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The Non-Linear Effects of Fixed Broadband on Economic Growth in Africa

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Abstract

The study assesses the non-linear nexus between fixed broadband and economic growth. It focuses on data from 33 African countries for the period 2010 to 2020. The empirical evidence is based on unit root tests, panel smooth transition regression, and the generalized method of moments. The following findings are established: (i) 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%.(ii) Below this threshold, each 1% increase in fixed broadband subscriptions induces a decline in the economic growth of about 2.58%. Above the threshold, economic growth would increase by 2.43% when fixed broadband subscriptions increased by 1%. Sensitivity analyses and GMM estimation show that these results are robust. Therefore, due to the 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. This study complements the extant literature by providing thresholds at which fixed broadband affects economic growth.

1. Introduction

The study focuses on the non-linear nexus between information and communication technology development and economic growth in Africa for three main reasons, which build from the extant literature. These include: (i) the relevance of economic growth in driving development outcomes; (ii) the importance of information and communication technology (ICT) in boosting the catch-up process and facilitating human development and (iii) 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 development to be realized (Vu, 2011; Peprah, Ofori & Asomani, 2019; Asongu & 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 & 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, Vogel & Ekanayake, 2008; Tchamyou, Erreygers & Cassimon, 2019).

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, Asongu & Odhiambo, 2019). 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 & 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 & Odhiambo, 2019a, 2019b) which is a determinant of the catch-up process (Vu & 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, Piesse & Webster, 2017), investigating nexuses between financial access and economic prosperity (Adam, Musah & Ibrahim, 2017; Assefa & Mollick, 2017); understanding country-centric cases related to economic output and inflation (Bonga-Bonga & Simo-Kengne, 2018); linkages between foreign aid, volatility, and growth that are sector-specific (Kumi, Ibrahim & Yeboah, 2017); nexuses between variations in economic prosperity and access to finance (Ibrahim & Alagidede, 2017) and connections between innovation and economic growth variation (Yaya & 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. The empirical results are disclosed in Section 4 before the study concludes in Section 5 with implications and future research directions.

2. Theoretical underpinnings

This section is focused on theoretical underpinnings pertaining to the linkage between ICT and economic growth. According to the attendant literature (Hassan, 2005; Asongu & Odhiambo, 2020), the theoretical nexus between ICT and economic growth can be articulated along a plethora of channels which include: (i) 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 the capital (i.e., human and physical). (ii) The *training channel* is relevant in that ICT provides opportunities for labor activities, especially in the management of human resources. (iii) 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. (iv) 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 which 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, 2021b). According to the authors, technology is fundamental in both firm and cross-country catch-up processes (Ohlin 1933; Samuelson 1939; Stolper-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 percent increase in mobile unique subscriber penetration and mobile broadband device adoption, the average annual contribution to GDP growth is estimated to be 0.172 percent and 0.016 percent, 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 & Sanchez-Robles, 2003; Durham, 2004; Li & Liu, 2005; Solomon, 2011; Messer & Townsley, 2003; Kwan & 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:

Hypothesis 1: 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 PTR (Panel Threshold Regression) modeling proposed by Hansen (1999) or to the PSTR (Panel Smooth Threshold Regression) 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 economics 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, 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 duration of support for companies), 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, ε_{it} a vector of the error terms *iid* $(0, \sigma_\varepsilon^2)$.

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, Gonzàlez et *al.* (2005) is consistent with less contemporary studies by Granger and Teräsvirta (1993), Teräsvirta (1994), Jansen and Teräsvirta (1996), 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 $c_1 < c_2 < \cdots < c_m$, 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, γ is a positive parameter which describes the transmission from one regime to another. When $\gamma \to \infty$, the indicator function approaches an indicator function $I(q_{it} > c_j)$ which takes the value 1 si $q_{it} > c_j$. Moreover, when $\gamma \to 0$, the transition function becomes a homogeneous fixed effects panel that is linear. Indeed, a very high value of γ leads us towards 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 following in Equation (3):

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

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):

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

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:

- $0 < G(q_{it}; \gamma, c) < 1$, pour$\beta_1 < 0$, on aura$\beta_0 + \beta_1 < s_{it} < \beta_0$, Et,

- Si par contre$\beta_1 > 0$, on a :$\beta_0 < s_{it} < \beta_0 + \beta_1$

If$\gamma$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 $\beta_0$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), González et *al.* (2005), just as Luukkonen et *al.* (1988) proposes 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) below:

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

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:$H_0: \beta_1' = \beta_2' = \cdots = \beta_m' = 0$. The linearity assumption is tested using standard tests. We use the Wald statistic (LM_F) in Equation (6):

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

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, Gonzàlez et al. (2005) suggest using Fisher (LMF_1) which is defined in Equation (7):

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

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:

$$H_0: \beta_1' = \beta_2' = \cdots = \beta_m' = 0 \qquad (8)$$

An extension of these tests is performed on the premise of the pseudo-likelihood ratio ($pseudo_{LRT}$) by Colletaz and Hurlin (2006). In Equation (9), the statistic for the underlying test is presented:

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

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 LM statistic is distributed according to a chi-square law with mK degrees of freedom where K is the number of independent variables and m the number of regimes.

However, with a small sample size, González 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 González 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 & Odhiambo, 2022; Odhiambo, 2009,2022; Emara & Katz, 2022).

The control variables selected are:

- Output per capita defined by the lagged variable of real GDP growth rate ($y(-1)$).

- 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.

- Trade openness (Ouv), obtained by dividing the difference between exports and imports as a% of GDP by 2 ($X - M/_{2GDP}$).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.

- 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) or the threshold of public spending (Mondjeli, 2015).

- 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 &Tsopmo, 2017).

- 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 (Ekodo, 2018). 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 (Sija, 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 Appendix 1 while Appendix 2 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. Insofar as our methodological framework takes into account the possible existence of unobservable heterogeneities in our sample,

we performed 5-unit root tests among which: (i) the Im, Pesaran, and Shin - IPS (2003) test, which takes into account heterogeneities under the alternative hypothesis of absence of unit root; and (ii) the Levin, Lin, and Chu-LLC (2002) test,[1] which is instead based on panel homogeneity under the alternative hypothesis. The results of these unit root tests are reported in Table 1 below.

Table 1: Results of Unit Root Tests on Panel Data (Common unit root process)

Method	Statistic	Prob
Im, Pesaran and Shin W-Stat	-13.8867	0.0000
Levin, Lin & 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: (***) gives the significance at 1%; values in brackets are probabilities. Source: estimation from Authors usingd'Eviews 15.Notes: IPS: Im, Pearson and Shin W-stat Unit Root Test; LLC: Levin, Lin et Chu Unit Root Test; ADF: Augmented Dickey-Fuller

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, 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 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 (*pvalue* < 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 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 short duration of support (regime 1) to a regime of long duration of support (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 (González 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

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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 one % leads to an increase in economic growth of 2.43%.

Table 2: Estimation of the PSTR model

Variables	Specification 1		Specification 2		Specification 3	
	Regime 1	Regime 2	Regime 1	Regime 2	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 (0.02)	
γ	2.51		2.5		0.13	
c	60.08		61		62.12	

Note: 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: Authors.

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:

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

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 (Arellano & Bond, 1991; Arellano & Bover, 1995; Blundell et al., 2000; 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. 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 & 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 indispensible because, the GMM results inform the study of the presence of a non-linear nexus between fixed broadband and economic growth.

Table 3: Estimation of the GMM Model

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
$Number\ of\ observations$	1364	1364	1364

*Notes: The values in parentheses are the standard errors calculated for each variable. *Significant at 10%. **Significant at 5%. ***Significant at 1%.Source: Authors.PDL: Polynomial Distributive Lag*

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.

6. 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 & Bouhajeb, 2015; Khan et *al.,* 2016; Ildırar et *al.,* 2016; Garza et *al.,* 2018; 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 González et *al.* (2005), 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, Pesaran and Shin (2003) and Levin, Linand Chu (2002), we arrive at the following results: (i) 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%.(ii) 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 Generalized Method of Moments estimation of the dynamic panel (Arellano & Bond, 1991; Arellano & Bover, 1995; Blundell et *al.,* 2000) 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 SDGs-specific outcomes would provide more room for policy implications.

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Appendix 1: Description of the Variables Used

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	+/-

Appendix 2: Descriptive statistics of panel data between

	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: Authors' calculations