*	-6.84*	
	ln(c)	0	-1.68	4.75	4.96	-4.94	-1.57	
	ln(n)	0	-1.80	4.51	4.4	-5.80	-1.65	
	ln(T)	0	-1.06	8.76	8.71	-2.72	-1.08	
	ln(F)	2	-3.65	14.19	14.16	-15.04	-2.74	1983; 2005
Kenya	ln(y)	0	0.78	35.33	20.66	1.54	0.68	
	ln(k)	0	-1.29	1.63*	1.67*	-75.02*	-6.02*	
	ln(c)	0	-1.47	17.58	17.55	-4.83	-1.32	
	ln(n)	3	-7.76	13.79	14.25	-20.33	-3.18	1974; 1984; 1995
	ln(T)	0	-3.34	2.35	2.03	-14.16	-2.58	
	ln(F)	2	-3.56	13.86	13.52	-15.06	-2.72	1987; 1995

Note: * indicates rejection of the null hypothesis of unit root at 5%.

Continued on next page

Table 3: Unit root test results (continued)

Country	Variable	BP test	CKP (2009) test					
		# Breaks	ADF^{gls}	P_T	MP_T	MZ_α	MZ_T	Break Dates
Nigeria	ln(y)	0	-0.53	53.42	53.87	-0.89	-0.45	
	ln(k)	0	-2.47	11.22	8.54	-10.73	-2.31	
	ln(c)	0	-2.47	11.21	8.54	-10.73	-2.31	
	ln(n)	2	-2.47	20.37	20.78	-10.19	-2.18	1981; 1985
	ln(T)	1	-2.44	17.09	16.94	-10.01	-2.06	1986
	ln(F)	1	-3.55*	11.16	11.18	-14.90	-2.73	1986
Senegal	ln(y)	1	-4.15*	6.6	6.68	-22.59	-3.33	1997
	ln(k)	0	-1.64	0.02*	0.02*	-7292.85*	-60.38*	
	ln(c)	0	-1.28	10.92	9.02	-2.71	-1.16	
	ln(n)	0	-3.40*	6.29	6.47	-14.12	-2.65	
	ln(T)	0	-2.46*	4.73	3.13	-9.21	-2.02	
	ln(F)	0	-1.05	12.77	7.59	-3.11	-1.06	
S. Africa	ln(y)	0	-1.06	6.4	6.12	-4.25	-1.19	
	ln(k)	0	0.42	16.24	9.57	-1.64	-0.53	
	ln(c)	0	-0.95	30.24	17.98	-1.06	-0.60	
	ln(n)	0	-1.88	14.88	15.34	-5.94	-1.72	
	ln(T)	0	-1.65	5.22	4.86	-5.57	-1.50	
	ln(F)	0	-2.03	20.75	17.15	-5.31	-1.63	
Sudan	ln(y)	0	-0.93	31.87	31.25	-2.15	-0.81	
	ln(k)	0	-1.57	16.68	15.3	-5.90	-1.63	
	ln(c)	3	-4.81*	12.51	12.13	-19.28	-3.06	
	ln(n)	0	-1.36	34.86	33.78	-2.40	-0.99	
	ln(T)	0	-1.37	7.28	6.82	-3.59	-1.31	
	ln(F)	0	-1.00	12.17	12.58	-1.93	-0.97	
Togo	ln(y)	2	-3.79	14.2	14.65	-15.99	-2.82	1980; 1991
	ln(k)	0	-2.26	9.84	8.14	-11.22	-2.36	
	ln(c)	2	-3.25	15.62	14.38	-13.15	-2.56	
	ln(n)	0	-2.31	10.15	10.59	-8.76	-2.04	
	ln(T)	0	-1.96	3.85	3.89	-7.49	-1.76	
	ln(F)	0	0.24	15.99	9.34	-2.03	-0.70	
Zambia	ln(y)	0	-1.39	5.94	5.84	-18.31	-2.88	
	ln(k)	0	-1.75	0.81*	0.84*	-150.12*	-8.59*	
	ln(c)	0	-1.11	33.33	23.78	-0.67	-0.44	
	ln(n)	0	-1.46	26.29	24.08	-3.36	-1.14	
	ln(T)	1	-4.22*	6.92	7.21	-17.54	-2.96	2009
	ln(F)	0	-3.02*	1.99	1.99	-12.28	-2.48*	

Note: * indicates rejection of the null hypothesis of unit root at 5%.

Table 4: Results of the ARDL F-test of cointegration

Country	ARDL order	F-stat	A:$\chi^2_{sc}(1)$	B:$\chi^2_{hc}(1)$	C:$\chi^2_{n}(2)$	D:F_{ff}
Benin	(1,0,0,0,1,0)	2.98	0.07[0.79]	1.35[0.24]	1.76[0.42]	2.01[0.14]
Cameroon	(1,2,0,0,2,2)	7.1***	2.54[0.11]	2.28[0.13]	7.21[0.03]**	0.56[0.65]
Congo	(2,2,1,0,0,2)	2.79	0.01[0.91]	1.81[0.18]	2.59[0.27]	0.81[0.50]
C. d'Ivoire	(1,1,0,2,2,2)	10.65***	0.68[0.41]	2.26[0.13]	0.24[0.89]	2.16[0.12]
Gabon	(1,1,0,0,2,0)	14.11***	3.78[0.05]*	0.17[0.68]	1.19[0.55]	1.33[0.29]
Ghana	(1,1,1,0,0,2)	3.82	0.04[0.83]	10.98[0.00]***	1.16[0.56]	5.57[0.00]***
Kenya	(1,0,0,0,0,0)	7.98***	7.26[0.01]**	2.54[0.11]	2.39[0.30]	1.92[0.15]
Nigeria	(1,2,0,0,0,0)	1.82	0.32[0.57]	0.00[0.98]	3.52[0.17]	6.72[0.00]***
Senegal	(1,1,0,0,1,1)	3.18	4.41[0.04]**	0.41[0.52]	0.19[0.91]	2.57[0.07]*
S. Africa	(1,2,1,1,2,0)	4.04	1.94[0.16]	0.10[0.75]	0.94[0.62]	2.16[0.12]
Sudan	(2,1,0,0,1,0)	4.37*	0.93[0.33]	1.42[0.23]	0.04[0.98]	0.91[0.45]
Togo	(1,0,0,0,0,0)	3.24	1.48[0.22]	3.44[0.06]*	25.83[0.00]***	0.66[0.58]
Zambia	(1,1,1,0,0,0)	1.16	2.37[0.12]	0.02[0.89]	5.29[0.07]*	6.16[0.00]***

Notes: *, **, *** denote significance level at 10%, 5% and 1%, respectively.

A:Breusch-Godfrey serial correlation LM test; B:Breusch-Pagan test for heteroskedasticity;

C:Normality test based on a test of skewness and kurtosis of residuals;

D:Ramsey RESET test using powers of the fitted values.

Table 5: Long-run estimates based on ARDL approach

Country	Dependent variable=ln(y)									
	Parameters									
	ln(k)	ln(c)	ln(n)	ln(T)	ln(F)	Trend	Constant	DU1	DU2	ECT_{t-1}
Cameroon	1.94***	0.85***	0.84	0.65***	-0.20	0.02	-16.47***			-0.2970***
	(3.56)	(3.76)	(0.64)	(4.57)	(-1.38)	(0.73)	(-3.86)			(-4.75)
C. d'Ivoire	-0.07	0.10	-0.18	0.28**	0.11*	-0.02***	5.87***			-0.7222***
	(-0.52)	(1.17)	(-0.86)	(2.75)	(1.90)	(-3.66)	(5.52)			(-6.73)
Gabon	0.29**	-0.38***	0.62*	-0.16	0.02	0.004	10.23***			-0.7375***
	(2.33)	(-3.60)	(1.75)	(-0.95)	(0.24)	(0.71)	(5.50)			(-9.23)
Ghana	0.45**	0.004	0.26	0.08	0.09	0.01**	2.56			-0.3420***
	(2.10)	(0.03)	(0.68)	(1.43)	(0.78)	(2.16)	(1.13)			(-5.66)
Kenya	0.30*	1.40***	0.22	-0.01	0.12	0.01	-4.48			-0.2135*
	(1.94)	(2.96)	(1.45)	(-0.12)	(1.09)	(1.66)	(-1.87)			(-1.90)
Senegal	0.37*	0.29	0.02	-0.01	0.03	-0.003	2.06**	0.02		-0.6819***
	(1.74)	(1.11)	(0.18)	(-0.16)	(0.72)	(-0.87)	(2.06)	(0.42)		(-5.76)
S. Africa	0.35***	-0.12*	-1.10***	0.13**	0.03	-0.02***	4.78***			-0.2596***
	(2.82)	(-1.76)	(-4.37)	(2.65)	(0.40)	(-5.01)	(3.37)			(-3.04)
Sudan	0.35***	0.37	-0.16	-0.03	-0.02	0.003	2.05			-0.4805***
	(3.61)	(0.69)	(-0.43)	(-0.43)	(-0.45)	(0.33)	(0.63)			(-5.29)
Togo	1.35	0.17	0.45	-0.05	-1.26	0.04	6.02	-0.12	-0.16*	-0.2472**
	(0.97)	(0.46)	(1.25)	(-0.39)	(-0.85)	(1.01)	(1.39)	(-1.47)	(-2.03)	(-2.29)

Notes: *, ** and *** indicate significance level at 10%, 5% and 1%, respectively; t-statistics are in parentheses.

Table 6: Results of the Granger causality test

Country	Optimal lag k	ln(c)$\nrightarrow$ln(y)		ln(y)$\nrightarrow$ln(c)	
		χ^2	P-value	χ^2	P-value
Benin	1	0.75	0.39	0.64	0.43
Cameroon	4	18.97	0.00***	9.91	0.04**
C. d'Ivoire	1	0.19	0.67	0.01	0.94
Congo	4	2.13	0.71	6.17	0.19
Gabon	4	9.99	0.04**	2.80	0.59
Ghana	4	5.67	0.23	1.25	0.87
Kenya	4	12.74	0.01 **	5.30	0.26
Nigeria	4	15.98	0.00***	6.49	0.17
Senegal	1	0.30	0.58	1.02	0.31
Sudan	4	2.68	0.61	11.66	0.02**
S. Africa	3	4.94	0.18	0.48	0.92
Togo	4	2.41	0.66	2.76	0.60
Zambia	2	1.19	0.55	6.84	0.03**

Notes: $\nrightarrow$ stands for "does not Granger cause". *, ** and *** indicate rejection of the null at 10%, 5% and 1% level of significance, respectively.

A. Appendix: Details on data sources and measurements

A.1. Financial development

Ang and McKibbin (2007) reported the difficulties in representing the level of financial development in empirical literature. Traditionally, previous studies have used monetary aggregate indicators such as the broad money (M2 or M3) to GDP, the bank credit to the private sector, the credit provided by the domestic banking sector or the importance of the commercial banks in the financial system. However, the authors showed that the different indicators are unsatisfactory since these variables capture only a limited aspect of the financial system regarding the diverse services in the financial systems. Therefore, the authors suggest constructing an index of financial deepening that is made of relevant financial variables and which represents a broad aspect of the financial sector. Similarly, Gries *et al.* (2009) and Menyah *et al.* (2014) used the same approach to evaluate the financial development in their respective studies. Following this review, we constructed a financial development index through a principal component analysis. This approach is suitable as it avoids multicollinearity and over-parameterization problems and the imbalanced representation of some dimensions of the financial system due to the use of only one financial indicator. Since the SSA financial sector is bank-centered, the financial development index is constructed using three standard financial ratios: the broad money to GDP (M2 to GDP), the total domestic credit to the private sector to GDP and the total domestic credit provided by the banking sector to GDP. All the variables are considered in the natural logarithm form. Since the different variables are highly correlated, the principal component enables one to extract the first unrotated principal component and to reduce the dimension of the dataset (three variables to one in our case) while retaining much information from the original set of variables (Gries *et al.*, 2009). Table 7 summarizes the result of the principal component analysis. It reveals that the index contains at least 60% of the initial variance for each country, suggesting that sufficient financial sector information is considered.

Table 7: Results of principal component analysis

Country	Principal component (%)	Component matrix		
		Broad money	Credit to private sector	Credit provided by banking sector
Benin	64.85	0.1423	0.7037	0.6961
Cameroon	79.93	0.5588	0.6236	0.5467
Congo	57.65	-0.0062	0.7061	0.7080
C. d'Ivoire	69.52	0.4034	0.6554	0.6385
Gabon	73.10	0.5481	0.6085	0.5739
Ghana	78.79	0.6147	0.5679	0.5474
Kenya	66.29	0.2101	0.6935	0.6892
Nigeria	79.98	0.6272	0.5611	0.5402
Senegal	66.09	0.2582	0.6950	0.6711
S. Africa	81.22	0.4893	0.6113	0.6220
Sudan	87.71	0.5796	0.5785	0.5737
Togo	85.77	0.5550	0.5882	0.5882
Zambia	67.10	0.6583	0.6026	0.4510

Note: The column Principal component represents the value of the initial eigenvalues as a percentage of the total variance the first principal component contains.

The financial deepening index corresponds to the geometric mean of the three selected financial indicators weighted following the eigenvectors of the first principal component. Denoting F, M, P and B the financial development index, the broad money to GDP, the total domestic credit to the private sector to GDP and the total domestic credit provided by the banking sector to GDP, respectively, the composite indicator for country i at time t is given by:

$$ln(F_{it}) = (n_{i1})^2 ln(M_{it}) + (n_{i2})^2 ln(P_{it}) + (n_{i3})^2 ln(B_{it})$$

where n_{i1}, n_{i2}, n_{i3} are the elements of eigenvector (see Table 7) of the country i obtained through the principal component analysis.

A.2. Physical capital

The physical capital data are retrieved from the Penn World Table (Feenstra *et al.*, 2015). It has been constructed from data on depreciated past investments distinguished by type of asset and using the perpetual inventory method. The authors considered four assets, namely structures (residential and non-residential), machinery (computers, communication equipment and other machinery), transport equipment and other assets (software, other intellectual property products and cultivated assets). Information on the assets was collected from different sources (such as the National Accounts statistics). The depreciation rates δ used for each asset are 1.1% for residential structures, 3.1% for non-residential structures, 31.5% for computers, 11.5% for communication equipment, 12.6% for other machinery, 18.9% for transport equipment, 31.5% for software, 15% for other intellectual property products and 12.6% for cultivated assets. Since each country has its own asset composition and which varies over time, the average depreciation rate differs by country and with time. The capital stock K_{it} at constant national prices for asset i at time t was estimated based on the following specification:

$$K_{it} = (1 - \delta_i)K_{it-1} + I_{it}$$

where I_{it} is the investment at constant national prices for asset i with $I_{it} = Ic_{it}/Ip_{it}$. Ic_{it} is the investment at current national prices for asset i and Ip_{it} is the investment deflator. For further details on the capital stock computation refer to the Appendix C in Feenstra *et al.* (2015).

A.3. Arable land

The data on arable land in World Development Indicators provided by the World Bank (2016) were compiled from the Food and Agriculture Organization (FAO) of the United Nations. Arable land is an aggregation of land under temporary crops, temporary meadows for mowing or for pasture, land under market or kitchen gardens and land temporarily fallow (i.e. land left fallow for less than five years). Different sources (primary through land use questionnaires and secondary such as national publications) are used to compile information on each type of land. Arable is computed based on a weighted aggregation.