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THE NON-LINEAR RELATIONSHIP BETWEEN ICT DIFFUSION AND ECONOMIC GROWTH: EMPIRICAL EVIDENCE FROM MENA REGION AND AFRICAN COUNTRIES

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ABSTRACT

This research examines the non-linear effects of information and communication technology (ICT) diffusion on economic growth in 30 MENA and African countries from 2000 to 2020. The study employs panel smooth transition regression (PSTR) and the generalized method of moments (GMM) to analyze the data. Some main conclusions are presented as follows.

First, the PSTR models effectively capture the smooth non-linear effects of ICT diffusion on economic growth. In countries with high levels of ICT development, ICT diffusion positively impacts economic growth when ICT diffusion is below a threshold of 3.88. Above this threshold, the effects change. In less ICT-developed countries, ICT development initially negatively correlates with economic growth up to a threshold of 2.10. Beyond this threshold, the relationship reverses, becoming positive.

Second, in the least ICT-advanced countries, a "leapfrog effect" is observed, where ICT's impact on economic growth shows a continuous upward trend.

Finally, the GMM results show that the effects of ICT on economic growth differ between more and less ICT-advanced countries. In the most ICT-advanced countries, the relationship between ICT and economic growth follows an inverted "U" shape. In the least ICT-advanced countries, the relationship takes on a "U" shape.

Keyword: ICT development, Economic Growth, Panel Smooth Transition Regression Model, countries MENA and Africans

JEL Code : O11, H50, O33, C24

INTRODUCTION

In recent decades, information and communication technology (ICT) has been developed and applied rapidly. With billions of connections and different communication channels, the internet has revolutionized the way people function. Given the growing importance of ICTs and the way they are changing the world, a number of theoretical and empirical studies have been carried out to examine the impact of ICTs on economic growth.

In developed countries, most studies examining the linear relationship between ICT diffusion and economic growth show that ICT has a significant positive impact on economic growth

(Niebel T. 2018) and productivity (Bloom et al., 2012; Liao H et al, 2016, Cardona et al, 2013, Timmer and van Ark, 2005; World Bank, 2016). However, studies of developing countries, particularly those in the Middle East and North Africa (MENA) (Hassan 2005; Sassi and Goaied 2013) and sub-Saharan Africa (SSA) regions, have yielded mixed results, and the researchers believe there will be differences in the impact on growth (Andrianaivo and Kpodar 2011; Lee et al. 2012; Wamboye et al. 2015; Albiman and Sulong 2016). As a result, this question remains open to further research.

In our view, the results of studies carried out in developed countries should not be generalized to developing countries, for a number of reasons. First, as the spread of ICTs in these latter countries began later than in others, the process of catching up is taking specific paths. At the same time, it is important to remember that the benefits derived from ICTs are not uniformly distributed. As of 2020, approximately 5.3 billion people, or 56% of the world's population, have been touched by the digital revolution. Sadly, 2.7 billion individuals lack Internet access due to inadequate broadband connectivity. Among the developing countries, Africa ranks as the least connected continent, characterized by stark disparities. By the end of 2021, mobile telephony will account for over 80% of total connectivity, while the Internet will merely constitute 43%. Second, the developing countries have inadequate absorptive capacities, such as appropriate levels of human capital or other complementary factors such as R&D spending, and therefore earn less than the developed countries (Dewan and Kraemer, 2000; Dedrick.J et al., 2013; Dimelis and Papaioannou, 2010; Zuhdi et al., 2012; Chavura, 2013). According to Mwakatumbula et al. (2019) less technology used than expected due to lack of ICT infrastructure. Third, ICTs can give developing countries the opportunity to "leapfrog" traditional methods of increasing productivity, as mentioned by Steinmueller (2001). These additional productivity gains could be induced by ICT spillover effects or network effects, as ICT can reduce transaction costs and accelerate the knowledge creation process. Nevertheless, network effects seem to be more marked when numerous companies in a given region or industry sector use similar levels and types of ICT. Numerous studies have explored the unexpected effects of ICT on economic growth, particularly in relation to network effects (Gruber & Koutrompis, 2011; Hawash & Lang, 2010; Vu, 2011). Forth, the externalities of communication networks suggest that the impact of ICTs may also have a threshold effect, as ICTs can only have lasting effects on countries if they penetrate to some extent throughout the economy (according to Jean C. Kouam et al., 2022 and Albiman , M.M., & Sulong, Z., 2016, 2017). Likewise, Gómez-Barroso et al (2020b) point out that the positive benefits of ICT use are not always immediately perceptible.

Therefore, in order to fill the gaps in the existing empirical literature, it is necessary to examine the relationship between ICT and economic growth from a new perspective, taking into account the particularities of developing countries and the characteristics of ICT.

This paper examines the non-linear impact of different levels of ICT penetration on economic growth in 30 African and MENA countries between 2000 and 2020. It contributes to the literature and complements the existing body of knowledge in several ways. First, different from previous studies, the ICT development index used in this paper consists of three different sub-indices: ICT access, ICT use and ICT skills. The index calculates how digitally a country's citizens are. It is used as the variable of interest and transition. In most empirical studies, the Internet, mobile phones, fixed-line phones, and broadband are used for econometric calculations. Second, this paper adopts the panel smooth transition regression (PSTR) model as the regime-switching model proposed by González et al. (2005). Third, a second non-linearity related to the magnitude of the impact of the ICT development index on economic growth is shown.

The remainder of the paper is organized as follows. Section 2 outlines a brief review of relevant literature on the relationship between ICT development and economic growth. Section 3 presents the model and discusses the data, while the empirical results and robustness analysis are presented in Section 4. Finally, the paper concludes the empirical results and provides some policy implications.

2. LITERATURE REVIEW

This section reviews the existing literature on the impact of ICT on economic growth. We offer a summary of the various empirical interpretations of the nature of the relationship between ICT and economic growth, formulating the hypothesis of non-linearity.

Economic literature has identified several channels through which the impact of ICTs on growth is recognized. These channels include several effects. Firstly, the multiplier effect, which stems from investment in ICTs, and the "deflator" effect, which refers to the reduction in inflation due to lower prices in the ICT sector, which then affect other sectors. Next, the "capital deepening" effect, which relates to the increase in labor productivity following an increase in ICT use, and the "quality" effect, which highlights improvements in ICT characteristics. Finally, there is the "total factor productivity" effect, which expresses the improved efficiency of labor, capital and their combination resulting from ICT investments (Aghaei & Rezagholizadeh, 2017; Quah, 2002). Economic theory is consistent with the position that ICT can stimulate economic prosperity through, among other things, consumption, employment and technology transfer, (Durham, 2004; Vu, 2019).

In many ways, ICTs are different from the high-tech industries of the past, which drove industrial growth and economic development, such as steel, chemicals and machinery. For many applications and some types of production, the entry conditions for production do not require massive investment in fixed plant or infrastructure, or in the accumulation of experience. In addition, it is often the case that ICT applications complement efforts to improve production quality, speed and flexibility, offering a compensatory advantage over existing production capacity shortfalls (Lal, 2000). Since almost all the components and many of the systems incorporating these technologies are available internationally on highly competitive markets, and are easily transportable, these technologies appear to be easily transferable to any country capable of using them productively.

According to Steinmüller (2001), all these elements indicate that ICTs have the capacity to support the "leap forward" development strategy, i.e. to bypass some of the processes of human capacity building and fixed investment in order to reduce the productivity and production gaps that distinguish industrialized and developing countries.

With regard to the link between ICT and catch-up potential, Duncombe, (2006) assert that ICTs enable economic agents to offer favorable conditions and opportunities, thus stimulating economic growth. Furthermore, Asongu et al. (2019) establish that ICT enhances the capacity of economic sectors to facilitate the catch-up process in terms of economic development.

Based on the theoretical ideas discussed, this study tests one main hypothesis, namely that the link between ICT and economic growth is not linear.

In parallel with these theoretical advances, many empirical studies on the relationship between ICT and economic growth have been carried out in both developed and developing countries. Some have analyzed the linear relationship between ICT and economic growth, while others have assessed the non-linear relationship, emphasizing the impact of ICT in growth analysis using threshold effects. The findings using a linear model show that ICT has a positive and significant impact on economic growth (Colecchia and Schreyer, 2002, Oulton, 2001, Toader et al. 2018, Fernandez-Portillo et al. 2020, Cioaca et al. 2020). For example, Emara and Katz (2022) study the economic impact of telecommunications on economic growth in Egypt and report that for every 1% increase in penetration of unique mobile subscribers and adoption of mobile broadband devices, the estimated average annual contribution to gross domestic product (GDP) growth is 0.172% and 0.016%, respectively.

In these studies, different ICT-related variables are used, such as fixed telephone, mobile telephone, Internet, ICT investment and ICT capital.

A few studies address non-linearity using threshold regression techniques. In one such study, Jean C. Kouam et al (2022) used access to electricity as a threshold variable to determine the relationship between fixed broadband subscriptions and economic growth in 33 African countries for the period 2010-2020. The results suggest that the proportion of the population with access to electricity above and below which the relationship between fixed broadband and economic growth changes sign is around 60%. Below this threshold, every 1% increase in the number of fixed broadband subscriptions leads to a fall in economic growth of around 2.58%. Above this threshold, economic growth would increase by 2.43% when fixed broadband subscriptions rise by 1%. Sassi and Goaied (2013) also found a positive non-linear effect of the Internet, cell phones and ICT imports on economic growth in the MENA region.

In a similar line of reasoning, Hawash and Lang (2010) used a sample of 33 developing countries over the period 2002-2006 and were able to confirm that high levels of information technology (IT) adoption have negative effects on total factor productivity, thus confirming the existence of a non-linear relationship.

Albiman and Sulong (2017) use data from a sample of sub-Saharan African countries over the period 1990-2014, and present evidence that fixed-line, mobile and internet subscriptions, all per 100 inhabitants, have non-linear effects on economic growth, with a precise estimated threshold level for each ICT variable. In their study for Sub-Saharan African region, Wemboye et al (2015) showed a negative linear effect of ICT indicators (cell phones, Internet and fixed telephone lines) on economic growth in. However, when the rates of these indicators doubled, the relationship became positive and statistically significant.

Vu (2011) examines the impact of the use of personal computers, cell phones and Internet penetration on a sample of 85 countries over the period 1996-2005. The findings show that ICT has a positive effect on economic growth, but that this effect decreases as the penetration rate increases.

On another note, the IMF study by Kpodar and Adranaivo (2011) of a group of African countries over the period 1988-2007 uses three ICT indicators: cell phones, Internet penetration and fixed telephone lines, to find evidence of a positive linear impact on economic growth, with no evidence of non-linear effects. On the other hand, the IMF study by Kpodar and Adranaivo (2011) on a group of African countries over the period 1988-2007 uses three

ICT indicators: cell phones, Internet penetration and fixed telephone lines to show linear positive impact on economic growth, without finding evidence of non-linear effects.

Given the above considerations, the purpose of this article is to provide additional information on previous research that has examined the impact of the complex relationship between ICT and economic growth.

3. METHODOLOGY AND DATA SOURCES

This study examines the impact of ICT development thresholds on economic growth in 30 African and MENA countries, using real per capita GDP growth rates as the dependent variable and the ICT Development Index as the threshold or transition variable.

Following the literature on the determinants of economic growth (Barro and Sala-i-Martin, 2003; Easterly et al., 2006; Anyanwu, 2014; Akobeng, 2016), we considered several control variables, including the trade openness rate, inflation rates, public spending and credit extended to the private sector. We use the PSTR (Panel Smooth Threshold Regression) method proposed by Gonzàlez et al. (2005). This approach allows us to simulate situations where the transition from one regime to another is gradual (smooth transition). Therefore, the transition function will not be an indicator, but rather a continuous function.

3.1 Methodology

This sub-section looks at the choice and model of specification: threshold panel modeling. Most studies of threshold panel models refer either to the PTR (Panel Threshold Regression) model proposed by Hansen (1999), or the PSTR (Panel Smooth Threshold Regression) model initiated by Gonzalez et al. (2005). These models can show several regimes of a relationship between two or more variables.

The benefits of threshold regression models are twofold. First, parameter coefficients can take different values depending on the system. Second, the coefficients change gradually when transitioning from one state to another (Villavicencio and Mignon, 2011). The bootstrap method was also used to test the statistical significance of the threshold effect.

To estimate the non-linear effect of ICT development on economic growth as a function of the ICT development index, we estimate the PSTR model

$$y_{it} = \mu_i + \beta_1 Idi_{it-1} + \beta_2 Idi_{it-1} \Phi(Idi_{it-1}, \gamma, C) + \alpha x_{it} + \varepsilon_{it} \qquad \textbf{(1)}$$

Avec μ_i les effets fixes du pays et ε_{it} les résidus

y_{it}, Idi_{it-1} and x_{it} represent respectively economic growth, the lagged ICT development index of a period and a vector of control variables.

$\Phi(Idi, \gamma, C)$ is a transition function that depends on the threshold variable Idi, the smoothing parameter γ and the transition threshold C.

The parameter γ characterizes the transition in the vicinity of threshold value C.

The coefficients β_1 and β_2 respectively designate the parameter vector of the threshold parameter model (C) and a smoothing parameter γ that characterizes both the transition between the two regimes and the existence or non-existence of non-linearities governed by the ICT development index (transition variable).

The PSTR method identifies an infinite number of regimes, each describing a different effect of ICT development on economic growth, depending on Idi_{it-1}. The effect of ICT development on economic growth for $Idi_{it-1} \leq C$ is equal to β_1 , while it is equal to $\beta_1 + \beta_2$ for $Idi_{it-1} \rangle C$.
We thus find the two extreme PTR regimes.

The explanatory variable of interest is the ICT development index (Idi). Consequently, the direct effect of ICT variables on real GDP growth will be given by β_1 when the level of these variables is less than or equal to C, and by ($\beta_1 + \beta_2$) for a level of these variables greater than C.

The parameter γ determines the slope of the transition function. When the number of thresholds is equal to 1, the model has the two extreme regimes separating low and high values of with a single monotonic transition of coefficients from β_1 to ($\beta_1 + \beta_2$) as Idi_{it-1} increases.

In accordance with Granger and Teräsvirta (1993) and González et al. (2005), we use the following logistic transition function:

$$\Phi\left(Idi_{i,t-1}, \gamma, c\right) = \left[1 + e^{\left(-\gamma \prod_{=1}^{m}\left(Idi_{i,-1} - c_z\right)\right)}\right]^{-1} \in [0,1] \quad \gamma \rangle 0 \quad c_1 \langle ...... \langle c_m \qquad (2)$$

On the other hand, when γ ⟶ 0, the transition function becomes constant and the PSTR estimation reduces to that of a panel with individual fixed effects.

Taking into account the threshold effect introduced by the transition function $\Phi\left(Idi_{i,t-1}, \gamma, c\right)$, the sensitivity of growth to ICT development in country i at date t is given by the following expression: $s_{it} = \frac{\partial y_{it}}{\partial Idi_{it-1}} = \beta_1 + \beta_2 \Phi\left(Idi_{it-1}, \gamma, C\right)$ (3)

This equation shows that the sensitivity of growth to ICT development can be considered as a combination of the coefficients β_1 and β_2. These two coefficients are obtained in the two extreme regimes.

If the coefficient $\beta_2 \langle 0$ the sensitivity s_{it} is: $\beta_1 + \beta_2 \langle s_{it} \langle \beta_1$. If the coefficient $\beta_2 \rangle 0$ the sensitivity s_{it} is: $\beta_1 \langle s_{it} \langle \beta_1 + \beta_2$

Note that the coefficient β_1 corresponds to the impact of ICT on economic growth when the transition function tends towards zero. Indeed, if the transition function tends towards 1, the sensitivity s_{it} corresponds to $\beta_1 + \beta_2$

To approximate the PSTR model, we suggest a four-step procedure proposed by Colletaz and Hurlin (2006) and Fouquau et al. (2008).

The initial step involves testing the validity of the linear model in comparison to a threshold effects model that incorporates a minimum of one transition function. If the linear model is proven to be inadequate, the subsequent step involves evaluating the appropriate number of transition functions to be incorporated into the model. Our testing process involves multiple iterations to assess the various potential functions until we reach a point where the alternative hypothesis can be disproven. During the third step, we ascertain the appropriate number of thresholds. Finally, in the fourth step, we utilize nonlinear least squares (NLS) to estimate the parameters of the PSTR model.

In the PSTR model (equation 1), the linearity test involves the examination of two null hypotheses. The first null hypothesis, denoted as H0: γ = 0, tests for the absence of linearity. The second null hypothesis, denoted as H0: β2 = 0, tests for the absence of a specific linear relationship.

In line with the research carried out by González and colleagues (2005), as well as the studies by Colletaz and Hurlin (2006) and Fouquau et al (2008), several methods have been proposed for performing statistical tests. These methods use Wald's Lagrange multiplier and its Fisher version, as well as the likelihood ratio, as the basis for their test statistics.

Wald's LM test can be written as follows:

$$LMW = \frac{NT\left(SCR_0 - SCR_1\right)}{SCR_0} \qquad (4)$$

where N is the number of countries, T the number of years;

SCR0 consists of the residuals from the single-effects model and SCR1 consists of the residuals from the two-system PSTR model. Under the null hypothesis, Wald's LM statistic is distributed according to a chi-square distribution with k degrees of freedom, where k is the number of explanatory variables. However, if the sample size is small, Gonzalez et al. (2005) suggest using the Fisher test defined as follows:

$$LMF = \frac{\left(\frac{SCR_0 - SCR_1}{m}\right)}{\left(\frac{SCR_0}{TN - N - mk}\right)} \qquad (5)$$

This statistic is distributed under the null hypothesis according to a Fisher distribution $F\left(mk, TN - N - m\right)$. This test is used not only to reject the linearity hypothesis in favor of a PSTR model, but also to determine an "optimal" transition variable from a set of potential variables. We note that m is the number of regimes.

According to González et al (2005), the optimal transition variable is the one that minimizes the p-value of the linearity test. Finally, the Likelihood Ratio test, whose distribution follows a chi-square distribution with k degrees of freedom, is expressed as follows:

$$LRT = -2[\log(SCR_1) - \log(SCR_0)] \qquad (6)$$

Residual non-linearity tests are performed to determine the number of transition functions or states in the model. In this test, the null hypothesis of a PSTR model with a single transfer function (H0: r = 1) is faced with the alternative hypothesis of a PSTR model with at least two transfer functions (H0: r = 2).
Of the three test statistics available, we can opt for the test statistic introduced by González et al. (2005). This particular statistic is derived from the Lagrange multiplier (LM) and its Fisher equivalent (LMF).

Of the three statistical tests available, we can opt for the test statistic introduced by González et al. (2005). This particular statistic is derived from the Lagrange multiplier (LM) and its Fisher equivalent (LMF).

3.2 Data sources

The statistics we use cover the period 2000-2020 and are published by the World Bank and the International Telecommunication Union. We choose the growth rate of real GDP per capita as the explained variable. The explanatory variable is the ICT development index.

We choose five control variables. The first is the lagged variable of real GDP growth rate. The second indicator is the domestic credit to private sector/GDP (Credit) ratio, which reflects financial sector developments. Trade openness (Trade) is the third variable, approximated by import and export flows. The liberalization of international trade is increasingly evident in the countries examined (Kremer et al., 2013). Due to its impact on telecommunications, this variable affects economic growth by increasing per capita income. The fourth variable is the inflation rate (Inflation). High inflation can lead to worsening price competitiveness and have a negative impact on economic growth. Our fifth variable is general government final consumption expenditure (% of GDP). There is no consensus in the literature on the direction of the relationship between public spending and economic growth. Indeed, empirical work shows that public spending can influence economic growth negatively or positively depending on the nature and quality of public spending (Gupta et al., 2005) or the threshold of public spending (Mondjeli, 2015).
T
o compare whether the impact of ICT proliferation varies on economic growth in different countries with different levels of ICT development, we divided the entire sample into two groups: the group of countries with a high level of ICT development and the group of countries with a low level of ICT development.

- **The ICT Development Index (Idi)**

The three dimensions used to assess the level of ICT development are: access, skills and use.
The approach employed in this paper to standardize and categorize the indicators aligns with the methodology utilized by the ITU, as outlined in the appendix (Table A1, table A2). The objective of the ICT Development Index (Idi) proposed in this study parallels that of the Idi computed by the ITU, which aims to evaluate the level of ICT development in countries. The Idi is comprised of three key components: ICT infrastructure, ICT usage, and ICT skills. It is

measured on a scale ranging from 0 (indicating low ICT development) to 10 (indicating high ICT development). The index comprises 11 indicators, although in the interests of continued generalization, five indicators have been excluded due to insufficient data quality. Rather than excluding a country entirely due to limited data availability, we opted to calculate an aggregate index score based on a smaller dataset.

The comparative analysis of the Idi Index is carried out by country (Figure 1), by year (Figure 2) and by component (Figure 3).

By analyzing ICT development scores by country, the ranking reveals the gap in ICT development between MENA countries and African countries. High-income MENA countries are characterized by relatively high Idi scores.

The figure 1 shows the Idi for various countries in Africa and the Middle East, with the average line drawn at 3.16. This means that, for all the countries represented, the average value of the Idi is 3.16. The countries to the left of the average line (3.16) have a lower than average Idi. This includes countries such as Burundi, Mozambique, Burkina Faso, Madagascar, Uganda, Mali, Togo, Benin, Cameroon, Mauritania, Nigeria, Senegal, Kenya, Ghana and Eswatini. These countries have lower levels of infrastructure development than the sample average.

Countries to the right of the average line have an above-average Idi of 3.16. This includes countries such as Egypt, Gabon, Algeria, Morocco, Tunisia, South Africa, Oman, Qatar, Kuwait and Bahrain. These countries have more developed infrastructures than the sample average.

The countries with the highest Idis are mainly Gulf countries, such as Kuwait, Qatar and Bahrain, with IDIs close to 7.

The graph shows a significant disparity in infrastructure development between the different countries. Gulf countries tend to have much more developed infrastructures than most African countries.

Figure 1: ICT Development Index (IDI) for the different countries in the sample (Average from 2000 to 2020)

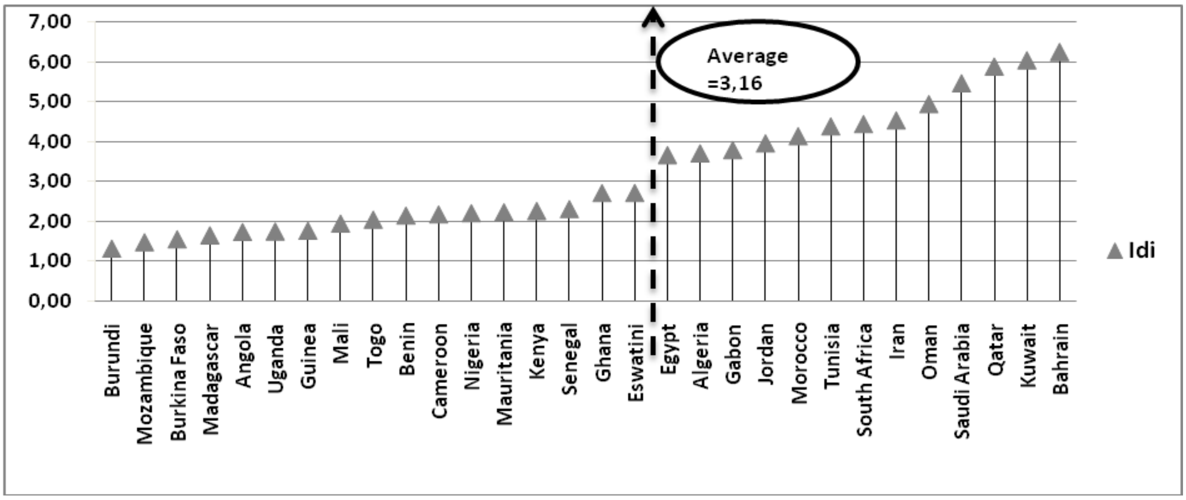
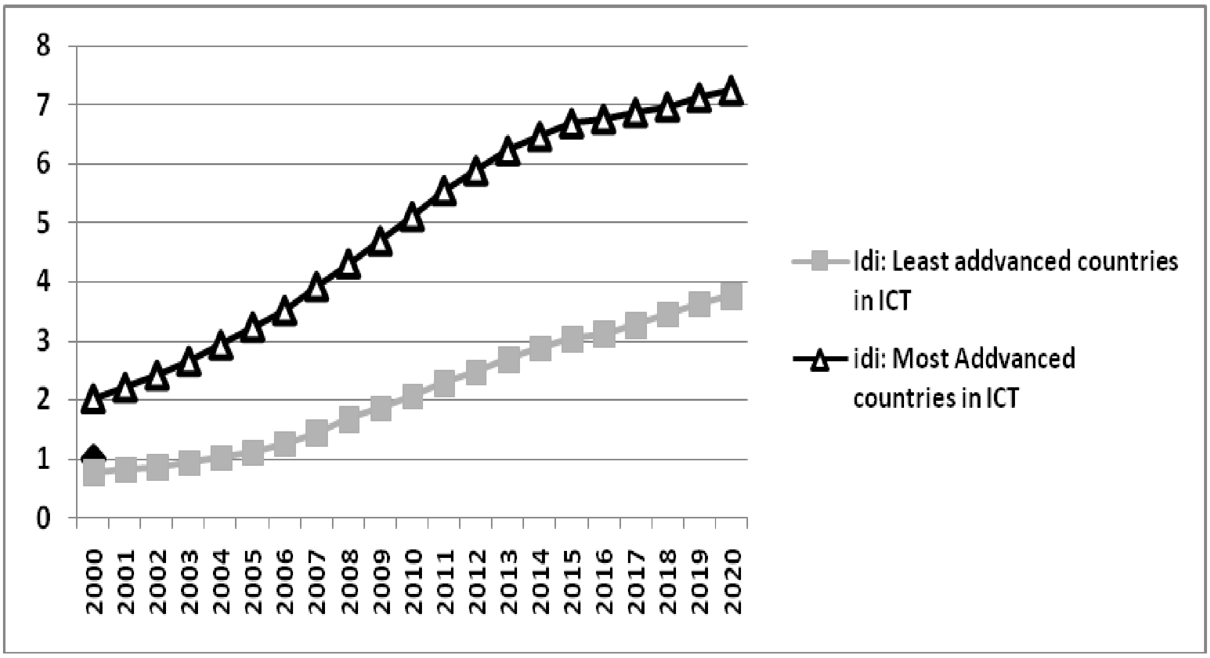


Figure 2 shows the information and communication technology (ICT) development index for the least and most ICT-advanced countries between 2000 and 2020.

The Idi score for the most advanced countries shows a steady upward trend, from just over 3 in 2000 to almost 8 in 2020. This indicates significant improvements in ICT infrastructure and use in these countries over the past two decades. Similarly, the least advanced countries are also showing an upward trend, but at a slower pace. Starting from just over 1 in 2000, their IDI score is gradually rising to reach around 3.5 in 2020.

Figure 2: Evolution of the ICT Development Index (Idi) for the two groups of countries in the sample from 2000 to 2020.

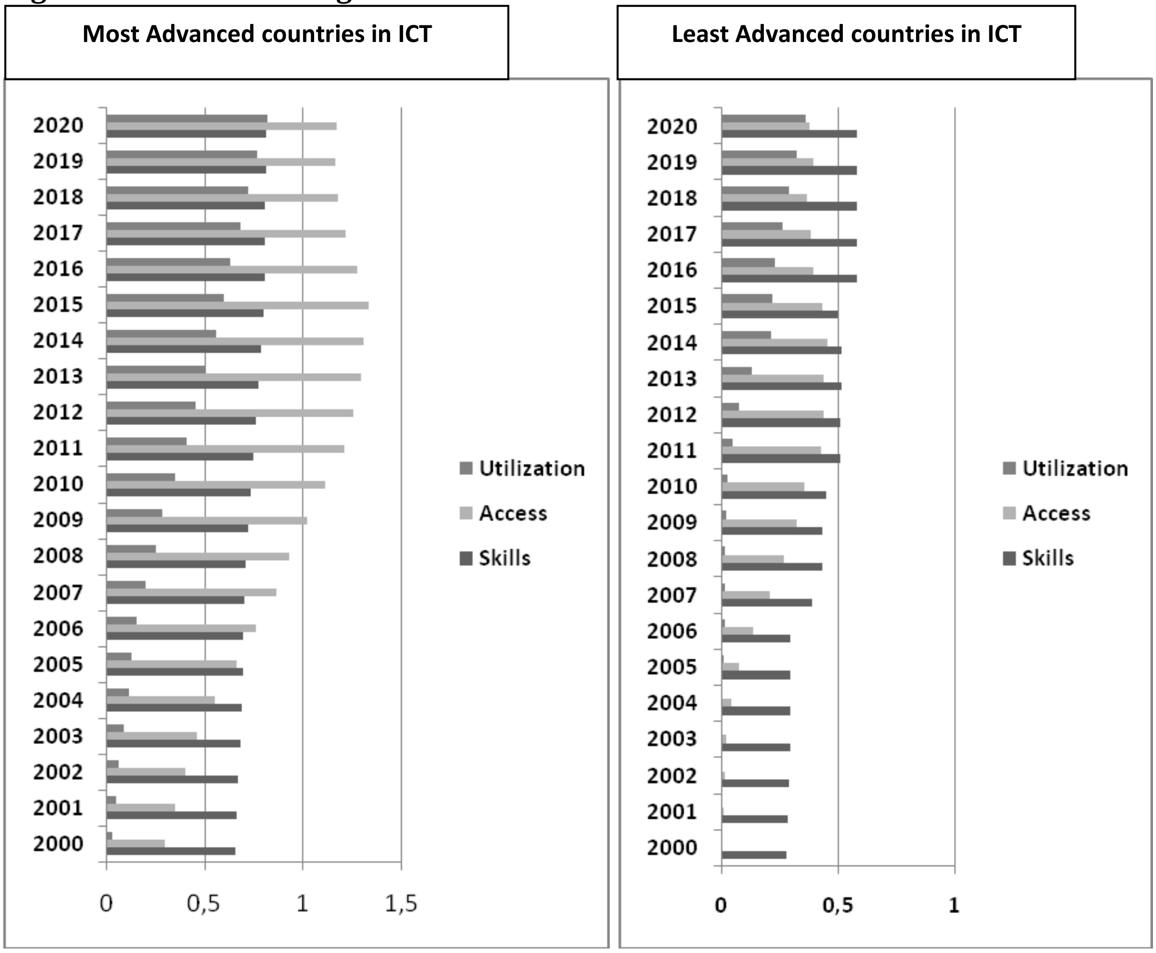


As for the year-over-year ranking of ICT indicators, Figure 3 shows that ICT continues to grow in the countries surveyed, enabling more and more people to be connected. The development of these three sub-indices (access, use and skills) can be seen that ICT in these countries is constantly developing. In fact, the Idi index rose by an average of 5.42% throughout the period.

The use sub-index increased by 22.61%, while the access sub-index increased by 9.85%. This trend is partly due to lower baseline values in African countries, but also reflects the rapid adoption of ICT services such as the Internet and mobile. In fact, the most dynamic countries in the ranking (those with faster-than-average growth in Idi score or rank) are mostly high-income countries.

Another explanation is that the skills sub-indices are already high in most countries, while the access and use sub-indices remain significantly lower, and many countries continue to make progress in the use of ICTs.

Figure 3: Growth of the global ICT sector

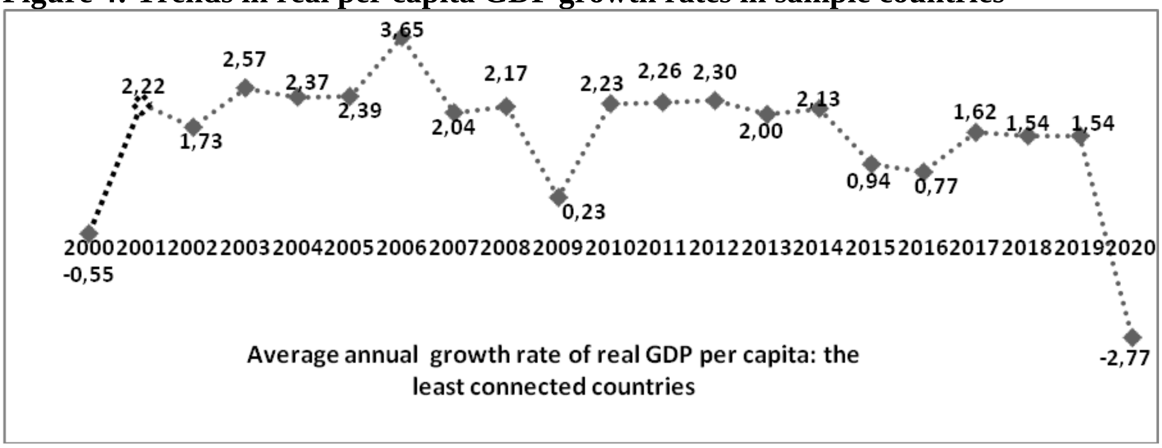


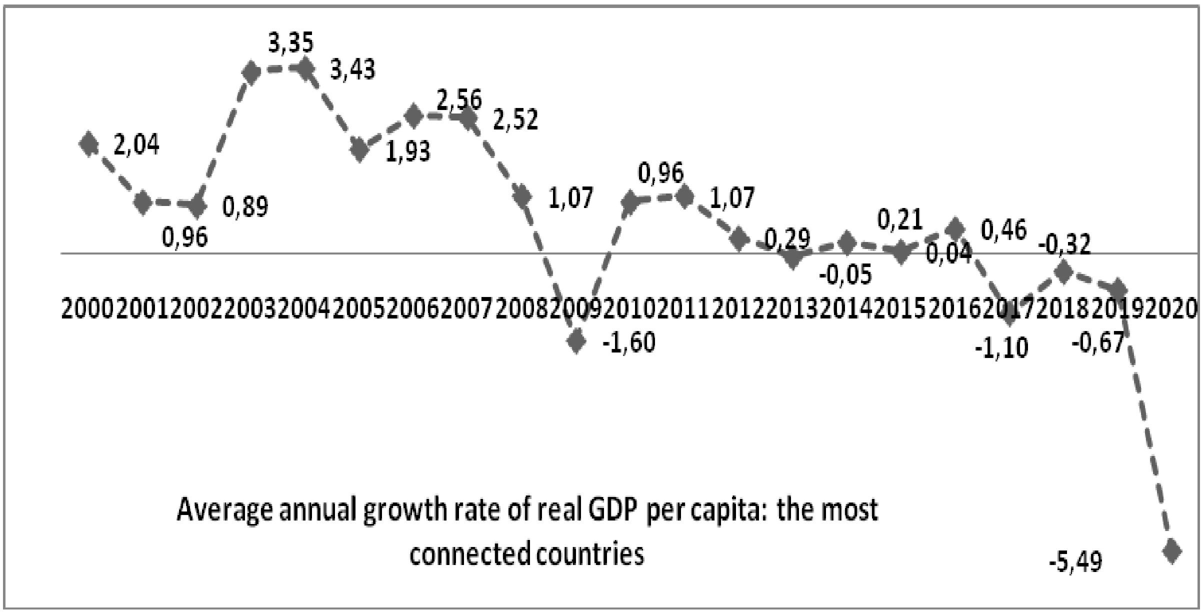
Overall, we can see that as the ICT access index grows, so does the ICT use index.

- **GDP growth rate per capita**

Figure 4 shows that growth rates have followed a sawtooth curve, while remaining low and sometimes even negative. The evolution of real GDP growth rates in the countries in the sample is unstable and fluctuating, and trends cannot be described in most cases. On average, in African countries, the rate went from 1.6% in 2000 to -1.96% in 2009, to 2.34% in 2011, then to -3.02% in 2020. Growth rates in MENA countries are lower than in some African countries.

Figure 4: Trends in real per capita GDP growth rates in sample countries





3.4 Descriptive analysis of model variables

Our data analysis led us to identify two groups of countries: the most ICT advanced and the least advanced. Once identified, we provide descriptive statistics for the two groups of countries. The results of these analyzes are summarized in Appendix Table A5, from which some lessons can also be drawn. First, each plan contains at least 45% of the total number of observations.

This means that statistical and econometric inferences are applicable, as the data provide conclusive tests and fairly consistent estimates for each plan. Second, without going into details, the two regimes differ fundamentally with respect to macroeconomic variables such as inflation, domestic credit to the private sector as a percentage of GDP, general government final consumption expenditure as a percentage of GDP and the opening rate. Finally, the average growth rate of both regimes is not relatively stable. The slowdown has been particularly pronounced in countries in the Middle East and North Africa, whose major economies are more integrated into world markets than most other African countries. African oil exporters have maintained growth despite falling oil prices, thanks to previously unearthed resources.

Before performing the econometric analysis, we tested the stationarity of the series using the Im, Pesaran, and Shin (IPS) (2003) test and the Levin, Lin, and Chu (LLC) (2002) test. The IPS and LLC tests provide two main results (see Appendix Table A6). According to the first result, the variables GDP growth rate, inflation and trade openness are stationary in level. In fact, the test value was 1% higher than the critical value. The second outcome, in regards to the other factors of credit and trade openness, indicates that they are not at a constant level. It is important to note that when it comes to trade openness, the two tests yield distinct findings. We retain the result of the IPS test because it corrects for the autoregressive root homogeneity suffered by the LLC test.

After analyzing these results, we carry out statistical and econometric tests on our data. The results of the econometric estimations are presented in the next section.

4. RESULTS

The following section outlines the findings from the estimation of the correlation between ICT development and economic growth. Initially, we examine the presence of non-linear relationships by utilizing the ICT development index as the transitional variable and determining the number of regimes. Subsequently, we present the outcomes of estimating the PSTR model through the employment of nonlinear least squares (NLS). Lastly, we verify the robustness of the previous findings by re-estimating a non-linear growth equation in relation to ICT development using the dynamic panel Generalized Method of Moments (GMM) (Arellano and Bond, 1991, Arellano and Bover, 1995 and Blundell and Bond, 1997).

4.1 The results of the PSTR model and empirical examination using a non –linear least squares (NLS)

Table 1 reports the results for the various estimates. To begin, the first step entails examining linearity through the utilization of the PSTR model, whereby the transition variable is the ICT development index. The outcomes of this linearity evaluation are determined by employing the Fisher statistic and the findings are subsequently presented in row 1 in table 1. This specific table demonstrates that the linearity examination unequivocally results in the rejection of the null hypothesis pertaining to the model's linearity in relation to a PSTR specification. Moreover, the LMF test, when applied, also leads to the rejection of the null hypothesis at the critical threshold of 5%.

As a result, this outcome substantiates the non-linear nature of the correlation between economic growth and the ICT development index within the countries included in the study. Since we know that the linearity assumption is rejected, the second step is to determine the optimal number of transfer functions needed to capture all nonlinearities. Tests to ascertain the absence of residual nonlinearity led to the identification of the number of states. The results of these tests are shown in row 2 in Table 1. The null hypothesis (H0) is accepted for a critical threshold of 5%. Thus, there is a single transitional function and two ICT development regimes. This result reflects the idea that the non-linear relationship between ICT development and economic growth.

In the third step, we estimate the parameter γ for both groups of countries. Row 3 in Table 1 shows that the γ parameter is around 2.87 for the least ICT-advanced countries and around 4.55 for the most ICT-advanced countries. The higher γ for the most advanced countries in ICT means a faster speed of transition between regimes.

In the last step, we refer to Gonzalez et al (2005) and use nonlinear least squares (NLS) to estimate the location parameter C. It should be noted that in PSTR models, the slope coefficients do not have a direct interpretation. However, the signs of the slope coefficients ($\beta1$) do provide insight into the relationship between the explanatory variable and the explained variable in relation to the transition variable.

If the sign of ($\beta2$) is positive, it signifies that as the transition variable increases, the corresponding slope coefficients also increase. By utilizing the estimations from the PSTR model, we are able to derive the impact of ICT development on economic growth. The influence of the ICT development variable for a given country i at a specific time t is determined by taking the weighted average of the parameters ß1 and ß2, which are acquired from the extreme regimes.

Row 4 in Table 1 presents the following findings. First, the estimated transition parameters C reveal the midpoint between two regimes, which are 3.88 and 2.1 respectively for the most ICT-advanced and least ICT-advanced countries. In addition, the coefficient of the Idi shows different signs in the two regimes. Second, column 1 in row 4 reports the non-linear analysis for the most ICT-advanced. The ICT development index (Idi) coefficient in the first regime is positive and significant at the 1% level, while it is negative and significant at the 1% level in the second regime.

Based on the equation (3), the sensitivity varies between 0.021 and 0.806 for the countries that are most interconnected. Interestingly, for this particular group, once a certain threshold (3.88) is surpassed, the advantages gained from investments in ICT development diminish as the country progresses further. Figure 5 shows the sensitivity of growth to ICT diffusion as a function of the level of ICT development.

For high levels of ICT development, the sensitivity of economic growth to ICT development is relatively low. From a certain threshold, which we can place at around 3.88, for the Idi variable, the PSTR model highlights a change in slope in the relationship between development and economic growth. From this threshold onwards, the sensitivity of growth begins to decline, before dropping off considerably

In terms of control variables, the coefficients of credit granted to the private sector and the inflation rate have a negative but insignificant impact on economic growth. Conversely, trade openness has a positive and significant impact. The coefficient associated with the variable general government final consumption expenditure is negative and significant. According to Scully's research in 1989, it is demonstrated that the detrimental impact of heightened public expenditure on economic growth can be attributed to a decline in efficiency within the public sector.

Third**,** the estimation results for the least ICT-advanced countries are presented in column 2 in row 4. The estimated ICT coefficient in the first regime (below the 2.1 threshold) is significantly negative at the 1% level, while it becomes positive and significant at the 1% level in the second regime (above the 2.1 threshold).

The range of sensitivity is between -1.67 and -0.54. Initially, the impact of ICT development on this group is negative, but it gradually becomes less negative over time. While the ICT development index appears to have a negative effect, this effect lessens as the country invests more in ICT. Figure 5 shows that the change from low ICT regime to high ICT regime is relatively gradual. The estimated threshold value of 2.1 points to the half-way of the transition

The observed patterns of control variables are not always consistent with expectations formulated by theory. One notable consistency is the negative correlation between the inflation rate and economic growth. The coefficient on credit to the private sector is negative but not statistically significant. On the other hand, the opening rate and general government final consumption expenditure have a positive and significant effect on economic growth.

Table 1 Estimation of the two-regime PSTR model

	Non-linearity test of the PSTR mode				
	H0: Linear model **Ha: PSTR model with at least one threshold variable**				
	The most advanced countries in ICT				
Fisher LM test	**4.25** **P-value=0,039**				
	The least advanced countries in ICT				
	4.52 **P-value=0,033**				
	Threshold effect test				
	Fstat	**P-value**	**10%**	**5%**	**1%**
	The most advanced countries in ICT				
Single threshold model	**19.49*** **	**0,03**	**13.34**	**16.46**	**20.64**
Double threshold model	**3.2**	**0.68**	**12.34**	**13.96**	**17.78**
	The least advanced countries in ICT				
Single threshold model	**18.26** **	**0.05**	**16.2198**	**17.8431**	**26.9486**
Double threshold model	**7.79**	**0.62**	**17.5936**	**18.8581**	**23.2099**

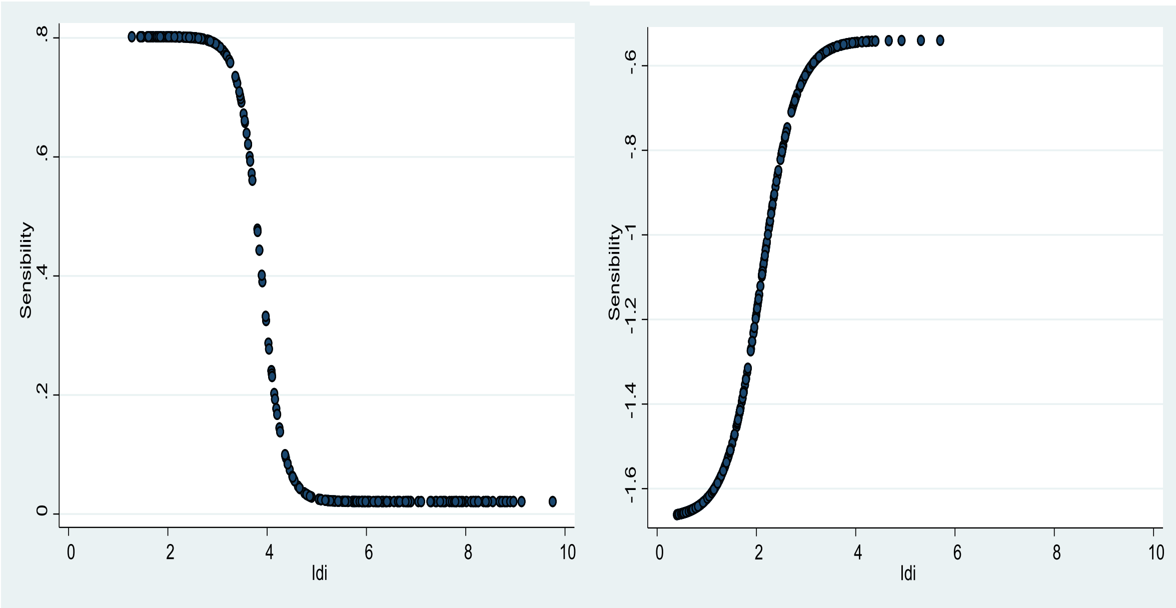
Estimated threshold values		
	Estimated values	**Confidence interval 95%**
The most advanced countries in ICT	**4.55**	[4.36 4.61]
The least advanced countries in ICT	**2.87**	[2.76 2.89]

Non –linear least squares (NLS)		
	The most advanced countries in ICT (1)	**The least advanced countries in ICT (2)**
Variable explained	**Economic growth**	**Economic growth**
First regime: ß1	**0.802*** **	**-1,67*** **
Second regime: ß2	**-0.781*** **	**1,13*** **
Slope : γ	**4.55**	**2,87**
Location Parameters : C	**3.88*** **	**2,1*** **
Inflation	**-0.004**	**-0,038*** **
Trade	**0.032*** **	**0,043*** **

Government	**-0.125****	**0,104***
Credit	**-0.02**	**-0,033**
Number of observations	**208**	**323**
Number of groups	**13**	**17**

Note: The level of significance is given by * (1%), ** (5%) and *(10%).**
The sign of β1 materializes the orientation of the sensitivity of the variables in a low Idi regime. The sign of β2 materializes the orientation of variable sensitivity in a high Idi regime.
Source: Author's calculations, extracted from STATA 15

Figure 5: Sensitivity of growth to the ICT development index
Most advanced countries in ICT **Least advanced countries in ICT**



Estimated transition function in Eq. (2) of the PSTR model in Eq. (1)

Overall, these results underline the importance of ICT development for economic growth, although their impact on economic growth depends on the level of ICT development.

Our empirical results add another dimension to the non-linear relationship between ICT development and economic growth, insofar as the impact of ICT development is also non-linear in terms of magnitude. The marginal effect of the ICT development index is weaker the higher the level of ICT development. Thus, beyond a threshold, the impact of ICT on economic growth should be greater in countries with a lower level of ICT development.

In short, our empirical results seem to support the thesis that the relationship between ICT development and economic growth is nonlinear. This study is in line with others, in particular, as already mentioned, that of Jean C. Kouam et al (2022), who found that there is a threshold of access to electricity beyond which the impact of ICT (fixed broadband) on economic growth becomes significant.

As a robustness check, in what follows we use another estimation method with the same variables as mentioned above.

4.2 Robustness tests

To ensure the reliability of previous results, we re-evaluate a non-linear growth equation, which is specifically modeled with respect to ICT development, using the Generalized Method of Moments (GMM) for dynamic panels.

This GMM approach, introduced by Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1997), offers several advantages. Notably, it effectively addresses the issue of endogeneity bias that may arise from ICT development indicators and other control variables. However, it is important to note that this methodology does not yield a smooth transition.

The regression equation then takes the following form:

$$y_{it} = \alpha_i + \beta_1 Idi_{it} + \beta_2 Idi_{it}^2 + \beta_3 X_{it} + \mu_{it} \qquad (7)$$

μ_{it} et X_{it} respectively represent the error term, the other variables being defined above.

Equation (7) contains the quadratic variable Idi, which accounts for the nonlinearity in the growth equation. The standard also allows the marginal impact of the ICT sector on growth to depend on the level of ICT development. The detection method is based on the use of lagged variables. If the ICT development variable is considered endogenous, we use the lagged values of the second period as a tool, while taking into account other variables assumed to be weakly exogenous (in the sense of Arellano and Bond, 1991).

The expression of ICT development growth rate is:

$$\frac{\partial y_{it}}{\partial Idi_{it}} = \beta_1 + 2\beta_2 Idi_{it} = 0 \Rightarrow Idi^* = -\frac{\beta_1}{2\beta_2}$$

The marginal effect of ICT development on growth is linear in the quadratic model, reflecting information loss compared to the PSTR model, where elasticity is a nonlinear function of ICT development.

In Table 2, the estimated GMM results confirm those obtained from the PSTR model, particularly with regard to the sign of the variable of interest, which is the ICT development index, in the least connected countries and the most advanced ICT countries. The GMM specification also reveals a threshold equal to $\frac{\beta_1}{-2\beta_2} = 8.51$ for the most connected countries and $\frac{\beta_1}{-2\beta_2} = 3.49$ for the least connected countries.

For both groups of countries, the adjustment parameter associated with the lag of the dependent variable is positive and significant.

The coefficient of the ICT index shows different signs in the two groups. The Sargan J test was used to examine the over-identification of limitations in a statistical model. Based on the test results, the p-value = 0.221 and 0.993, indicating that the null hypothesis cannot be rejected and that the instruments are valid. The reliability of dynamic estimation according to Arrellano-Bover/Blundell-Bond (Sargan 1958) and (Kitamura 2006) is not called into question.

As we have just explained, the estimates concerned the most advanced ICT countries (first group) and the least advanced ICT countries (second group).

For the first group, the coefficient of the Idi is positive and significant at the 1% level, while the coefficient on the quadratic term, Idi^2, is negative and significant, indicating a bell-shaped relationship between ICT development and economic growth. This result shows that the relationship between ICT development and economic growth follows an inverted U shape, suggesting the existence of a threshold above which the impact of ICT diffusion on economic growth could vary. When the value of ICT is below this threshold, economic growth is positively affected by ICT development. However, the negative impact of ICT diffusion on growth can be seen if the value of ICT is above this threshold.

Indeed, this result is in line with the study by Ishnazarov-Akram et al. (2021), which found non-linear effects of ICT on economic growth. Using data for over 170 countries over the period 1990-2019, the authors showed that all three variables (Internet users, cell phone users and number of secure servers) have a non-linear (inverted U-shaped) relationship with economic growth. For example, the inflection point for the Internet is estimated at 30%. This means that Internet penetration has a positive effect on economic growth until the share of the population using the Internet reaches 30%. Once Internet penetration exceeds this threshold, ICT development hampers economic growth.

In terms of control variables, the coefficients of trade openness and government spending have a significant positive impact on economic growth. Conversely, the inflation rate and credit extended to the private sector have a negative but non-significant impact on economic growth.

As for the second group, the GMM estimation shows that the sign of the coefficient of the Idi is negative and significant at the 1% level, while the coefficient on the quadratic term, Idi^2, is positive and significant, reflecting the existence of a U-shaped relationship between the ICT development index and economic growth.

The digital progress in African countries is falling behind, as indicated by the thresholds, despite their efforts to invest in information and communication technology (ICT). These findings corroborate those of Banga and Velde (2018), Melia (2020) and Yoon (2020) that digital skills shortages and ICT infrastructure deficits are a barrier to the appropriation of digital technologies.

While in the most ICT-advanced countries, Idi has a positive impact on economic growth, but this effect diminishes as Idi increases, in the least ICT-advanced countries, Idi has a negative impact on economic growth, but this effect becomes positive as Idi increases.

When we analyze the control variables, we find that the impacts of the variables, credit to the private sector and public spending, on economic growth are significantly positive at the 1% level, with the exception of the non-significant opening rate variable. Inflation has a significant negative impact on economic growth in less advanced countries.

Table 2 GMM regression results

Variable explained Economic growth	**(1) The most advanced countries in ICT**	**(2) The least advanced countries in ICT**
Economic growth(-1)	**0.172*** **	**0.198*** **
Idi	**1.608*** **	**-3.32*** **
Idi2	**-0.094***	**0.475*** **
Inflation	**-0.061**	**-0.119*** **
Credit(-1)	**-0,027**	**0,113*** **
Trade	**0.048*** **	**0,016**
Government (-1)	**0.221*** **	**0,153*** **
Dummy year 10	**--------**	**0.834**
Dummy year 20	**-------**	**-4.201*** **
Time	**-0.376*** **	**--------**
Constante	**-6.859*** **	**1.888***
Sargan P-value	**0.221**	**0.993**
Test of linearity P-value	**0.0345**	**0.000**
Number of instruments	**227**	**278**
Number of observations	**247**	**323**
Number of groups	**13**	**17**
Optimal level of Idi	**8.51**	**3.49**

Note: The level of significance is given by * (1%), ** (5%) and *(10%).**
In columns 1 and 2, all variables are considered as instruments).

The Sargan statistic tests the null hypothesis of non-correlation between instruments and residuals.

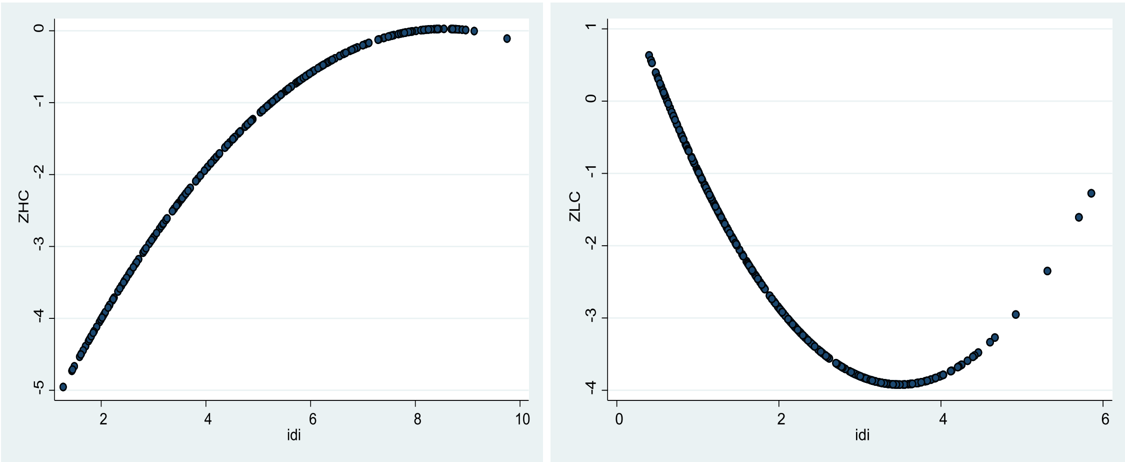
Test of linearity : testnl _b[idi] = _b[idi2]
chi2(1) =19.15 Prob > chi2 =0.000
chi2(1) =4.47 Prob > chi2 =0.0345

According to figure 6, for the most advanced ICT countries, we can observe that initially, when the Idi is low and the curve follows an upward trajectory, an increase in the Idi increases economic growth. However, once the threshold beyond which the curve begins a downward trajectory has been passed, an increase in the Idi leads to a reduction in economic growth. In the least developed countries, we observe the opposite effect. The Idi has a non-linear (U-shaped) relationship with economic growth. For example, the inflection point for the Idi is 3.4. This means that ICT penetration has a negative effect on economic growth until this index reaches 3.4. Once ICT diffusion exceeds this threshold, ICT development promotes economic growth.

ICT-advanced countries generally have higher rates of economic growth due to increased productivity, innovation and global trade. These countries invest heavily in education, research and development, which fosters the emergence of a skilled workforce and technological advances. Advanced ICT infrastructures, including high-speed internet and modern telecommunications networks, support a range of economic activities. The presence of leading companies in these countries on world markets has contributed to significant economic gains.

Figure 6: Relationship between ICT development and economic growth

Most advanced countries in ICT **Least advanced countries in ICT**



Overall, our results confirm the existence of a leapfrog effect. As pointed out by Ishnazarov Akram et al (2021), countries with an underdeveloped ICT infrastructure can benefit more from the development of ICT. The relationship between ICT development and economic growth is clear, with ICT-advanced countries enjoying significant economic benefits. Conversely, countries with underdeveloped ICT sectors face challenges that limit their economic potential. In order to address these disparities, investment in infrastructure, education and ensuring political stability are needed to fully exploit the benefits of ICT for economic growth.

CONCLUSION AND POLICY IMPLICATIONS

This study examines the non-linear impact of ICT diffusion on the economic growth of 30 MENA and African countries during the period 2000-2020 using PSTR and GMM methods. We also compared the differences between the effects of different levels of ICT development. The chosen approach differs from the extensive empirical and theoretical literature according to which the relationship between economic growth and ICT development is linear. The main results are as follows.

First, there is strong evidence that the PSTR model captures a non-linear, smooth effect of ICT diffusion on economic growth. The linearity test clarifies the non-linear relationship between ICT development and economic growth in the sample countries, and confirms the optimal threshold of the ICT development index, which is around 2.1 for the least connected countries and around 3.88 for the most advanced countries in ICT. These thresholds largely explain economic growth. Second, if we compare the differential impact of ICT on economic growth between the group of most ICT advanced countries and the group of least ICT advanced countries, we find differences between these two groups of countries. In the most advanced ICT countries, the effect of ICT penetration on economic growth is positive at the lowest levels of penetration but negative at the highest levels, while in the least ICT-developed countries, the effect moves from negative to positive. Third, this empirical knowledge exhibits a second form of nonlinearity in the magnitude of the impact of ICT on economic growth, as the positive effects associated with high levels of ICT development become increasingly irrelevant. We provide evidence for the "leapfrog effect" of ICT on economic growth. Countries with laggards in ICT development can benefit greatly from digitization. Fourth, and finally, the GMM results confirm a non-linear relationship between ICT use and economic growth. In the least developed ICT countries, the ICT endowment must meet a certain threshold to use ICT for economic growth. In contrast, in the most ICT-advanced countries, above a certain ICT endowment threshold, ICT use can negatively affect economic growth.

According to our empirical findings, if policymakers aim to improve economic growth, they can improve ICT access, promote ICT use, and improve ICT-related skills, which will help promote ICT adoption in both countries. However, as ICT growth reaches a higher stage, policymakers need to carefully manage and control the negative impact of ICT on economic growth to avoid various risks associated with additional spending

REFERENCES

[1] Aghaei, M., & Rezagholizadeh, M. (2017). The impact of information and communication technology (ICT) on economic growth in the OIC Countries. Economic and Environmental Studies, 17(2 (42)), 257-278

[2] Akobeng, E (2016), Gross Capital Formation, Institutions and Poverty in Sub-Saharan Africa', Journal of Economic Policy Reform, in press.

[3] Albiman, M. M., & Sulong, Z. (2017). The linear and non-linear impacts of ICT on economic growth, of disaggregate income groups within SSA region. Telecommunications Policy 2017, 1-18

[4] Albiman, Masoud Mohammed, Zunaidah Sulong, (2016). The role of ICT use to the economic growth in Sub Saharan African region (SSA). Journal of Science and Technology Policy Management 7: 306–29.

[5] Andrianaivo, M. & Kpodar, K. (2011). ICT, financial inclusion, and growth evidence from african countries. IMF Working Papers, 11(73), 1. http://dx.doi.org/10.5089/ 9781455227068.001

[6] Antonia López-Villavicencio and Valérie Mignon (2011). On the impact of inflation on output growth: Does the level of inflation matter? Journal of Macroeconomics Volume 33, Issue 3, September 2011, Pages 455-464

[7] Anyanwu, J. C. (2014), Factors Affecting Economic Growth in Africa: Are There any Lessons from China? African Development Review, Vol. 26, pp. 468–93.

[8] Arellano, M. and Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence with an application for employment equation, Review of Economic Studies, Vol. 58 No. 2, pp. 277-297.

[9] Arellano, M. and Bover, O. (1995). Another look at the instrumental variables estimation of errorcomponents models, Journal of Econometrics, Vol. 68, pp. 29-51.

[10] Asongu,S.A.,Anyanwu,J.C. and Tchamyou,V.S.(2019), Technology driven information sharing and conditional financial development in Africa, Information Technology for Development,Vol.25No.4, pp.630-659

[11] Barro, R. (1991), Economic growth in a cross section of countries, Quarterly Journal of Economics, Vol. 106 No. 2, pp. 407-433.

[12] Barro, R. and Sala-i-Martin, X. (1992), Convergence, Journal of Political Economy, Vol. 100 No. 2, pp. 223-251

[13] Ben Youssef A., M'henni H., (2004), Les effets des technologies de l'information et de la communication sur la croissance économique : le cas de la Tunisie', Région et Développement, n° 19, pp. 131-150.

[14] Bloom, Nicholas, Raffaella Sadun, and John Van Reenen. (2012). Americans do I.T. better: US multinationals and the productivity miracle, forth coming American Economic Review.
[15] Blundell, R. and Bond, S. (1998), Initial conditions and moment restrictions in dynamic panel data models, Journal of Econometrics, Vol. 87, pp. 115-143.
[16] Cardona M., Kretschmer T., Strobel T. ICT and productivity: conclusions from the empirical literature. Information Economics and Policy, 25 (3), 109, 2013.
[17] Chavula, H.K. (2013), Telecommunications development and economic growth in Africa, Information Technology for Development, Vol. 19 No. 1, pp. 5-23.
[18] Cioaca, S.I., Cristache, S.E., Vuta, M., Marin, E., & Vuta, M. (2020). Assessing the impact of ICT sector on sustainable development in the European Union: an empirical analysis using panel data. Sustainability, 12(2), 592, 1-16. doi: https://doi.org/10.3390/su12020592
[20] Colecchia, A., & Schreyer, P. (2002). ICT Investment and Economic Growth In the 1990s: Is the United States a Unique Case?: A Comparative Study of Nine OECD Countries, Review of Economic Dynamics, 5, 408-442.
[21] Colletaz, G., & Hurlin, C. (2006). Threshold effects of the public capital productivity: An international panel smooth transition approach. Document de Recherche du Laboratoire d'Economie d'Orléans, 2006-1
[22] Dedrick, J., Kraemer, K.L. and Shih, E. (2013), Information technology and productivity in developed and developing countries, Journal of Management Information Systems, Vol. 30 No. 1, pp. 97-122.
[23] Dewan, S. and Kraemer, K.L. (2000). Information technology and productivity: evidence from country-level data, Management Science, Vol. 46 No. 4, pp. 548-562.
[24] Dimelis, S.P. and Papaioannou, S.K. (2010), FDI and ICT effects on productivity growth: a comparative analysis of developing and developed countries, European Journal of Development Research, Vol. 22 No. 1, pp. 79-96.
[25] Duncombe, R. A. (2006) Using the Livelihoods Framework to Analyse ICT Applications for Poverty Reduction through Microenterprise, Information Technologies and International Development 3(3): 81–100.
[26] Durham, J. B. (2004). Economic growth and institutions: Some sensitivity analyses, 1961- 2000. International Organization, 58(3), pp. 485-529.
[27] Emara,N.and Katz,R.L.(2022). The economic impact of telecommunications in Egypt,SSRN Working Paper, available.
https://papers.ssrn.com/sol3/papers.cfm?abstract_id54055699 (accessed 12 may 2022).
[28] Fernandez-Portillo A, Almodovar-Gonzalez M, Hernandez-Mogollon R (2020) Impact of ICT development on economic growth. A study of OECD European union countries. Technol Soc 63:101420. https://doi.org/10.1016/j.techsoc.2020.101420
[29] Fouquau, J., Hurlin, C., & Rabaud, I. (2008). The Feldstein–Horioka puzzle: A panel smooth transition regression approach. Economic Modelling, 25, 284–299.
[30] Gerschenkron, A., (1962), Economic Backwardness in Historical Perspective, Harvard University Press.
[31] Gomez-Barroso, J. L., & Marban-Flores, R. (2020b). Telecommunications and economic development–The 21st century: Making the evidence stronger. Télécommunications Policy, 44(2), Article 101905.
[32] Gonzalez A., Teräsvirta T. et Dick V. D. (2005). Panel smooth transmission regression models, Working Paper Series in Economics and Finance : Stockholm School of Economics.
[33] Granger, C. W. J., and T. Teräsvirta (1993). Modeling Nonlinear Economic Relationships. Oxford : Oxford University Press.

[34] Gruber, H., & Koutroumpis, P. (2011). Mobile telecommunications and the impact on economic development. Economic Policy, 26(67), 387–426. Hamit-Haggar, M. (2012).
[35] Gupta, S., Clements, B., Baldacci, E., Mulas-Granados, C. (2005). "Fiscal Policy, Expenditure Consumption and Growth in Low-income Countries", Journal of International Money and Finance, 24 (3), p. 441-463.
[36] Hansen B. E. (1999): "Threshold effects in non-dynamic panels: estimation, testing, and inference », Journal of Econometrics 93 (2), pp. 345-368.
[37] Hawash, R., & Lang, G. (2010). The impact of information technology on productivity in developing countries. Faculty of Management Technology Working paper no. 19. Cairo, Egypt: German University of Cairo.
[38] Im K.S., M.H. Pesaran & Y. Shin (2003). Testing for unit roots in heterogeneous panels, Journal of Econometrics, 115, pp.53-74.
[39] Ishnazarov Akram, Nargiza Kasimova, Shakhnoza Tosheva, and Arletta Isaeva. (2021). ICT and economic growth: evidence from cross country growth modeling. In The 5th International Conference on Future Networks amp Distributed Systems (ICFNDS 2021), December 15, 16, 2021, Dubai, United Arab Emirates. ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3508072.3508204
[40] Jean C. Kouam Nkafu , Simplice Asongu (2022). "The non-linear effects of fixed broadband on economic growth in Africa » Journal of Economic Studies 0144-3585 DOI 10.1108/JES-03-2022-0159
[41] Katz, M. and K. Shapiro (1986). Technology adoption in the presence of network externalities, Journal of Political Economy, 94(4), 822–41.
[42] Kremer, Stephanie, Alexander Bick and Dieter Nautz (2013). Inflation and growth: new evidence from a dynamic panel threshold analysis, Empirical Economics, 44(2), pp.861-878. http://dx.doi.org/10.1007/s00181-012-0553-9
[43] Lal, Kaushalesh. 2000. Adoption of information technology and its consequences in a development context. Unpublished Ph.D. Thesis. Rotterdam.
[44] Liao H., Wang B., Li B., Weyman-Jones T. (2016) ICT as a general-purpose technology: The productivity of ICT in the United States revisited. Information Economics and Policy, 36, 10, 2016
[45] Mondjeli, M. N. (2015). Too Much Public Expenditures, Less Economic Growth? Economics Bulletin, 35 (3), p. 1985-1991.
[46] Mwakatumbula, H. J., Moshi, G. C., & Mitomo, H. (2019). Consumer protection in the telecommunication sector: A comparative institutional analysis of five African countries. Telecommunications Policy, 43(7), 101808. https://doi.org/10.1016/j.telpol.2019.02.002
[47] Oulton N (2002) ICT and productivity growth in the UK. Oxford Review of Economic Policy 18 (3) 363–379. [Google Scholar]
[48] Qureshi, S. (2005) How Does Information Technology effect development? Integrating Theory and practice into a Process Model, Proceedings of the Eleventh Americas Conference on Information Systems, Omaha, NE, USA.
[49] Sassi, S., Goaied, M., (2013). Financial development, ICT diffusion and economic growth: lessons from MENA region. Telecommunication Policy 37 (4-5), 252–261
[50] SCULLY G. W. (1989). The size of the state, economic growth and the efficient utilization of national resources. Public Choice, 63, 1989, pp 149-164.
[51] Stanley,T.D.,Doucouliagos,H.,&Steel,P.(2018). Does ICT generate economic growth? Ameta- regression analysis. Journal of Economic Surveys, 32(3), 705-726.
[52] Timmer MP, van Ark B (2005) Does Information and Communication Technology Drive Productivity Growth Differentials? A Comparison of the European Union Countries And The United States. Oxford Economic Papers 57 (4) 693–716. [Google Scholar]

[53] Toader E, Firtescu BN, Roman A, Anton SG (2018) Impact of information and communication technology infrastructure on economic growth: an empirical assessment for the EU countries. Sustainability (basel) 10(10):3750. https://doi.org/10.3390/su10103750
[54] Vu, K. M. (2011). ICT as a source of economic growth in the information age: Empirical evidence from the 1996–2005 periods. Telecommunications Policy, 35(4), 357–372
[55] Vu, K., (2019). The internet-growth link: An examination of studies with conflicting results and new evidence on the network effect, Telecommunications Policy, 43(5), pp. 474-483.
[56] W. Edward STEINMUELLER (2001). ICTs and the possibilities for leapfrogging by developing countries. International Labour Review, Vol. 140 (2001), No. 2
[57] Wemboye, E., Tochkov, K., & Sergi, B. S. (2015). Technology adoption and growth in sub-saharan african countries. Comparative Economic Studies, 57(1), 136–167. http://dx.doi.org/10.1057/ces.2014.38
[58] World Bank (2016). World Development Indicators. Washington, DC: World Bank. [Online] Available: http://data.worldbank.org/products/wdi. (December 17th, 2017).
[59] World Bank. (2020). World Development Indicators. WDI. data.worldbank.org/country/ Sub Saharan Africa
[60] Zuhdi, U., Mori, S. and Kamegai, K. (2012), Analyzing the role of ICT sector to the national economic structural changes by decomposition analysis: the case of Indonesia and Japan, Procedia – Social and Behavioral Sciences, Vol. 65, pp. 749-754, doi: 10.1016/ j.sbspro.2012.11.194

Appendix A

Table A1 - Methodology for calculating the ICT Development

The Idi index is divided into three sub-indices - access, utilization and skills - each of which reflects a different aspect and component of the ICT development process. ICT skills indicators include primary, secondary and tertiary gross enrollment ratios. ICT accessibility indicators include fixed telephone subscriptions per 100 inhabitants and mobile telephone subscriptions per 100 inhabitants. ICT use indicators include the percentage of people using the Internet

The ICT Development Index (Idi) proposed in this work serves the same purpose as the Idi calculated by the ITU to assess countries' level of ICT development.

The Idi comprises three components: ICT infrastructure, ICT usage and ICT skills. The reference value for fixed telephony (mobile telephony) is 60% (120%).

A. Access

1- **Fixed-telephone subscriptions per 100 inhabitants**: X1

2- **Mobile-cellular telephone subscriptions per 100 inhabitants**: X2

Access Index = (((X1/60)*0,5)+((X2/120)*0,5))/100

B. Utilization

Pourcentage de personnes utilisant Internet : Y

Utilization index= Y/100

C. Skills

1 - Gross primary school enrolment rate: L1

2 - Gross secondary school enrolment rate: L2

3 - Gross tertiary school enrolment rate: L3

Skills index = (L1+L2+L3)/(100*3)

Idi=(0,4*Access+0,4*Utilization+0,2*Skills)*10

Source: ITU.

Table A2- Indicators included in the IDI

1. Fixed-telephone subscriptions per 100 inhabitants
2- Mobile-cellular telephone subscriptions per 100 inhabitants
3- International Internet bandwith (bit/s) per internet user
4- Percentage of households with a computer
5- Percentage of households with Internet access
6 - Percentage of Individuals using the Internet
7 - Fixed-broadband subscriptions per 100 inhabitants
8 - Active mobile-broadband subscriptions per 100 inhabitants
9 - . Adult literacy rate
10 - Secondary gross enrolment ratio
11 - Tertiary gross enrolment ratio

Table A3- List of countries

South Africa, Angola, Benin, Burkina Faso, Burundi, Cameroon, Estwani, Gabon, Ghana, Guinea, Nigeria Kenya, Madagascar, Mali, Mauritania, Mozambique, Senegal, Togo, Uganda.
Algeria, Egypt, Jordan, Morocco, Tunisia.
Saudi Arabia, Bahrain, Iran, Oman, Kuwait, Qatar.

Table A4: Data definitions

Variables	Indicators	Source
Economic Growth	GDP per capita growth rate, economic growth indicator	WDI(2021)
Credit	Domestic credit to the private sector as a percentage of GDP, an indicator of financial development	WDI(2021)
Trade	Trade openness is derived via the sum of exports and imports as % GDP	WDI (2021)
Inflation	Inflation rate measured by the consumer price index	WDI(2021)
Government	General government final consumption expenditure (% of GDP).	WDI(2021)
ICT variables	Fixed-telephone: Fixed-telephone subscriptions per 100 inhabitants Mobile : Mobile-cellular telephone subscriptions per 100 inhabitants Internet : Internet users per 100 people	UIT(2021)
Skills	Gross enrolment ratio in primary, secondary and tertiary education	WDI(2021)

Table A5 - Descriptive statistics

	The least advanced countries in ICT				
	Obs	Mean	Std. Dev.	Min	Max
Economic Growth	357	1.597058	3.23312	-15.0422	14.9979
Idi	357	2.114543	1.134942	0.39825	5.85527
Trade	357	63.52419	26.61056	20.7225	175.798
Credit	357	16.00434	7.23366	1.96654	40.0559
Inflation	357	9.213674	21.09795	-3.23339	324.997
Government	357	14.12449	4.821985	0.951747	31.3443
	The most advanced countries in ICT				
	Obs	Mean	Std. Dev.	Min	Max
Economic Growth	273	3.528685	-12.5121	15.9889	15.9889
Idi	273	2.115688	1.27389	9.75186	9.75186
Trade	273	29.16516	30.2465	191.873	191.873
credit	273	22.21155	5.94905	138.42	138.42
inflation	273	5.902356	-4.86328	39.90734	39.90734
Government	273	4.197506	7.66051	30.0035	30.0035

Table A6 - LLC and IPS unit root test results

	LLC			IPS		
Variables	At level	By différence	Conclusion	At level	By différence	Conclusion
Economic Growth	-2,36***		I(0)	-7,18***		I(0)
Idi	3,39	-5,25***	I(1)	15,04	-7,65***	I(1)
Inflation	-7,2***		I(0)	-8,97***		I(0)
Credit	0,112	-9,3***	I(1)	4,52	-11,57***	I(1)
Trade	-2,65***		I(0)	-1,11	-12,21***	I(1)
Government	0,034	-9,82***	I(1)	-0,66	-12,79***	I(1)