The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/0144-3585.htm

The non-linear effects of fixed broadband on economic growth in Africa

Jean C. Kouam
Nkafu Policy Institute, Yaoundé, Cameroon, and
Simplice Asongu
University of Johannesburg, Johannesburg, South Africa

Received 14 March 2022
Revised 13 May 2022
17 June 2022
Accepted 20 June 2022

Abstract

Purpose – The study assesses the non-linear nexus between fixed broadband and economic growth. The study focuses on data from 33 African countries for the period 2010 to 2020.

Design/methodology/approach – The empirical evidence is based on unit root tests, panel smooth transition regression and the generalized method of moments.

Findings – The following findings are established in this study. (1) The proportion of the population with access to electricity above and below which the relationship between fixed broadband and economic growth changes in sign is about 60%. (2) Below this threshold, each 1% increase in fixed broadband subscriptions induces a decline in economic growth of about 2.58%. Above the threshold, economic growth would increase by 2.43% when fixed broadband subscriptions increase by 1%. Sensitivity analyses and generalized method of moments (GMM) estimation show that these results are robust.

Practical implications – Due to the coronavirus disease (COVID-19) pandemic, which requires countries to take adequate measures to curb the spread of the pandemic, especially by means of virtual economic activities, any national policy aiming at improving the access of populations to high levels of fixed broadband services should be preceded by the implementation of an electrification program for at least 60% of the total population. Otherwise, providing a good quality internet connection for the benefit of the population would not produce the expected effects on economic growth and would, therefore, be counterproductive.

Originality/value – This study complements the extant literature by providing thresholds at which fixed broadband affects economic growth.

Keywords Africa, Fixed broadband, Economic growth, Non-linear effects

Paper type Research paper

1. Introduction

The study focuses on the non-linear nexus between information and communication technology (ICT) development and economic growth in Africa for three main reasons, which build from the extant literature. These include (1) the relevance of economic growth in driving development outcomes, (2) the importance of ICT in boosting the catch-up process and facilitating human development and (3) the imperative to fill existing gaps in the body of knowledge on the role of ICT in driving development outcomes. These three elements of motivation are put in more perspective in what follows.

First, though there are cases where economic growth could be immiserizing, there is a general consensus that economic growth is needed for many avenues of economic

---

JEL Classification — E23, F21, F30, L96, O55

The authors are indebted to the editor and reviewers for constructive comments.

Journal of Economic Studies
Vol. 50 No. 5, 2023
pp. 881-895
Emerald Publishing Limited
0144-3585
DOI 10.1108/JES-03-2022-0159

development to be realized (Vu, 2011; Peprah *et al.*, 2019; Asongu and Odhiambo, 2020). This is essentially owing to the premise that economic growth engenders a plethora of favorable economic development outcomes, *inter alia*, consumption and investment opportunities, social mobility, employment avenues, amelioration of living standards and enhancement of overall societal well-being (Hassan, 2005; Ngouhouo and Nchofoung, 2021). Accordingly, with the advent of globalization, there has been a growing body of literature on the importance of information technology in boosting outcomes of economic development (Veeramacheneni *et al.*, 2008; Tchamyou *et al.*, 2019a, b).

Second, from intuition and empirical evidence, economic growth within a country can be improved through factors such as ICT, which enhances the capacity of economic sectors in facilitating the catch-up process in terms of economic development (Hong, 2016; Tchamyou *et al.*, 2019a, b). As posited by the attendant literature, ICT is relevant in driving activities of production as well as global value chains because it *inter alia*, mitigates poverty, boosts competitiveness, increases transparency and consolidates the management of public affairs (Sassi and Goaied, 2013; Tchamyou, 2017).

Moreover, relative to other continents of the world, the policy relevance of ICT is more worthwhile in Africa because while the continent is characterized by the lowest ICT penetration rate, it equally has the highest growth rate in ICT (Asongu and Odhiambo, 2019a, 2019b) which is a determinant of the catch-up process (Vu and Asongu, 2021). This tendency is indicative of the potential that policy makers have to leverage ICT for targeted development outcomes such as economic growth. The present study is premised on how such ICT can be leveraged to improve economic growth potentials in the African continent.

Third, the positioning of this research, as articulated in the previous paragraph, is also motivated by a gap in the existing literature. Accordingly, the extant literature on economic growth in Africa has focused on the following strands, for the most part: assessing determinants of external flows (Okafor *et al.*, 2017); investigating nexuses between financial access and economic prosperity (Adam *et al.*, 2017; Assefa and Mollick, 2017); understanding country-centric cases related to economic output and inflation (Bonga-Bonga and Simo-Kengne, 2018); linkages between foreign aid, volatility and growth that are sector-specific (Kumi *et al.*, 2017); nexuses between variations in economic prosperity and access to finance (Ibrahim and Alagidede, 2017) and connections between innovation and economic growth variation (Yaya and Cabral, 2017).

The remainder of the study is structured as follows: Section 2 provides insights into the theoretical underpinnings while the data and methodology are discussed in Section 3, and the empirical results are disclosed in Section 4 before the study concludes in Section 5 with implications and future research directions.

2. Theoretical underpinning

This section is focused on theoretical underpinnings pertaining to the linkage between ICT and economic growth. According to the attendant literature (Hassan, 2005; Asongu and Odhiambo, 2020), the theoretical nexus between ICT and economic growth can be articulated along a plethora of channels which include (1) the *competitive mechanism*, owing to the fact that ICT provides opportunities by which companies, as well as nations, can become more competitive in order to improve corporate and cross-country catch-up, respectively.

According to the argument, ICT improves competitive prospects because it, *inter alia*, contributes to efficiency, more productivity and improvements in capital (i.e. human and physical). (2) The *training channel* is relevant in that ICT provides opportunities for labor activities, especially in the management of human resources. (3) With regards to the *linkage channel*, ICT by definition represents a factor through which technology can be transferred from one corporation or country to another. (4) Looking at the *demonstration channel*, firms and countries can use ICT to imitate other firms and countries in order to catch up in corporate performance and economic development, respectively. The underlying catch-up avenues that are facilitated by ICT ultimately boost output and economic prosperity in firms and countries, respectively.

The discussed theoretical linkage is consistent with non-contemporary literature on linkages between ICT and economic growth documented in Ofori and Asongu (2021a, b). According to the authors, technology is fundamental in both firm and cross-country catch-up processes (Ohlin, 1933; Samuelson, 1939; Stolper and Samuelson, 1941). Emara (2022), in analyzing the asymmetric dynamic relationship between FinTech adoption and poverty reduction in Sub-Saharan Africa (SSA), shows that an improvement in FinTech can initially decrease the extreme poverty rate, leading to a decrease in total poverty as a percentage of the population. Moreover, Emara and Katz (2022) examine the economic impact of telecommunications on economic growth in Egypt and show that for every 1% increase in mobile unique subscriber penetration and mobile broadband device adoption, the average annual contribution to gross domestic product (GDP) growth is estimated to be 0.172% and 0.016%, respectively.

A corresponding theory is the modernization theory which is consistent with the position that information technology is quite relevant in driving economic prosperity by means of *inter alia*, consumption, employment and transfer of technology (Sen, 1999; Bengoa and Sanchez-Robles, 2003; Durham, 2004; Li and Liu, 2005; Solomon, 2011; Messer and Townsley, 2003; Kwan and Chiu, 2015; Vu, 2019). The theoretical premise shows that ICT enables economic agents to provide a level-playing field that is relevant for opportunities that drive economic growth (Duncombe, 2006). On the basis of the discussed theoretical insights, this study tests one main hypothesis as follows:

H1. ICT affects economic growth, and the nexus is non-linear.

3. Methodology and data

3.1 Methodology

This section focuses on the choice and model of specification: threshold panel modeling. Most studies on threshold panel models most often refer: either to the panel threshold regression (PTR) modeling proposed by Hansen (1999) or to the panel smooth threshold regression (PSTR) modeling initiated by Gonzalez *et al.* (2005). These are models that can highlight several regimes of a relationship between two or more variables. In Hansen's (1999) model, the transition from one regime to another is abrupt.

As for the PSTR modeling, the passage from one regime to another is done gradually (i.e. smoothly) through a continuous transition function and not as in the PTR. It allows the elasticity of the outcome variable in relation to the explanatory variable not only to be time dynamic in terms of variation, but also to be space dynamic in terms of variation contingent on the threshold variable. It follows that PSTR modeling incorporates the heterogeneity of the nexus between the outcome variable, the explanatory variable and the transition variable.

As part of the analysis, this study tests the existence of a non-linear relationship between ICT and economic growth through PSTR modeling. The PSTR model is presented as follows in Equation (1):

$$y_{it} = \alpha_i + \lambda_t + \beta_0 X_{it} + \beta_1 X_{it} G(q_{it}; \gamma, c) + \varepsilon_{it} \tag{1}$$

where $i = 1, \ldots\ldots, N$ is the number of individuals and $t = 1, \ldots\ldots, T$ determines the period of analysis, y_{it} is the dependent variable, α_{i} and λ_{t} the vectors of the individual country and time fixed effects, respectively, and X_{it} is the matrix of explanatory variables.

$G(q_{it};\gamma,c)$ is the continuous and normalized transition function and associated with the threshold variable q_{it} (which in our case is the proportion of the population with access to electricity), with the threshold parameter c and a smoothing parameter γ, β_0 and β_1, respectively, denoting the vector of the parameters of the linear model and of the non-linear model and ε_{it} a vector of the error terms *iid* (0, σ_ε^2).

The normalized transition function $G(q_{it};\gamma,c)$ takes values that are comprised in the interval (0 1) and enables the system to gradually make a transition from one regime to another. For the functional form of this transition, function to be defined, Gonzalez *et al.* (2005) is consistent with less-contemporary studies by Granger and Teräsvirta (1993) and Teräsvirta (1994) in suggesting that the following logistic form of order m in Equation (2) should be retained:

$$G(q_{it};\gamma,c) = \left(1 + exp\left(-\gamma\prod_{j=1}^{m}(q_{it} - c_j)\right)\right)^{-1} \tag{2}$$

where, $\gamma > 0$ et $c_1 < c_2 < \ldots < c_m$, où $c_j = (c_1 \ldots c_m)$ is a vector grouping the threshold parameters. For $m = 1$, the model has two extreme regimes that distinguish the low values of q_{it} to its high values, and γ is a positive parameter that describes the transmission from one regime to another. When $\gamma \rightarrow \infty$, the indicator function approaches an indicator function $I(q_{it} > c_j)$ which takes the value 1 si$q_{it} > c_j$. Moreover, when $\gamma \rightarrow 0$, the transition function becomes a homogeneous fixed effects panel that is linear. Indeed, a very high value of γ leads us toward a model with respect to Hansen (1999) with a sudden transition.

Taking into account the transition function described above, the theoretical modeling of PSTR looks like the Equation (3) as follows:

$$y_{it} = \alpha_i + \lambda_t + \beta_0 X_{it} + \sum_{j=1}^{m} \beta_j\, G_j\, X_{it}\left(q_{it}^{j};\gamma,c\right) + \ \varepsilon_{it} \tag{3}$$

In the light of the threshold incidence introduced by the transition function G, the sensitivity of the outcome variable in relation to the explanatory variable of country i at the date t as in Equation (4) as follows:

$$s_{it} = \frac{\partial y_{it}}{\partial X_{it}} = \beta_0 + \beta_1 G(q_{it};\gamma,c) \tag{4}$$

Equation (4) above illustrates how the dependent variable being sensitive with respect to the explanatory variable can be taken into account as a combination of the coefficients β_0 and β_1 obtained in the two extreme regimes. In order to define the transition function, the following requirement is worthwhile:

(1) $0 < G(q_{it};\gamma,c) < 1$, for $\beta_1 < 0$, we have $\beta_0 + \beta_1 < s_{it} < \beta_0$, and

(2) If $\beta_1 > 0$, we have: $\beta_0 < s_{it} < \beta_0 + \beta_1$.

If γ is substantially high, the PSTR becomes a two-speed threshold model (PTR model). Hence, the direct impact of the variable of interest on the endogenous variable is β_0 for individuals characterized by a variable of interest that is below the threshold and $(\beta_0 + \beta_1)$ for individuals characterized by a variable of interest that is higher than the threshold.

The first step in estimating a PSTR is first to check for non-linearity. In order to make an assessment, Gonzalez *et al.* (2005) propose a test that consists in comparing a linear model to a PSTR model. Accordingly, when $\gamma = 0$, then the function G (,) has the value ½ whatever the value of the threshold variable is assigned. The threshold incidence hence disappears, and the model is simply a linear panel. It is the same when $\beta_1 = 0$. Given the fact that under the null hypothesis nuisance parameters are contained in the model (Davis, 1987), Gonzalez *et al.* (2005), just as Luukkonen *et al.* (1988), propose to replace the transition function $G(q_{it}; \gamma, c)$ by its Taylor expansion of order 1 in the neighborhood of $\gamma = 0$.

For m régimes, the regression to be estimated is Equation (5) as follows:

$$y_{it} = \alpha_i + \lambda_t + \beta_0' X_{it} + \beta_1' q_{it} X_{it} + \ldots + \beta_m' q_{it}^m X_{it} + \varepsilon_{it}^* \tag{5}$$

where the vectors of parameters $\beta_0', \ldots, \beta_m'$ are multiples of γ and $\varepsilon_{it}^* = \varepsilon_{it} + R_m \beta^* X_{it}$ with R_m being the residual of the Taylor expansion. The null hypothesis of the linearity test becomes as follows: H_0: $\beta_1' = \beta_2' = \ldots = \beta_m' = 0$. The linearity assumption is tested using standard tests. We use the Wald statistic (LM_F) in Equation (6) as follows:

$$LM = \frac{TN(SSR_0 - SSR_1)}{SR_0} \sim \chi^2(K) \tag{6}$$

where SSR_0 and SSR_1 denote, respectively, the sum of the squares of the panel residuals under the null hypothesis (linear panel model with individual effects) and the sum of the squares of the panel residuals under the alternative hypothesis (model PSTR with m regimes). When the sample size is small, Gonzalez *et al.* (2005) suggest using Fisher (LMF_1) which is defined in Equation (7) as follows:

$$LM_F = \frac{(SSR_0 - SSR_1)/mK}{SSR_0/(TN - N - m(K+1)} \sim F(mK, TN - N - m(K+1)) \tag{7}$$

where k is the number of explanatory variables, LMF follows a Fisher law to mK and $TN - N - m(K+1)$ degrees of freedom F $(mK, TN - N - m(K+1))$. Under the null hypothesis, all linearity tests follow a chi-square with k degrees of freedom χ_K^2. Testing the linearity hypothesis for m regimes ($\gamma = 0$) again amounts in Equation (8) to testing as follows:

$$H_0: \ \beta_1' = \beta_2' = \ldots = \beta_m' = 0 \tag{8}$$

An extension of these tests is performed on the premise of the pseudo-likelihood ratio ($pseudo_{LRT}$). In Equation (9), the statistic for the underlying test is presented as follows:

$$pseudo_{LRT} = -2[log(SSR_0) - log(SSR_1)] \sim \chi^2(mK) \tag{9}$$

where, SSR_0 is the sum of the squares of the residuals of a linear model with individual, SSR_1 represents the sum of the square of the residuals of the model that is unconstrained (PSTR). With respect to the null hypothesis, the lagrange multiplier (LM) statistic is distributed according to a chi-square law withmK degrees of freedom where K is the number of independent variables and m the number of regimes.

However, with a small sample size, Gonzalez *et al.* (2005) propose the employment of an alternative statistic LM_F which is distributed under the null hypothesis according to a Fisher F's law $(mK, TN - N - m(K+1))$.

The underlying test makes it possible to reject or not the linearity hypothesis in favor of a PSTR model, but also to determine an "optimal" value of the transition variable. With respect to Gonzalez *et al.* (2005), this value corresponds to the one that minimizes the p-value of the linearity test.

3.2 The variables and data used

In this study, the endogenous variable is the growth rate of the economy as measured by the growth rate of real GDP (y) and the exogenous variable of interest is the rate of subscriptions to fixed-line broadband access services (*dig*). The transition variable here is the proportion of the population with access to electricity (*elec*). The choice of the endogenous, exogenous and transition variables is informed by contemporary information technology and economic growth literature (Asongu and Odhiambo, 2022; Odhiambo, 2009, 2022; Emara and Katz, 2022).

The control variables selected are as follows:

1. Output per capita defined by the lagged variable of real GDP growth rate ($y(-1)$).
2. Private investment (Inv), measured by the share of private sector gross fixed capital formation in GDP, captures the influence of the private sector on economic activity. The theory predicts that investment generally stimulates economic growth and the expected sign is positive.
3. Trade openness (*Ouv*) obtained by dividing the difference between exports and imports as a % of GDP by 2 $\left(X - M/_{2GDP}\right)$. The reason for taking this variable into account in this study is that liberal theories of international trade and endogenous growth admit that a country's openness to the outside world promotes growth, provided that it has relative price competitiveness.
4. Public expenditure (*Dep*). The inclusion of this variable is justified by the numerous existing studies on the links between public spending and economic growth. Several empirical works indeed establish that public spending can influence economic growth either negatively or positively depending on the nature and quality of public spending (Devarajan *et al.*, 1996; Gupta *et al.*, 2005).
5. The inflation rate (π) captured by the growth rate of the consumer price index (CPI). The CPI is one of the better proxies for prices than the GDP deflator in developing countries because a large proportion of spending is consumer spending (Mondjeli andTsopmo, 2017).
6. The population growth rate (*pop*). The potential effects of population growth on economic growth remain an object of debate among economists. The two theses that drive the debate are the orthodox and heterodox theories. Proponents of the orthodox theory argue that population growth positively affects economic growth (Chan *et al.*, 2005; Dao, 2012; Thuku *et al.*, 2013), while proponents of the heterodox theory argue that population growth negatively affects the growth of the economy (Song, 2013).

This paper aims to show that the effects of information technology (captured here by the number of fixed-line broadband subscriptions per 100 inhabitants) on economic growth in Africa are a function of the electricity coverage of territories (proportion of the population with access to electricity). The procedure for determining this optimal electricity coverage consists of three steps. First, we justify the non-linearity between fixed broadband and economic growth by conducting a linearity or homogeneity test.

For this purpose, we conduct the appropriate Fisher standard test in small sample sizes. Then, we determine the number of regimes or the number of transition functions of the PSTR model using the Fisher test. Finally, we estimate the PSTR model using the non-linear least-squares method, after which the value of the optimal inflation rate is determined endogenously. Thus, if electricity coverage is higher than the optimal value determined, any improvement in the number of fixed-line broadband access subscriptions would have positive effects on economic growth. Otherwise, the effects would be negative.

3.3 Data and statistical properties of variables

The data used are annual, taken from the World Bank's World Development Indicators (2021) and cover the period from 2010 to 2020. The sample considered includes 33 African countries. The choice of this country is mainly based on the availability of data. Accordingly, a balanced panel dataset is needed for the implementation of the PSTR regressions. The definitions of variables, corresponding sources and expected signs are disclosed in Table A1 while Table A2 presents the corresponding descriptive statistics.

4. Empirical analysis

4.1 Unit root tests on the panel model data

The verification of the stationarity of the data of our model (i.e. non-existence of unit root) is conducted in order to avoid a possible spurious regression. In so far as our methodological framework takes into account the possible existence of unobservable heterogeneities in our sample, we performed five-unit root tests among which (1) the Im, Pesaran and Shin - IPS (2003) test, which takes into account heterogeneities under the alternative hypothesis of absence of unit root and (2) the Levin *et al.* (2002) test, which is instead based on panel homogeneity under the alternative hypothesis. The results of these unit root tests are reported in Table 1 below.

4.2 Linearity or homogeneity test

The homogeneity test aims to verify the existence of a possible non-linearity between fixed broadband and economic growth conditional on the level of access of the population to electricity. The non-linearity test allows us to demonstrate that there is a threshold from which the number of individuals with a subscription to fixed broadband access services would affect growth differently (positively/negatively).

The hypotheses of the linearity test are as follows: the null hypothesis is H_0: $\beta_0 = 0$ against the alternative H_1: $\beta_1 \neq 0$. However, this test is not standard since, under the null hypothesis, the PSTR model contains unidentified nuisance parameters (Hansen and Teräsvirta, 1996). Thus, consistent with Seleteng *et al.* (2013), we adopt the solution developed by Luukkonen *et al.* (1988), who propose to replace the transition function $G(q_{it}; \gamma, c)$ by the limited expansion first-order Taylor and at point $\gamma = 0$ the null hypothesis of the test becomes $H_0 : \gamma = 0$.

The results of the non-linearity tests are presented in the table below. We present, respectively, the LM_W and LM_F statistics described previously. These tests allow the null hypothesis of the linear model to be rejected at a 5% significance level (p value < 0.05).

4.3 Determination of the number of regimes

This is to test the number of regimes or, equivalently the number of transition functions. The test consists in verifying the null hypothesis that the PSTR model has only one transition

Method	Statistic	Prob
Im, Pesaran and Shin W-Stat	−13.8867	0.0000
Levin, Lin and Chu t*	−5.8029	0.0000
ADF-Fisher chi-square	257.856	0.0000
ADF -Choi Z-stat	−12.841	0.0000
Breitung t-stat	−3.3276	0.0004

Note(s): (***) gives the significance at 1%; values in brackets are probabilities. Source: estimation from authors using Eviews 15

IPS: Im, Pearson and Shin W-stat Unit Root Test; LLC: Levin, Lin et Chu unit root test and ADF: augmented Dickey–Fuller

Table 1. Results of unit root tests on panel data (Common unit root process)

function ($m = 1$) versus the alternative hypothesis that the PSTR model engenders a minimum of functions of transition ($m = 2$). Test decisions are based on the LM_w and LM_F.

If the corresponding coefficients are statistically significant at the critical threshold of 5%, the null hypothesis is rejected and the position that there are at least two transition functions is upheld. Otherwise, we do not reject the null hypothesis and establish that the model has two regimes and therefore has a threshold.

Regarding the number of regimes, it emerges from the table below that the null hypothesis (H0) is not rejected for a critical threshold of 5%. In other words, at a significance level of 5%, it is impossible to reject the null hypothesis of a PSTR model with one threshold (two regimes). There is thus a single threshold allowing the transition from a regime of small proportion of the population with access to electricity (regime 1) to a regime of a large proportion of the population with access to electricity (regime 2). This threshold is expressed in the form of a score.

Given the choices of rmax = 2 and m = 1, the optimal number (LM_F criteria) of threshold functions is $r = 1$. This result reflects the existence of a non-linearity in the relation between fixed broadband and economic growth conditional on the level of access of the population to electricity.

4.4 Model estimation results

The estimated parameters of the PSTR model are reported in Table 2. According to the objectives of the research, two main conclusions can be drawn from this table (column 1). First, the proportion of the population with access to electricity is around 60%. We obtain a unique rate because in the estimation procedure of the PSTR model, the first step is to eliminate specific effects (Gonzalez *et al.*, 2005).

Second, the rate of fixed broadband access subscriptions (dig) significantly explains economic growth and has the expected sign in both regimes. Thus, below the 60% threshold (indicating that the population's access to electricity is low), any increase in the fixed broadband subscription rate by 1% induces a decrease in economic growth of 2.56%. However, above this threshold (indicating that a high proportion of the population has access to electricity), an increase in the rate of fixed broadband subscriptions of 1% leads to an increase in economic growth of 2.43%.

4.5 Robustness analysis of the results obtained with a GMM model

In order to test the robustness of the PSTR model results, we estimate a growth equation that is expressed as follows:

$$y_{it} = \alpha_i + \lambda_t + \beta_0 X_{it} + \beta_1 dig_{it}^2 + \varepsilon_{it} \tag{10}$$

where the variables are defined as indicated for equation (1). To estimate equation (10), we use the dynamic panel generalized method of moments (GMM), which has the advantage of controlling for endogeneity between variables (Tchamyou, 2019, 2020). The instrumentation method chosen is as follows: (a) for the control variables, lagged values of one period are used while the endogenous variable is lagged by two periods. The disadvantage of the GMM method is that it no longer allows for the representation of a smooth transition.

In Table 3, the estimated results of the GMM confirm those obtained from the PSTR model, particularly with regard to the sign of the variable of interest, which is the number of subscriptions to broadband Internet services.

The GMM estimation shows that the sign of the variable is negative while it is positive when the variable is squared; this reflects the existence of a U-shaped relationship between the number of subscriptions to high-speed Internet services and economic growth in Africa.

Table 2.
Estimation of the PSTR model

Variables	Specification 1 Regime 1	Regime 2	Specification 2 Regime 1	Regime 2	Specification 3 Regime 1	Regime 2
dig	−2.56*** (0.49)	2.43*** (0.49)	−2.68*** (0.55)	2.50*** (0.56)	−2.87*** (0.72)	2.76*** (0.72)
ouv	−0.03 (0.13)	−0.15 (0.16)	0.08 (0.08)	−0.23* (0.12)	−0.13*** (0.06)	−0.12 (0.10)
π	−0.07 (0.07)	−0.06 (0.11)	−0.01 (0.04)	−0.09* (0.05)	−0.01 (0.04)	−0.12 (0.10)
pop	0.61 (1.11)	3.20*** (1.03)	−0.02 (0.56)	2.75*** (0.61)	−0.18 (0.61)	0.56 (0.72)
inv	0.05 (0.07)	−0.30*** (0.11)	0.16*** (0.05)	−0.37*** (0.08)		
Dep	−0.07** (0.08)	−0.11 (0.11)				
$y(-1)$	−0.31*** (0.09)	−0.44*** (0.15)	0.20*** (0.07)	−0.14 (0.15)	0.22*** (0.09)	−0.26 (0.17)
Test of linearity (LR_F Test)	30.19 (0.0.00)		27.2 (0.000)		23.163 (0.000)	
Test of the number of regimes (LR_F Test)	12.11 (0.097)		7.75 (0.257)		13.25 (0.03)	
γ	2.51		2.5		0.13	
c	60.08		61		62.12	

Note(s): The values in parentheses are the standard errors calculated for each variable. The sign (−) materializes the negative impact of the variables on the economic growth. The (+) sign represents the positive impact of the variables on economic growth. *Significant at 10%. **Significant at 5%. ***Significant at 1%
Source(s): Authors

Variable	Specification 1	Specification 2	Specification 3
dig	-0.60^{***} (0.26)	-0.34^{**} (0.19)	-0.27 (0.17)
dig^2	0.02^{***} (0.01)	0.01^{*} (0.007)	0.01 (0.006)
$elec$	0.01 (0.02)	0.002 (0.84)	-0.0005 (0.01)
ouv	0.07 (0.41)	0.04 (0.51)	0.04 (0.06)
π	-0.21^{***} (0.09)	-0.09 (0.07)	-0.09 (0.07)
pop	1.04^{***} (0.522)	0.29 (0.26)	0.26 (0.29)
$y(-1)$	-0.35 (0.23)	-0.53 (0.43)	-0.56 (0.43)
inv	-0.03 (0.05)	0.03 (0.02)	
Dep	-0.06 (0.09)		
c	5.14^{***} (1.37)	2.58^{**} (1.22)	3.39^{***} (1.29)
$AR(1)$	0.16 (0.12)	0.13 (0.22)	0.10 (0.26)
$AR(2)$	0.37^{***} (0.11)	0.23^{**} (0.10)	0.23^{**} (0.09)
$PDL(1)$	0.391^{***} (0.16)	0.69^{**} (0.31)	0.77^{**} (0.31)
$PDL(2)$	-0.439^{***} (0.17)	-0.70^{**} (0.28)	-0.76^{**} (0.32)
Fisher Test	35.059^{***}	49.28^{***}	61.11^{***}
$J-statistic$	3.82	5.81	4.62
Prob ($J-statistic$)	0.77	0.92	0.73
Number of instruments specified	25	23	21
Number of countries	33	33	33
Number of observations	1,364	1,364	1,364

Note(s): The values in parentheses are the standard errors calculated for each variable. *Significant at 10%. **Significant at 5%. ***Significant at 1%

Source(s): Authors. PDL: Polynomial Distributive Lag

Table 3.
Estimation of the GMM model

The insignificance of the variable of interest and its squared series on the one hand and, of some control variables on the other hand, lies in the fact that GMM modeling leads to a loss of information related to the linearity constraint that the quadratic model imposes on the marginal effect (Eggoh and Villieu, 2013). Moreover, given that the GMM technique is employed exclusively as a robustness check, the computation of the total effect of fixed broadband as in corresponding literature (Emara, 2022) is not indispensable because the GMM results inform the study of the presence of a non-linear nexus between fixed broadband and economic growth.

The J-Statistics values of the Hansen test in the three specifications informs that study that the instrumental variables used in the GMM system are exogenously related to the error term using the probability value. The probability associated with the first statistics is 0.77, which reflects the validity of the instruments used (orthogonally conditions verified). According to Sargan (1958), a minimum probability of 0.25 is required to accept that the instrument is valid and exogenously related to the error term. Thus, the three statistics from the three specifications meet the orthogonally conditions. It is worthwhile to note that a probability value of less than 0.25 implies that the instrument is not valid and is endogenously related to the error term, and, therefore, does not meet the orthogonal condition.

5 Concluding implications and future research directions

Since the onset of the COVID-19 pandemic, access to technology has become more essential than ever to ensure the continuity of economic life and to make a real and lasting contribution to economic development. In the empirical literature, many authors support this thesis and attribute economic growth to the development of technology.

However, the impact of technology on growth has not yet been unanimously accepted by economists. Indeed, several works establish that better access to technology would positively affect growth (Latrach and Bouhajeb, 2015; Khan *et al.*, 2016; Ildı rar *et al.*, 2016; Garza-Rodriguez *et al.*, 2020; Makonda, 2018), while others argue that the effects would be rather negative (Napo, 2018) or even neutral (Houngbedji, 2018).

In general, these authors establish that the relationship between fixed broadband and economic growth is linear. The originality of our study lies in the fact that it shows that the effects of fixed broadband on economic growth are rather non-linear in Africa when we consider the number of people with access to electricity. To do so, we apply a panel smooth transition regression model initially developed by Gonzalez *et al.* (2005), which is estimated from World Bank data over the period 2010–2020 on a panel of 33 African countries.

After showing the stationarity of the variables used with the unit root tests of Im *et al.* (2003) and Levin *et al.* (2002), we arrive at the results as follows: (1) the proportion of the population with access to electricity above and below which the relationship between fixed broadband and economic growth in Africa would change sign is about 60%; (2) below this threshold, each 1% increase in fixed broadband subscriptions induces a decline in economic growth of about 2. 58%; but above the threshold, economic growth would increase by 2.43% when fixed broadband subscriptions increase by 1%. Sensitivity analyses and GMM estimation of the dynamic panel (Tchamyou, 2020) show that these results are robust.

In the light of the established findings, due to the COVID-19 pandemic, which requires countries to take adequate measures to curb the spread of the pandemic (facilitation of distance work, distance education, access to health care, payment of bills, *inter alia*), any national policy aiming at improving the access of populations to high-level fixed broadband services should be preceded by the implementation of an electrification program for at least 60% of the total population. Otherwise, the provision of a good quality connection for the benefit of the population would not produce the expected effects on economic growth and would, therefore, be counterproductive.

The findings in the study leave room for improvement, especially within the perspective of considering other mechanisms and policy variables by which economic growth can be enhanced. Moreover, given the fact that in the post-2015 era of sustainable development goals, inclusive and sustainable development are important in policy and scholarly discourses, focusing on other sustainable development goals (SDGs)-specific outcomes would provide more room for policy implications.

References

Adam, I.O., Musah, A. and Ibrahim, M. (2017), "Putting the cart before the Horse? Re-examining the relationship between domestic savings and economic growth in selected sub-saharan african countries", *Journal of African Business*, Vol. 18 No. 1, pp. 102-123.

Asongu, S.A. and Odhiambo, N.M. (2019a), "Basic formal education quality, information technology, and inclusive human development in sub-Saharan Africa", *Sustainable Development*, Vol. 27 No. 3, pp. 419-428.

Asongu, S.A. and Odhiambo, N.M. (2019b), "How enhancing information and communication technology has affected inequality in Africa for sustainable development: an empirical investigation", *Sustainable Development*, Vol. 27 No. 4, pp. 647-656.

Asongu, S.A. and Odhiambo, N.M. (2020), "Foreign direct investment, information technology and economic growth dynamics in Sub-Saharan Africa", *Telecommunications Policy*, Vol. 44 No. 1, p. 101838.

Asongu, S.A. and Odhiambo, N.M. (2022), "Information technology and sustainability in developing countries: an introduction", *Telecommunications Policy*, Vol. 46 No. 6, p. 102383.

Assefa, T.A. and Mollick, A.V. (2017), "Financial development and economic growth in Africa", *Journal of African Business*, Vol. 18 No. 3, pp. 320-339.

Bengoa, M. and Sanchez-Robles, B. (2003), *Does Foreign Direct Investment Promote Growth? Recent Evidence from Latin America*, Universidad de Cantabria, Mimeo.

Bonga-Bonga, L. and Simo-Kengne, B.D. (2018), "Inflation and output growth dynamics in South Africa: evidence from the markov switching vector autoregressive model", *Journal of African Business*, Vol. 19 No. 1, pp. 143-154.

Chan, A., Lutz, W.E. and Robbine, J.M. (2005), "The demographic window of opportunity", *Asian Population Studies*, Vol. 1 No. 2, pp. 147-256.

Dao, M.Q. (2012), "Population and economic growth in developing countries", *International Journal of Academic Research in Business and Social Sciences*, Vol. 2 No. 1, pp. 9-15.

Davis, R. (1987), "Hypothesis testing when a nuisance parameter is present only under the alternative", *Biometrika*, Vol. 74 No. 1, pp. 33-43.

Devarajan, S., Swaroop, V. and Zou, H. (1996), "The composition of public expenditure and economic growth", *Journal of Monetary Economics*, Vol. 37 No. 2, pp. 313-344.

Duncombe, R. (2006), "Using the livelihoods framework to analyze ICT applications for poverty reduction through microenterprise", *Information Technologies and International Development*, Vol. 3 No. 3, pp. 81-100.

Durham, J.B. (2004), "Economic growth and institutions: some sensitivity analyses, 1961-2000", *International Organization*, Vol. 58 No. 3, pp. 485-529.

Eggoh, J.-C. and Villieu, P. (2013), "Un réexamen de la non-linéarité entre développement financier et croissance économique", *Revue D'économie Politique*, Vol. 123 No. 2, pp. 211-236.

Emara, N. (2022), "Asymmetric and threshold effects of fintech on poverty in SSA countries", SSRN Working Paper, available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4062335 (accessed 15 may 2022).

Emara, N. and Katz, R.L. (2022), "The economic impact of telecommunications in Egypt", SSRN Working Paper, available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4055699 (accessed 12 may 2022).

Garza-Rodriguez, J., Almeida-Velasco, N., Gonzalez-Morales and S & Leal-Ornelas, P.A. (2020), "The impact of human capital on economic growth: the case of Mexico", *Journal of the Knowledge Economy*, Springer; Portland International Center for Management of Engineering and Technology (PICMET), Vol. 11 No. 2, pp. 660-675.

Gonzalez, A., Teräsvirta, T. and Dick, V.D. (2005), "Panel smooth transmission regression models", *Stockholm School of Economics*, Stockholm, Working Paper Series in Economics and Finance.

Granger, C.W.J. and Teräsvirta, T. (1993), *Modelling Nonlinear Economic Relationships*, Oxford University Press, Oxford.

Gupta, S., Clements, B., Baldacci, E. and Mulas-Granados, C. (2005), "Fiscal policy, expenditure consumption and growth in low-income countries", *Journal of International Money and Finance*, Vol. 24 No. 3, pp. 441-463.

Hansen, E. and Teräsvirta, T. (1996), "Testing parameter constancy and super exogeneity in econometric equations", *Oxford Bulletin of Economics and Statistics*, Vol. 58 No. 4, pp. 735-763.

Hansen, B.E. (1999), "Threshold effects in non-dynamic panels: estimation, testing, and inference", *Journal of Econometrics*, Vol. 93 No. 2, pp. 345-368.

Hassan, M.K. (2005), "FDI, information technology and economic growth in the MENA region", 10th ERF paper, available at: http://www.mafhoum.com/press6/171T42.pdf (accessed 21 February 2019).

Hong, J.-P. (2016), "Causal relationship between ICT, R&D investment and economic growth in Korea", *Technological Forecasting and Social Change*, Vol. 116 March, pp. 70-75.

Houngbedji, H.S. (2018), "Transfert de technologie et croissance économique (UEMOA)", *Revue d'Economie et de Statistique Appliquée*, Vol. 15 No. 2, pp. 5-21.

Ibrahim, M. and Alagidede, P. (2017), "Financial development, growth volatility and information asymmetry in sub-saharan Africa: does law matter?", *South African Journal of Economics*, Vol. 85 No. 4, pp. 570-588.

Ildırar, M., Özmen, M. and İşcan, E. (2016), "The effect of research and development expenditures on economic growth: new evidences", *International Conference on Eurasian Economies*, pp. 36-43.

Im, K.S., Pesaran, M.H. and Shin, Y. (2003), "Testing for unit roots in heterogeneous panels", *Journal of Econometrics*, Vol. 115 No. 1, pp. 53-74.

Khan, J., Malik, Z.K. and Arafat, Z. (2016), "The impact of human capital on economic growth: evidence from selected Asian countries", *SUIT Journal of Social Sciences and Humanities*, Vol. 1 No. 1, pp. 1-16.

Kumi, E., Ibrahim, M. and Yeboah, T. (2017), "Aid, aid volatility and sectoral growth in sub-saharan Africa: does finance matter?", *Journal of African Business*, Vol. 18 No. 4, pp. 435-456.

Kwan, L.Y.-Y. and Chiu, C.-Y. (2015), "Country variations in different innovation outputs: the interactive effect of institutional support and human capital", *Journal of Organisational Behavior*, Vol. 36 No. 7, pp. 1050-1070.

Latrach, H. and Bouhajeb, M. (2015), "Contribution de l'éducation à la croissance économique dans les pays de l'OCDE : une analyse par les panels dynamiques", *International Journal of Innovation and Scientific Research*, Vol. 15 No. 1, pp. 150-160.

Levin, A., Lin, C.F. and Chu, J. (2002), "Unit root tests in panel data: asymptotic and finite sample properties", *Journal of Econometrics*, Vol. 108, pp. 1-24.

Li, X. and Liu, X. (2005), "Foreign direct investment and economic growth: an increasingly endogenous relationship", *World Development*, Vol. 33 No. 3, pp. 393-407.

Luukkonen, R., Saikkonen, P. and Terâsvirta, T. (1988), "Testing linearity against smooth transition autoregressive models", *Biometrika*, Vol. 75 No. 3, pp. 491-499.

Makonda, J.M. (2018), "Déterminants de la croissance économique dans les pays de la CEEAC", *Annale des Sciences Economiques et de Gestion*, Vol. 18 No. 2, pp. 175-194.

Messer, N. and Townsley, P. (2003), *Local Institutions and Livelihoods: Guidelines for Analysis*, Food and Agriculture Organisation, Rome.

Mondjeli, M. N.I. and Tsopmo, P. (2017), "Non-linéarité entre inflation et croissance économique: quels enseignements pour la zone BEAC ?", *Revue d'économie du développement*, Vol. 25, pp. 41-62, doi: 10.3917/edd.312.0041.

Napo, F. (2018), "Capital humain, productivité manufacturière et croissance économique dans les pays de l'UEM", *MPRA*, Paper No. 8945029, pp. 1-28, available at: https://mpra.ub.uni-muenchen.de/id/eprint/89450.

Ngouhouo, I. and Nchofoung, T.N. (2021), "Economic resilience in sub-saharan Africa: evidence from composite indicators", *Journal of the Knowledge Economy*. doi: 10.1007/s13132-020-00717-2.

Odhiambo, N.M. (2009), "Electricity consumption and the economic growth in South Africa: a tri-variate causality test", *Energy Economics*, Vol. 31 No. 5, pp. 635-640.

Odhiambo, N.M. (2022), "Information technology, income inequality and economic growth in sub-Saharan African countries", *Telecommunications Policy*, Vol. 46 No. 6, p. 102309.

Ofori, I.K. and Asongu, S.A. (2021a), "ICT diffusion, foreign direct investment and inclusive growth in sub-saharan Africa", *African Governance and Development Institute*, Yaoundé, Working Paper No. 21/029.

Ofori, K.I. and Asongu, S.A. (2021b), "ICT diffusion, foreign direct investment and inclusive growth in sub-saharan Africa", *Telematics and Informatics*, Vol. 65 December, p. 101718.

Ohlin, B.G. (1933), *Interregional and International Trade*, Harvard University Press, Cambridge, MA.

Okafor, G., Piesse, J. and Webster, A. (2017), "FDI determinants in least recipient regions: the case of sub-saharan Africa and MENA", *African Development Review*, Vol. 29 No. 4, pp. 589-600.

Peprah, J.A., Ofori, K.W. and Asomani, A.N. (2019), "Financial development, remittances and economic growth: a threshold analysis", *Cogent Economics and Finance*, Vol. 7 No. 1, p. 1625107.

Samuelson, P.A. (1939), "Interactions between the multiplier analysis and the principle of acceleration", *The Review of Economics and Statistics*, Vol. 21 No. 2, pp. 75-78.

Sargan, J.D. (1958), "The estimation of economic relationships using instrumental variables", *Econometrica*, Vol. 26 No. 3, pp. 393-415.

Sassi, S. and Goaied, M. (2013), "Financial development, ICT diffusion and economic growth: lessons from MENA region", *Telecommunications Policy*, Vol. 37 No. 4, p. 252 261.

Sen, A.K. (1999), *Development as Freedom*, Oxford University Press, Oxford.

Solomon, A.O. (2011), *The Role of Households in Solid Waste Management in East Africa Capital Cities*, Wageningen Academic Publishers, Wageningen, Vol. 4.

Song, S. (2013). "Demographic changes and economic growth: empirical evidence from Asia", *Honors Projects*, Paper No. 121, available at: https://digitalcommons.iwu.edu/cgi/viewcontent.cgi?article=1121&context=econ_honproj (accessed 1 August 2022).

Stolper, W.F. and Samuelson, P.A. (1941), "Protection and real wages", *The Review of Economic Studies*, Vol. 9 No. 1, pp. 58-73.

Teräsvirta, T. (1994), "Specification, estimation, and evaluation of smooth transition autoregressive models", *Journal of the American Statistical Association*, Vol. 89, pp. 208-218.

Tchamyou, V.S. (2017), "The role of knowledge economy in african business", *Journal of the Knowledge Economy*, Vol. 8 No. 4, pp. 1189-1228.

Tchamyou, V.S. (2019), "The role of information sharing in modulating the effect of financial access on inequality", *Journal of African Business*, Vol. 20 No. 3, pp. 317-338.

Tchamyou, V.S. (2020), "Education, lifelong learning, inequality and financial access: evidence from african countries", *Contemporary Social Science*, Vol. 15 No. 1, pp. 7-25, 30.

Tchamyou, V.S., Asongu, S.A. and Odhiambo, N.M. (2019a), "The role of ICT in modulating the effect of education and lifelong learning on income inequality and economic growth in Africa", *African Development Review*, Vol. 31 No. 3, pp. 261-274.

Tchamyou, V.S., Erreygers, G. and Cassimon, D. (2019b), "Inequality, ICT and financial access in Africa", *Technological Forecasting and Social Change*, Vol. 139 February, pp. 169-184.

Thuku, K.G., Gachanja, P. and Almadi, O. (2013), "The impact of population change on economic growth in Kenya", *International Journal Economics and Management Sciences*, Vol. 2 No. 6, pp. 43-60.

Veeramacheneni, B., Vogel, R. and Ekanayake, E.M. (2008), "Information technology, FDI andeconomic growth: an India case study", *Southwest Economic Review*, Vol. 35 No. 1, pp. 95-112.

Vu, K. (2011), "ICT as a source of economic growth in the information age: empirical evidence from the 1996-2005 period", *Telecommunications Policy*, Vol. 35 No. 4, pp. 357-372.

Vu, K. (2019), "The internet-growth link: an examination of studies with conflicting results and new evidence on the network effect", *Telecommunications Policy*, Vol. 43 No. 5, pp. 474-483.

Vu, K. and Asongu, S.A. (2021), "Backwardness advantage and economic growth in the information age: a cross-country empirical study", *Technological Forecasting and Social Change*, Vol. 159 October, p. 120197.

Yaya, K.Y. and Cabral, F.J. (2017), "Innovation and volatility of the GDP growth rate: case of the economies of sub-saharan Africa", *Journal of African Development*, Vol. 19 No. 1, pp. 88-112.

Further reading

Boamah, N.A. (2017), "The relevance of global sector influence in African sector portfolios", *African Journal of Economic and Management Studies*, Vol. 8 No. 2, pp. 205-220.

Dunne, J.P. and Masiyandima, N. (2017), "Bilateral FDI from South Africa and income convergence in SADC", *African Development Review*, Vol. 29 No. 3, pp. 403-415.

Fanta, A.B. and Makina, D. (2017), "Equity, bonds, institutional debt and economic growth: evidence from South Africa", *South African Journal of Economics*, Vol. 85 No. 1, pp. 86-97.

Traoré, S.S.L., Abdoulaye, M. and Bougoury, T.A. (2021), "Capital humain, technologie et croissance économique : cas du Mali", *Revue Française d'Economie et de Gestion*, Vol. 2 No. 12, pp. 175-194.

World Bank (2021), "World Development Indicators", The World Bank, available at: https://databank.worldbank.org/source/world-developmentindicators.

Appendix

Variable	Description	Source	ExpectedSign (s)
y	Real GDP growth rate	WDI	
y (−1)	Lagged variable of real GDP growth rate	WDI	+
dig	Number of fixed-line broadband subscriptions	WDI	+/−
elec	Proportion of population with access to electricity	WDI	
Inv	Ratio of private sector gross fixed capital formation to GDP	WDI	+
Ouv	Ratio of the sum of exports and imports to GDP	WDI	+
Dep	Ratio of public expenditure to GDP	WDI	+/−
π	Growth rate of the consumer price index	WDI	+/−
pop	Population growth rate	WDI	+/−

Table A1. Description of the variables used

	dep	*elec*	*inv*	*y*	π	*dig*	*pop*	*ouv*
Mean	22.23	54.02	26.54	4.55	4.68	2.34	2.31	−6.00
Median	20.92	49.70	25.04	4.46	4.12	0.52	2.63	−4.97
Maximum	42.71	100.00	53.59	19.68	17.87	24.20	3.88	11.32
Minimum	8.18	9.80	9.69	−5.72	−3.23	0.01	0.27	−33.42
Std Dev	8.66	30.50	9.07	3.01	3.94	4.38	0.79	6.71
Skewness	0.31	0.22	0.52	0.96	1.03	2.87	−0.67	−1.59
Kurtosis	2.20	1.64	2.83	7.82	4.41	11.11	2.53	7.10
Jarque–Bera	8.22	16.47	9.04	218.56	50.41	801.78	16.45	219.12
Probability	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Sum	4334.71	10533.24	5175.41	887.87	912.44	456.47	449.50	−1169.88
Sum Sq Dev	14541.31	180431.30	15963.35	1753.66	3004.94	3726.69	119.93	8731.91
Observations	195.00	195.00	195.00	195.00	195.00	195.00	195.00	195.00

Source(s): Authors' calculations

Table A2. Descriptive statistics of panel data

Corresponding author
Simplice Asongu can be contacted at: asongusimplice@yahoo.com