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Information and Communication Technology (ICT), Growth and Development in Developing Regions: Evidence from a Comparative Analysis and a New Approach

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Abstract
The majority of empirical literature acknowledges that information and communication technology (ICT) has a favourable effect on economic growth/development. Different studies, however, contend that this impact is modest or perhaps null, yielding inconsistent findings. In view of this complication, we therefore conducted a study with the aim to analyse the ICT diffusion-economic growth-development nexus for 73 countries over the period 2000–2018. The panel data was divided into three regions, namely sub-Saharan Africa (SSA), the Middle East and North Africa (MENA), and Latin America and the Caribbean (LAAC). For the analysis, the newly developed panel vector autoregression (PVAR) in the generalised method of moments (GMM) estimation approach was applied. Our findings suggest a long-run equilibrium relationship between the three variables. The findings differ from the causality results for the overall panel and each of the regions differs. The inconsistency in the causality results across the regions suggests that the level of ICT diffusion is still underdeveloped. The PVAR-GMM results reveal that (i) ICT diffusion is a significant and positive predictor of growth across the regions, with a greater effect reported in MENA; (ii) ICT diffusion is a significant and positive predictor of development across the regions with a lesser effect noticed in MENA. The study's implication for academia and practice is that (i) it provides important information on the ICT diffusion-economic growth-development nexus within the context of the econometric approaches used, and (ii) policymakers and managers of telecom businesses should accommodate sufficient support to further establish the ICT infrastructures and expand its penetration for all round sustainable and inclusive growth and development purposes.

Keywords ICT diffusion · Economic growth and development · Panel cointegration and causality · Regional groupings

JEL Classification O1 · O33 · O47 · O53 · O54 · O55

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Introduction

Over the past three decades, information and communication technology (ICT) has demonstrated a significant ability to promote economic growth and development. ICT is now an integral part of almost all the economic activities in societies/countries around the globe, including entertainment, commerce, education, weather forecasts, health care services, government services, and other endeavours.[1] ICT can promote creativity and reduce poverty and inequality by providing economic agents in developing countries with an enabling wealth of knowledge. According to previous studies, ICT can boost growth in businesses of any size and in economies at any stage of their development. The latter half of the twentieth century was characterised by industries investing heavily in ICT to become nationally and globally competitive. Reports by the World Bank Group (2006) and the United Nations Conference on Trade and Development (UNCTAD) (2004) suggest that rapid information diffusion in an economy can lead to improved standards of living, gains in employment, and gender equality.

On the empirical side, the ICT and inclusive growth nexus is succinctly captured in the recent literature that has investigated the business environment and its performance, cultural and social beliefs, education and teaching methods, well-being and poverty alleviation, capacity development, e-business processes, education and growth of small businesses, human capital and business growth, and energy consumption and investment (inter alia: Ashraf et al., 2017; Donou-Adonsou, 2019; Jacobs et al., 2019; Kowal et al., 2019; Lech, 2019; Madon, 2000; Palvia et al., 2018; Rondović et al., 2019; Saidi et al., 2018). A Vu et al. (2020) study recently surveyed the literature to probe the role that ICT plays in driving economic growth. The findings of the study generally show an ICT growth positive link, despite the effect of ICT on growth still being an open discourse among scholars. On this basis, we focused on regions that have received less attention from researchers, by using a newly developed estimation technique.

Figure 1 provides the average trends in the composite index of ICT, real GDP (proxy for economic growth), and the human development index (proxy for development), in a visual form for sub-Saharan Africa (SSA), the Middle East and North Africa (MENA), and Latin America and the Caribbean (LAAC) regions. It is clear in Fig. 1A, B, and C that the LAAC region is leading in ICT development and real GDP and development, followed by MENA and SSA. In summary, SSA performs the worst when compared to the LAAC and MENA regions. Given this backdrop, an empirical investigation of the causality between ICT diffusion and economic growth and development of these regions requires not only more and further research but also the use of an alternative up-to-date testing methodology that takes endogeneity issues into account, as proposed by Abrigo and Love (2016). Investigating the nexus

[1] See for example, Laperche (2012), Andrés et al. (2015), Penco (2015), Asongu and Asongu (2019), Asongu (2015, 2017, 2020), Shahbaz et al. (2016), Ahmed (2017), Tchamyou (2017), Das et al. (2018), Kouton et al. (2020), El Ghak et al. (2020), Mofakhami (2021) and Dhaoui (2021).

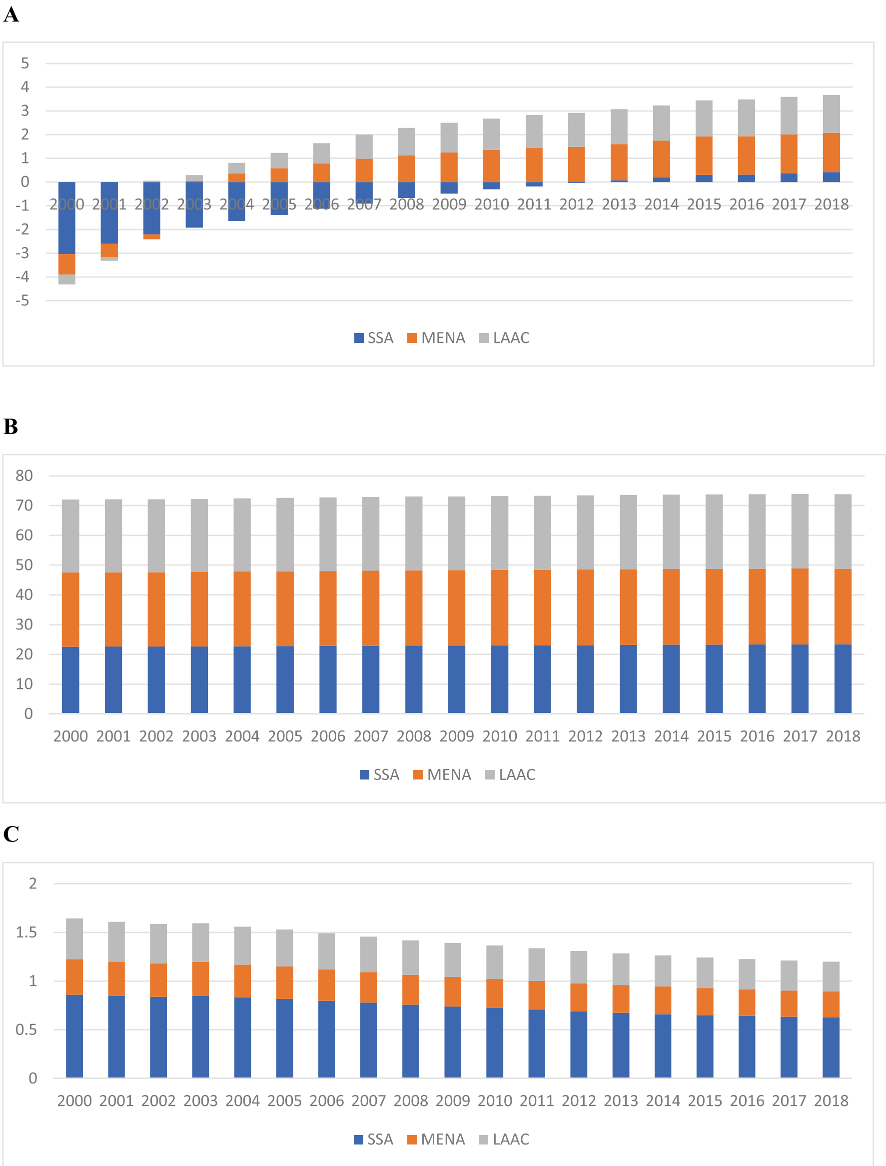


Fig. 1 **A** Composite index of ICT for SSA, MENA, and LAAC from International Telecommunication Union (ITU) database, 2019; **B** real RGDP (proxy for economic growth) for SSA, MENA, and LAAC from World Development Indicators database, 2019; and **C** human development index (proxy for development) for SSA, MENA, and LAAC from World Development Indicators database, 2019

between the three variables is important because the three regions can use ICT to accelerate their growth and levels of development.

This study investigates whether increasing ICT adoption affects economic growth and development in SSA, MENA, and LAAC. The academic and policy importance of the study is threefold: (i) the relevance of the knowledge economy for economic growth and economic development in the twenty-first century, (ii) SSA, MENA, and LAAC's lagging position as knowledge economies, and (iii) the comparatively high potential for ICT penetration in SSA, MENA, and LAAC. Knowledge economy is crucial for economic growth and development in the twenty-first century, according to the extant literature (Saba & Ngepah, 2021; Tchamyou, 2017). According to Asongu and Le Roux (2017), knowledge-based economies help to overcome the challenges associated with globalisation at macro and micro levels, which can threaten a country's economic success. Given the potential penetration ability of ICT, the World Bank knowledge economy index identified it as having the most influential impact on economic growth and development. According to recent research, in comparison to other regions (such as MENA, Asia, Latin America, and other developed nations) where ICT penetration has reached saturation levels, SSA still has a significant opportunity for its adoption (Penard et al., 2012; Asongu, 2018; Asongu & Le Roux, 2017). When one considers that, on the one hand, the SSA region is increasingly experiencing slow growth and backward development, while ICT has been shown to play a significant role in fostering economic growth and development elsewhere, and then the policy relevance of this becomes crucial (Asongu & Le Roux, 2017). Therefore, it is important to undertake a comparative analysis to assess whether SSA is gradually measuring up to other regions of the world.

This study was inspired by the fact that most empirical literature on the nexus between ICT, and growth has focused mainly on developed economies, with little literature focused on developing countries, especially in SSA, MENA, and LAAC. Given this, we contributed to the literature by playing a greater role in filling the gap that exists in the SSA, MENA, and LAAC regions, particularly in the period under consideration, as they have become regions where global ICT services/markets are growing fast (International Telecommunications Union (ITU), 2019). This study seeks to examine the causal-effect relationship between ICT diffusion, economic growth, and development for SSA, MENA, and LAAC countries for the years 2000–2018.

Extensive work in the empirical literature has been produced on ICT-economic growth linkages, while in most cases, development was not studied concurrently with the ICT-economic growth nexus, most especially for the regions under investigation in this study. It is important to include economic development in the ICT-economic growth nexus because this development takes its bearings from the levels of growth. Previous studies mostly consider the common measures of ICT in a disjointed manner (see for example, Lovric, 2012; Duner, 2015; Salimifar & Behname, 2013; Niebel, 2018, among others). However, these studies ignore the importance of principal component analysis (PCA) of ICT measures, which inform the comparative analysis of the developing regional blocks under consideration. Depending on the levels of development and regional division of the countries under consideration, the effect of ICT on growth may differ. This is because according to theory, developing nations may, on the one hand, benefit less from ICT investment because they do not have complementary ICT requirements. On the other hand, Steinmueller (2001) advances the hypothesis that developing countries can leapfrog the conventional methods of productivity. The additional gains from increased productivity can be triggered by "ICT-related spillovers or network effects (Stiroh, 2002)" because of the numerous benefits associated with the use of ICT infrastructures.

Studies that are closest to this article are based on the research work done by Pradhan et al. (2016a, b) and David (2019a, b), among others. However, our study differs from these in various ways. For example, Pradhan et al. (2016a, b) and David (2019a, b) used the traditional PVAR to investigate the nexus between telecommunications infrastructure and economic growth with other macroeconomic variables. However, it is unreliable to draw conclusions from the results of earlier studies due to methodology and data linked to cross-sectional dependence, endogeneity within the PVAR, and other econometric problems identified in the studies. Aside from this, the impact of ICT on economic growth and development, economic growth on ICT and development, and development on economic growth and ICT in developing SSA, MENA, and LAAC countries has not been examined in any of the studies in the literature. Given what constitutes our ICT diffusion variable and also considering that this could be significant, the ICT diffusion levels may improve with the levels of development, which in turn promotes growth. To put it another way, this study added to the body of knowledge by taking into account the possibility of studying the interrelationships between ICT diffusion, economic growth, and development. Therefore, the present study focuses on the investigation of the dynamic linkage between ICT diffusion, economic growth, and development in developing SSA, MENA, and LAAC countries. The results will assist policymakers to better understand the role of ICT diffusion and economic growth in development, economic growth and development in ICT diffusion, development in economic growth, and ICT diffusion for developing SSA, MENA, and LAAC countries.

The SSA, MENA, and LAAC developing regions were chosen for a number of reasons. First, the fast development of the ICT/telecom sector promotes growth through different levels of development, both in developing and developed countries. In the last two to three decades, the SSA, MENA, and LAAC economies have liberalised their policies in the ICT/telecom sector. Within the periods, the countries at different levels received investments by providing voice transmission facilities in the regions. The gradual development of the ICT/telecom industry affects the norms and standard of living of the populace, shortens travel distances, expedites business and commercial transactions, and creates investment and job opportunities.

The liberalisation of the sector in the regions led to a gradual rise in the demand for ICT/telecom services, the development of ICT infrastructure, and significant investment in the economies. Second, the SSA, MENA, and LAAC economies and levels of development are in a precarious/vulnerable condition currently. Since the 2000s, the SSA, MENA, and LAAC economies have experienced differing levels of economic growth and development. Nevertheless, the accomplished economic growth and development levels are not sufficient, and they face different problems within the regions. Third, most of the citizens in the regions live below or just above the poverty line, with SSA being the leading region (Le Goff & Singh, 2014), even though the regions are experiencing different levels of growth and ICT development trends. It does not need to be emphasised that countries in these regions scramble for scarce resources. Thus, the situation of growth and development in the regions is not an encouraging one and needs to be properly and efficiently managed. Besides, the role of ICT and development in the growth of the regions is not properly addressed.

This study is unique in presenting the newly developed PVAR in the GMM framework, which considers endogeneity problems to examine the causal-effect linkage between ICT diffusion, growth, and development. In addition, in this study, three panels of regions are used concurrently, namely SSA, MENA, and LAAC. This study contributes to a better and more precise understanding of the ICT-diffusion-growth-development nexus in a comparative context, by offering novel quantitative evidence on the subject matter under consideration. Previous studies have used haphazard approaches in analysing the ICT/growth nexus; however, the PVAR in the GMM framework approach improves on the earlier approaches by considering endogeneity issues that may exist between the variables. This is a key methodological contribution of the study. Consequently, findings from the study enable policymakers in each region to make more informed decisions related to ICT diffusion to accelerate growth and the levels of development.

The main theoretical contributions of the study are as follows: first, it shows analytically that modified economic growth theoretical frameworks based on neoclassical and endogenous growth theories could be used to investigate the (ICT) diffusion-economic growth-development nexus by applying a PVAR-GMM estimation approach that accounts for endogeneity issues. Second, the economic growth theoretical frameworks have an element which stands for technological progress; we therefore generated an index using principal component analysis (PCA), which serves as technological progress (i.e., ICT diffusion in the case of this study). The index comprises (i) mobile-cellular telephone subscriptions per 100 inhabitants (penetration of connected mobile lines), (ii) fixed-telephone subscriptions per 100 inhabitants (penetration of connected fixed lines), and (iii) percentage of individuals using the Internet (percentage of the population with access to the internet). Generating a technological variable which serves as an ICT index is unique when compared to previous studies within the context of regional comparative analysis. Hence, this contributes to economic growth theoretical frameworks when the technological variable constitutes the above-mentioned telecommunication/ICT infrastructures within the context of the three developing regions. Comparing our theoretical findings to other researchers' work will assist in demonstrating the extent of our findings' value.

The remainder of this paper is organised as follows: The "Literature Review" section presents the literature review. In the "Methodology and Data" section, we present the methodology and data. Results from our empirical analysis are presented and discussed in the "Empirical Results" section, while policy, theoretical, and managerial implications can be found in the "Policy, Theoretical, and Managerial Implications and Discussion" section. The "Conclusion" section concludes the study.

Literature Review

The empirical literature on the ICT-growth nexus has gained some impressive attention with different studies arriving at diverse conclusions and policy implications due to, among others: the use of different theoretical frameworks, different periods examined, different econometric models and specifications, and different countries used for the studies. The role and channel through which ICT promotes economic growth in an economy have been well documented in the literature; hence, this section provides an epigrammatic literature survey on the subject matter under consideration. Theories forecast a positive impact of ICT on growth, but empirical research on the topic over the past 30 years has yielded mixed results.

On the empirical front, studies that confirmed the positive impact of ICT/ICT indicators (such as the Internet, mobile phones, broadband penetration) on growth include, among others, studies such as those of Dewan and Kraemer (2000) for the case of 36 countries spanning 1985–1993, Pohjola (2001) for 23 OECD countries, Nour and Satti (2002) for Egypt and the Gulf countries, Seo et al. (2009) for 29 countries, Nasab and Aghaei (2009) for OPEC countries for the period 1990–2007, Vu (2011) for 102 countries over the period 1996–2005, Vu (2013) for Singapore, Ahmed and Ridzuan (2013) for East Asian countries, Saidi et al. (2015) for Tunisia, Hassan (2004) for 95 countries and 8 MENA countries between 1980 and 2001, Albiman and Sulong (2017) and Donou-Adonsou (2019) for sub-Saharan Africa, Salahuddin and Gow (2016) for South Africa, Ghosh (2017) for 15 MENA countries, Farhadi et al. (2012) for 159 countries, Latif et al. (2018) for BRICS countries, Jin and Cho (2015) for 128 countries, Pradhan et al. (2018) for G-20 countries, Sassi and Goaied (2013) for MENA countries, Sepehrdoust (2018) for OPEC developing countries, and Ward and Zheng (2016) for 31 provinces of China. The few studies that have reported insignificant/negative effects of ICT/any one of the ICT indicators on growth include, among others, studies such as that of Salahuddin and Alam (2015) for Australia spanning 1985–2012, Ishida (2015) for Japan over the period 1980–2010, Niebel (2018) for developed, developing, and emerging countries between 1995 and 2010, Haftu (2019) for SSA over the period 2006–2015, Zhang (2019) for Asian economies, and Ahmed (2020) for developed countries.

For the causality analysis referred to above, the findings on this subject, broadly speaking, can be classified into four groups. The first group includes studies whose findings are consistent with a bidirectional causality running between ICT/any of the ICT indicators and economic growth. These studies include, among others, studies such as Cronin et al. (1991) for the USA, which is the pioneering research, Madden and Savage (1998) for 27 Central and Eastern European countries for the 1990–1995 period, Madden and Savage (2000) for 43 countries, Pradhan et al. (2016a, b) for the case of 21 Asian countries in the short and long run over the period 1991–2012, Pradhan et al. (2017a, b) for 21 Asian countries spanning 2001–2012, Chakraborty and Nandi (2011) for 93 developing countries in the long run, Lam and Shiu (2010) for high-, upper-middle, lower-middle, and low-income countries, and Saidi et al. (2018) for 13 MENA countries. In contrast to the first, the second group of research advocates a one-way causal flow from ICT/any of the ICT indicators to economic growth. These include studies such as those of Dutta (2001) for 15 developed and 15 developing countries, Cieślik and Kaniewska (2004) for Poland, Waverman et al. (2005) using data for 92 countries, Chakraborty and Nandi (2011) for 93 developing countries in the short run, Roller and Waverman (2001) for 21 OECD countries, Yoo and Kwak (2004) for Korea, Mehmood and Siddiqui (2013) for Asian countries, Shiu and Lam (2008a) for China and its regions, and Ahmed and Krishnasamy (2012) for five Association of Southeast Asian Nations (ASEAN).

A third (middle-ground) group of studies exists in addition to the first and second groups of studies, which suggest causality running from economic growth to ICT/any of the ICT indicators. Studies that support this finding include, among others, the following: Beil et al. (2005), Veeramacheneni et al. (2007) for 10 Latin American countries using time-series data, and Pradhan et al. (2013, 2014, 2017a, b) for 34 OECD, G-20, Asian-21, and 32 high-income OECD countries, respectively. The last few groups of studies that reported no evidence of causality running between ICT/any of the ICT indicators and economic growth include, among others, studies such as the following: Shiu and Lam (2008b) for 105 countries, Veeramacheneni et al. (2007) for 10 Latin American countries using time-series data, and Pradhan et al. (2016a, b) for Asia and G-20 countries, while the Pradhan et al. (2016a, b, 2018) findings agree and validify all the four causality outcomes. The causality results of the previous empirical studies can be grouped into the following: (i) supply-leading hypothesis (ICT causes growth), (ii) demand-following hypothesis (growth causes ICT), (iii) feedback hypothesis (growth and ICT cause each other), (iv) neutrality hypothesis (no causality between growth and ICT) (Pradhan et al., 2019).

Njoh (2018), using cross-sectional (as opposed to longitudinal panel data) explored the nexus between the consumption of ICTs and development by focusing only on Africa. The study used the Cobb and Douglas production function. The study findings confirm the positive link between ICT and development. Focusing on relatively recent studies, Li and Wu (2020) explored how intangible capital affects the growth of ICT-intensive sectors in China by examining 29 sectors in 30 regions for the years 2003–2015. Their main finding revealed that value added in ICT-intensive sectors in China grows faster in regions with a faster development of intangible capital.

Fernández-Portillo et al. (2020a, b) investigated the ICT development-economic growth nexus for the case of OECD European Union countries over the period 2014 to 2017. They applied the partial least squares-structural equation modeling (PLS-SEM) estimation technique. The empirical results suggest that the use of ICT drives the economic growth of countries. The Nguyen and Doytch (2021) study provides evidence on the impact of ICT patents on economic growth from an international perspective between 1998 and 2016. They used a two-step system GMM to control for potential endogeneity in the data. They disaggregated their panel data into 26 advanced and 17 emerging market economies. The results revealed that (i) mutual causality exists between total patents and economic growth, but the absence of manufacturing sector growth has an effect on total patents; (ii) ICT patents have a unidirectional causal impact on both (that is, economic growth and the growth of services and manufacturing); (iii) advanced economies experienced a stronger impact of total patents on economic growth; (iv) ICT patents have a positive and significant impact on the growth of advanced economies and a negative and significant effect on the growth of emerging economies; (v) in the long-run, ICT patents have a positive and significant impact on economic growth, while total patents do not.

To compare rich and poor countries, the Appiah-Otoo and Song (2021) study examined the impact of ICT on economic growth for 123 countries over the period

2002–2017. The countries were disaggregated into four income groups, while the main estimation model was IV-GMM. In general, the results from the regression revealed that ICT increased economic growth in both countries; however, poor countries tended to gain more from the ICT revolution. Using an international cross-country approach, the Cheng et al. (2021) study examined the ICT diffusion-financial development-growth nexus based on a panel data set covering 72 countries from 2000 to 2015. The study applied a dynamic GMM estimation technique and found that the interaction between ICT and financial development played a critical role in driving economic growth in middle and low-income countries. While only mobile growth could raise growth, increasing Internet or secure Internet servers could not. In a different study focusing on sub-Saharan Africa (SSA), Kwesi and Asongu (2021) found that ICT diffusion and FDI induce inclusive growth in SSA. Overall, the result of the study shows that FDI modulates ICT dynamics to engender positive synergy effects on inclusive growth. The data of the Kwesi and Asongu (2021) study covers between 1980 and 2019, and they applied ordinary least squares and dynamic system GMM estimation approaches to establish robust findings.

Using spatial panel data analysis for the case of China (31 provinces), the Wang et al. (2021) study explored the impact of ICT on socio-economic development in the period 20,092,018. The findings revealed that ICT is essential in improving socio-economic development. While the spatial spillover effects of ICT negatively affect the socio-economic development in adjacent areas, implying that a digital divide exists among China's provinces and that this digital gap can lead to unbalanced socio-economic development. The Hussain et al. (2021) study examined the relationship between ICT and economic growth in the case of South Asian economies for the period 1995 to 2016. The study applied fully modified ordinary least square (FMOLS) and panel vector error correction model (VECM) techniques. The results revealed that in South Asian economies: (i) ICT penetration has a long-run positive impact on growth, (ii) Internet users' penetration has the greatest impact on growth, followed by mobile-phone subscribers' penetration and fixed-phone subscribers' penetration, respectively. Kallal et al. (2021) examined the ICT-economic growth nexus by performing a sectorial analysis for Tunisia, a developing country. The study data spanned between 1997 and 2015. They applied the panel pooled mean group form of the autoregressive distributed lag model. An analysis of the study yielded two main findings: (i) ICT diffusion has a positive long-term effect on Tunisia's economic growth, and (ii) a negative short-term effect, attributable to substantial investment bias towards ICT.

In the context of sustainable economic development, the study of Pradhan et al. (2021) examined the short-run and long-run dynamics between ICT infrastructure development, financial inclusion, and economic growth in 20 Indian states over the period 1991 to 2018. Using the Granger-causality technique, the results of the study revealed a strong temporal causality between these variables in both the short and long term. The study concluded by alluding to the fact that for the Indian states to attain sustainable economic development; these three variables must be seriously considered.

Sawng et al. (2021) examined the ICT investment-GDP growth nexus by using the causality approach for the case of South Korea over the period 1999–2016. Overall, the results revealed that ICT investment and GDP growth are affected bi-directionally except for the short-run case in which only ICT investment affected GDP growth. Nchofoung and Asongu (2022) investigated the effect of ICT on sustainable development and the mechanisms through which the effect is modulated. The study focused on a sample of 140 countries around the globe for the period 2000–2019. The study used batteries of econometric approaches. The results of the study showed that ICT has a positive and significant effect on sustainable development, but this depends on the choice of the ICT measurement, the geographical location of the economy, and the income group category of the countries. Studies that focused on the impact of technology transfers/innovations on economic growth include Farinha et al. (2018), Ferreira et al. (2019), Ferreira et al. (2020), and Kopczynska and Ferreira (2021), among others. For example, Ferreira et al. (2020) examined the impact of technology transfers and institutional factors (in terms of environmental patents) on economic growth in the case of Europe and Oceania. The authors applied a dynamic panel approach based on econometric methodologies. Overall, the results revealed that irrespective of the technology transfer and institutional factor differences, they generated a positive impact on the economic growth of the two continents (i.e. Europe and Oceania). Huang et al. (2022) examined the impact of cities' ICT on firm growth in the case of China during the years 2001–2016. The main findings of the study demonstrate that cities' ICTs positively promoted firm growth, including financial profitability, marketing performance, and innovation performance.

Based on the review of previous empirical studies, there is evidence of a lack of consensus in the literature, which could be attributed to a wide variety of reasons, as mentioned earlier. Apart from the fact that the results on the nexus between ICT and economic growth are inconclusive in the literature, none of them considered ICT diffusion, economic growth, and development in a newly developed PVAR in the GMM framework for the selected SSA, MENA, and LAAC countries, in a comparative analysis that focuses on the period 2000–2018. Thus, there is a need to fill this gap in the literature by providing robust and concrete up-to-date evidence on the ICT diffusion-growth-development nexus for the case of the three selected regions between 2000 and 2018.

We embarked on a robust empirical analysis in order to propose policies that define economic activities and accelerate development through the use of information and communication technology. This study differs from the existing literature because previous empirical studies primarily desired to investigate the ICT/ICT indicators-growth nexus and the ICT-development nexus, without exploring the ICT diffusion-economic growth-development nexus for the three regions concurrently. The role of technology in promoting economic growth is crucial for economic development going by the theories of growth, development, and technology (Schumpeter, 1934; Schumpeter & Backhaus, 2003; Solow, 1964; Romer, 1986; Mankiw et al., 1992). In addition, the present study is distinct from the previous empirical literature in that it combines ICT diffusion and economic growth and development in a newly developed PVAR in the GMM framework. Policies were proposed that could promote the ICT sector and economic activities that are meant to accelerate development in the three regions.

Methodology and Data

Brief Theoretical and Empirical Framework

The theoretical foundation from which the empirical model of this study stems is that of the neoclassical theory. The assumption of this theory is based on the fact that growth development has a functional relationship with technology, labour, and capital. It was further extended to corporate physical capital, human capital, and technological progress (Mankiw et al., 1992; Swan, 1956). Scholars such as Nasab and Aghaei (2009), Pradhan et al. (2014, 2016a, b), among others, further modified it to include ICT as an actor of technology, which has spillover effects on socio-economic factors, gross output, and the welfare of economic agents. Solow (1956, 1957) and Swan (1956) mathematically modelled growth development as a production function that has a technical relationship with physical capital, labour, and technology. This is stated as:

$$If\ Q = AK^{ß}L^{1-ß} \tag{1}$$

where Q, gross output; L, labour employed; K, capital stock; and A, technical efficiency.

$K^{ß}$ can be written as $\frac{K}{K^{1-ß}}$

By substitution

$$Q = A\left(\frac{K}{K^{1-ß}}\right)L^{1-ß} \tag{2}$$

$$Q = A\left(\frac{L^{1-ß}}{K^{1-ß}}\right)K \tag{3}$$

$$Q = A\left(\frac{L}{K}\right)^{1-ß}K \tag{4}$$

$$K = \frac{QK^{1-ß}}{AL^{1-ß}} \tag{5}$$

$$K = \frac{1}{A}\left(\frac{K^{1-ß}}{L^{1-ß}}\right)Q \tag{6}$$

$$K = \frac{1}{A}\left(\frac{K}{L}\right)^{1-ß}Q \tag{7}$$

Equation (7) shows that the capital-labour ratio and output have a direct relationship with total capital stock, and vice versa for technological change. The Cobb–Douglas production function provides a framework for determining the contributions to the growth rate output of technological change. The production function in Eq. (1) can be decomposed into the rate of change by transforming it into a logarithmic function as:

$$lnQ = lnA + ßlnK + (1 - ß)lnL \tag{8}$$

Taking the rate of change in output to change in time to determine the economic growth concerning time (i.e. differentiate to time)

$$\frac{\delta(LnQ)}{\delta t} = \frac{\delta(LnA)}{\delta t} + \alpha \frac{\delta(LnK)}{\delta t} + (1-\alpha)\frac{\delta(LnL)}{\delta t}$$
$$\text{Let } \frac{\delta(LnQ)}{\delta t} = \dot{Q}; \frac{\delta(LnA)}{\delta t} = \dot{A}; \frac{\delta(LnK)}{\delta t} = \dot{K} \text{ and } \frac{\delta(LnL)}{\delta t} = \dot{L} \tag{9}$$

Let

$$\frac{\delta(LnQ)}{\delta t} = \dot{Q}; \frac{\delta(LnA)}{\delta t} = \dot{A}; \frac{\delta(LnK)}{\delta t} = K\ \dot{and}\ \frac{\delta(LnL)}{\delta t} = \dot{L}$$

Therefore,

$$\dot{Q} = \dot{A} + ß\,\dot{K} + (1 - ß)\dot{L} \tag{10}$$

From (10), the rate of change in the variables is derived, thus making $\dot{A}$ the subject results to technological change.

$$\dot{A} = \dot{Q} - ß\,\dot{K} - (1 - ß)\dot{L} \tag{11}$$

The basic assumptions of the models include substitutability between capital and labour, thus emphasising the role of savings or investment ratios as crucial drivers of short-run economic growth, constant returns to scale, and diminishing marginal productivity of capital, exogenously determined technical progress. Technological progress is regarded as a long-run phenomenon and exogenously determined. However, in the modified Solow model (Lucas, 1988; Romer, 1986), technological progress under the assumption of increasing returns to scale is broadly defined as new knowledge (Grossman & Helpman, 1994; Romer, 1990), innovation (Aghion & Howitt, 1992), and public infrastructure (Barro, 1990), among other things (Kumar, 2014; Kumar & Kumar, 2012; Rao, 2010), and are treated as endogenous in the growth model. The aggregate output in country i at time t, Q_{it} is a function of capital input (physical, K_{it}, and human, H_{it}), man-hour input, L_{it} L_{it}, and level of technology at time t, A_t. This is formed as:

$$Q_{it} = \varphi K_{it}^{ß_i} H_{it}^{\Im_j} (A_t L_{it})^{1-ß_i-\Im_j} \tag{12}$$

Equation (12) is developed based on the following assumptions:

1. Factor inputs and aggregate output are assumed to be continuous in time.
2. There is a constant rate of growth in technology level and man-hour, g and n respectively.

3. Each of the countries augments its physical and human capital stock at the constant savings rate S_i^k and S_i^h.
4. Both physical and human capital stocks depreciate at the same rate, δ these assumptions (i.e. 3 and 4) induced capital accumulation equations as:

$$\frac{\delta K}{\delta t} = S_i^k Q_{it} - \delta K_{it} \tag{13}$$

$$\frac{\delta H_{it}}{\delta t} = S_i^h Q_{it} - \delta H_{it} \tag{14}$$

Thus, over any interval $TtoT + 1$, output per employed input say man-hour $\left({}^{Q}/_{L}\right)_{it}$ follows:

$$\ln\left({}^{Q}/_{L}\right)_{iT+\phi} - ln\left({}^{Q}/_{L}\right)_{iT} = g\phi + \left(1 - e^{-\aleph\phi}\right) \tag{15}$$

Therefore, Eq. (4) shows the change in the ratio of aggregate output to inputs across countries and time. From Eq. (1), this study's model is deduced on the basis that it is an expansion of the Solow (1956, 1957) and Swan (1956) growth model, with the inclusion of human capital stock. For SSA, MENA, and LAAC, the nexus among ICT diffusion, economic growth, and development is evaluated individually, to ascertain whether technological progress (ICT diffusion) accounts for change in economic development as it does in economic growth, based on the proposition of the economic *a priori*, while other variables/factors are held constant.

In this study, we applied a PVAR[2] in the GMM estimation framework, which is an extension of the traditional panel vector autoregression (PVAR) model introduced by Sims (1980), to explore the ICT-growth-development nexus. The newly developed PVAR in the GMM approach is preferable and differs from the traditional PVAR in the following ways: (i) concern about the direction of causality is of no importance because all the variables in the model are treated as independent and endogenous; (ii) it has more than one equation compared to other models; (iii) variables in the model are explained by their own lags and by the other variables' lagged values; (iv) unobserved individual heterogeneity in the panel data is taken into account; and (v) the choice and appropriateness of instruments along with improved asymptotic results are attributed to this estimation technique. Canova and Ciccarelli (2004) simplified the general way of presenting the PVAR model which is given below as:

$$Q_{i,t} = M_\theta \bar{\text{W}}_{i,t} + \grave{\text{A}}_1 y_{i,t-1} + \cdots + \grave{\text{A}}_\beta y_{i,t-\beta} + \xi_t \tag{16}$$

[2] The latest STATA PVAR programs used for this study were made available by Abrigo and Love (2016), and have been used by other researchers.

where $Q_{i,t}$ is a $K \times 1$ vector of a K panel data variable, $i = 1, \ldots, I$, $\ddot{W}_{i,t}$ is a vector of deterministic terms, M_θ is the associated parameter matrix, and the $\grave{A}'s$ are $K \times K$ parameter matrices attached to the lagged variables $Q_{i,t-\beta}$. The lag order (VAR order) is denoted by β, while the error term is ξ_t. We included three variables in our empirical model, as follows: information and communication technology (ICT), real GDP (a proxy for economic growth (RGDP)), and human development index (a proxy for development). The three variables in a PVAR model are represented as:

$$\begin{bmatrix} 1 & \ddot{W}_{12} & \ddot{W}_{13} \\ \ddot{W}_{21} & 1 & \ddot{W}_{23} \\ \ddot{W}_{31} & \ddot{W}_{32} & 1 \end{bmatrix} \begin{bmatrix} \Delta ICT_{i,t} \\ \Delta RGDP_{i,t} \\ \Delta HDI_{i,t} \end{bmatrix} = \begin{bmatrix} \ddot{W}_{10} \\ \ddot{W}_{20} \\ \ddot{W}_{30} \end{bmatrix} + \begin{bmatrix} \grave{A}_{11} & \grave{A}_{12} & \grave{A}_{13} \\ \grave{A}_{21} & \grave{A}_{22} & \grave{A}_{23} \\ \grave{A}_{31} & \grave{A}_{32} & \grave{A}_{33} \end{bmatrix} \begin{bmatrix} \Delta ICT_{i,t-\gamma} \\ \Delta RGDP_{i,t-\gamma} \\ \Delta HDI_{i,t-\gamma} \end{bmatrix} + \begin{bmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \end{bmatrix} \tag{17}$$

where $Q_{i,t}$ is a three-variable vector including 3 endogenous variables, which all influence one another: ICT, RGDP, and HDI. The 3×3 matrix W contains the coefficients of contemporaneous relationships between the three variables. The GMM estimator is used to obtain consistent estimates of the parameter in Eq. (15). We consider the forward orthogonal deviations or Helmert transformation to the first-difference transformation to remove the panel-specific fixed effects in the PVAR model. This is because fixed effects are usually correlated with the regressors due to lags of the dependent variables (Arellano & Bond, 1991; Blundell & Bond, 1998). Unlike the first-difference transformation, the forward orthogonal deviations would minimise the loss of data and allow the PVAR model to yield efficient estimates due to its capability to overcome weak instrumentation (Abrigo & Love, 2016; Arellano & Bover, 1995). The presence/absence of causality is deduced from the Wald tests of parameters based on the GMM estimates. To estimate the forecast error variance decomposition (FEVD) and impulse response function (IRF) models, this paper follows the IRFs and FEVDs framework provided byAbrigo and Love (2016),[3] which was an extension of Hamilton's (1994) and Lutkepohl's (2005) approaches.

Empirical Estimation Procedure and Data

PVAR in the GMM, cross-sectional dependence (CD), panel unit root test, panel cointegration, and panel Granger-causality test were the estimation techniques used to achieve the objective of this study. The first- and second-generation panel unit root and cointegration tests were utilised to investigate the stationarity condition and long-run equilibrium relationship among the variables, respectively. Some explanations about these tests can be found in the next section. To establish the causality and possible endogeneity that may exist between the variables, we utilised the PVAR Granger causality test in the GMM estimation framework.

This study used an annual panel data spanning 2000–2018 for 73 countries. We further disaggregated our data into regional groups, which included MENA (14

[3] Interested readers are referred to Abrigo and Love (2016) for more details. We refer this to readers to save space.

countries), LAAC (19 countries), and SSA (40 countries). The summary of the dataset can be found in Table 1 below, while Table 2 consists of the list of selected countries used for this study.

Empirical Results

Principal Component, Scatter Plots, and Descriptive Statistics Result Analysis

The first step of this study involved constructing an ICT variable via principal component analysis/method (PCA/PCM). We used this approach because of the significantly high collinearity between the three indicators of ICT in Table 3 below (see Panel D). In Table 3, retaining the first component and ignoring the remaining two means that the eigenvalue of the first component must be > 1 and those exceeding 0.40 in absolute value (Saba & David, 2020). Given that the first component fulfilled the condition, this implied that we ignored the other components because their eigenvalues were of less significance to the model. The choice of the first component was further supported by the Scree plot of the eigenvalues (see Fig. 2). Table 4 below presents the summary statistics' results for the entire sample and the regions under study. For the full sample, the mean (or median) values for ICT and economic growth (RGDP) and development (HDI) are around −2.16E-10, 23.899, and −0.559 (or 0.277, 23.726, −0.498), respectively. The maximum and minimum values for the three variables were found to be between 28.516 and−6.527, respectively. The standard deviation (SD) is 1.523, 1.745, and 0.272 for ICT, RGDP, and HDI respectively, indicating the variation in the samples. The skewness had both positive and negative values for ICT, RGDP, and HDI, which showed a positive and negative skewed distribution. To save space, a similar interpretation holds for the three regions. The Jarque–Bera statistics for the full sample and sub-regions suggested that the residuals for most of the variables, at least at the 1% significance level, were not normally distributed. To complement the results of the descriptive statistics, we present scatter plots in this study to show the possible linear relationship that may exist between the variables. In summary, a visual inspection of Fig. 3 shows that the variables exhibited a possible positive linear relationship between one another across the three regions and the entire sample. This is important because it foreshadows the relationship that should be expected between the variables in the main regression analysis.

Panel Unit Root Result Analysis

Table 5 presents the panel unit root results for the entire sample and the regions. To explore the stationarity panel unit root properties of the three variables, we chose three and one for the first- and second-generation panel unit root tests, respectively. The second-generation panel unit root test was for robustness checks. In Table 5, the first-generation panel unit root test results can be found, namely the Breitung Method (Breitung, 2001; Breitung & Das, 2005), the

Table 1 Summary of dataset

Variables	**Indicators**	**Variable description**	Source of data
HDI	Development	Human development index serves as a proxy for economic development since it has the elements of social and economic dimensions of nations around the world. And they include being healthy and long life, being well read/knowledgeable, and having a relatively good standard of living. Given that development is not only attributed to growth, there is need to also include non-economic factors, hence, our rational for including non-economic factors in order to capture a country's welfare in the analysis. We used this measure by following previous studies such as David (2019a, b) and Saba and Ngepah (2020a, b) among others	United Nations (UN) database 2020
RGDP	Real gross domestic product	Real GDP (constant 2010 US$) serves as a proxy for economic growth (billion dollars)	World Bank's World Development Indicators (WDI) database 2020
ICT	Information and communication technology	Information and communication technology is captured by ICT indicators (which comprises of three ICT variables) by applying principal component method/analysis (PCA)[a]. These indicators include: (i) Mobile-cellular telephone subscriptions per 100 inhabitants (penetration of connected mobile lines) (ii) Fixed-telephone subscriptions per 100 inhabitants (penetration of connected fixed lines) (iii) Percentage of individuals using the Internet (percentage of population with access to the internet)	International Telecommunication Union database 2019

Im-Pesaran-Shin (IPS) method (Im et al., 2003), and the Levine-Lin-Chu (LLC) method (Levin et al., 2002). For the first-generation panel unit root tests, the null hypothesis (H_0) of non-stationarity was rejected, given that the *p*-value was less than 10%. Hence, the results showed that all the variables were integrated in order $I(1)$.

When there is evidence of CD in the data, the first-generation panel unit root tests became unreliable because of the assumption that countries within and outside a region are politically, socially, and economically dependent on one another. Hence, accounting for CD in a panel data becomes an important issue. To handle this problem, we used the test statistic proposed by Frees (1995), Friedman's (1937) statistic, and Pesaran's (2004) CD test, to establish whether or not CD was present in our data. The results in Table 6 suggested that at the 1% significance level, the null hypothesis of cross-sectional independence was rejected for the tests, which showed the presence of CD in our data. Therefore, to test the robustness of the first-generation panel unit root test results, we applied the Pesaran (2007) panel unit

Table 2 List of countries classified into regional groups

No.	Entire sample	Sub-Saharan Africa (SSA)	Middle East and North Africa (MENA)	Latin America and the Caribbean (LAAC)
1	All the countries used for this study	Angola	Algeria	Argentina
2		Benin	Bahrain	Belize
3		Botswana	Egypt	Bolivia
4		Burkina Faso	Iran	Brazil
5		Burundi	Iraq	Chile
6		Côte d'Ivoire	Israel	Colombia
7		Cape Verde	Jordan	Dominican Republic
8		Cameroon	Kuwait	Ecuador
9		Chad	Lebanon	El Salvador
10		Congo, Republic of	Libya	Guatemala
11		Congo, Dem. Rep	Morocco	Honduras
12		eSwatini	Oman	Jamaica
13		Ethiopia	Saudi Arabia	Mexico
14		Gabon	Tunisia	Nicaragua
15		Gambia		Paraguay
16		Ghana		Peru
17		Guinea		Trinidad and Tobago
18		Guinea-Bissau		Uruguay
19		Kenya		Venezuela, RB
20		Lesotho		
21		Liberia		
22		Madagascar		
23		Malawi		
24		Mali		
25		Mauritania		
26		Mauritius		
27		Mozambique		
28		Namibia		
29		Niger		
30		Nigeria		
31		Rwanda		
32		Senegal		
33		Seychelles		
34		Sierra Leone		
35		South Africa		
36		Tanzania		
37		Togo		
38		Uganda		
39		Zambia		
40		Zimbabwe		

[a]To compose the ICT variable via PCA, we follow the study conducted by David (2019a) and Bera (2019). We used extrapolation and interpolation techniques to take care of few missing data. Studies that have used these techniques include David (2019a) and Saba and Ngepah (2019a, b, 2020a, b, 2021, 2022) and Saba (2020a, b, c), Saba and David (2020), Saba (2021a, b, c), Saba et al. (2021) and Saba (2023)

Table 3 Principal component and correlation matrix results

Panel (A): principal component results				
Component	Eigenvalue	Difference	Proportion	Cumulative
Component 1	2.319	1.739	0.773	0.773
Component 2	0.580	0.480	0.193	0.967
Component 3	0.100		0.034	1.000
Panel (B): principal component eigenvector results				
Variable	Component 1	Component 2	Component 3	Unexplained
Fixed-telephone	0.505	0.833	0.226	0
Mobile-telephone	0.588	−0.524	0.616	0
Internet access	0.631	−0.178	−0.755	0
Panel (C): retained eigenvector results				
Variable	Component 1	Unexplained		
Fixed-telephone	0.505	0.407		
Mobile-telephone	0.588	0.198		
Internet access	0.631	0.076		
Panel (D): correlation matrix results				
Variables	Fixed-telephone	Mobile-telephone	Internet access	
Fixed-telephone	1.000			
Mobile-telephone	0.450*** (0.000)	1.000		
Internet access	0.637*** (0.000)	0.869*** (0.000)	1.000	

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$, p-value in parentheses

Author's computations

root test, which considers CD. The results in Table 7 show that all the variables are stationary after the first differencing, which is also consistent with the results of the first-generation panel unit root test. This shows the reliability of our panel unit root analysis and implies that all the series are stationary/integrated at $I(1)$. Furthermore,

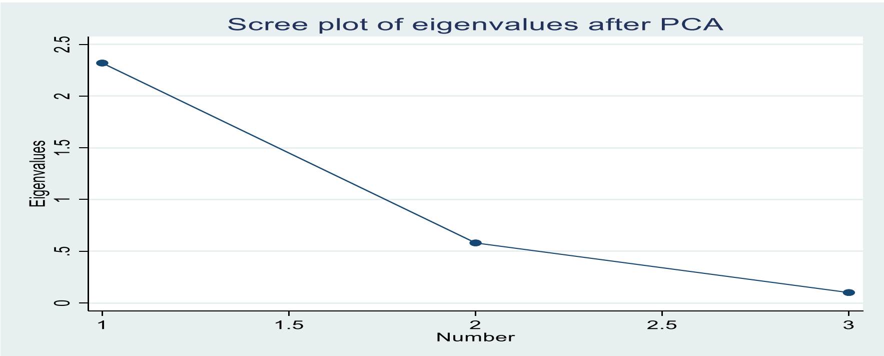


Fig. 2 Scree plot of eigenvalues from the PCA

Table 4 Descriptive statistics results

	Entire sample			**SSA**			**MENA**			**LAAC**		
Statistics	ICT	RGDP	HDI	ICT	RGDP	HDI	ICT	RGDP	HDI	ICT	RGDP	HDI
Mean	−2.16E-10	23.899	−0.559	−7.82E−01	22.989	−0.744	0.919	25.264	−0.308	0.969	24.808	−0.355
Median	0.277	23.726	−0.498	−0.519	23.016	−0.761	1.244	25.311	−0.307	1.147	24.470	−0.344
Maximum	2.16	28.516	−0.017	2.027	26.875	−0.017	2.16	27.277	−0.099	2.103	28.516	−0.166
Minimum	−6.527	20.309	−1.374	−6.527	20.309	−1.374	−3.776	23.400	−0.633	−1.738	20.657	−0.605
Std. Dev	1.523	1.745	0.272	1.491	1.354	0.225	1.044	0.999	0.104	0.764	1.781	0.097
Skewness	−0.955	0.28	−0.489	−0.648	0.532	0.138	−1.699	0.148	−0.322	−0.989	0.122	−0.384
Kurtosis	3.565	2.652	2.315	3.179	3.643	3.113	6.374	2.036	2.994	3.537	2.647	2.566
J–Bera	229.496	25.162	82.314	54.132	48.905	2.804	254.151	11.27	4.583	63.198	2.763	11.695
Prob	0.000	0.000	0.000	0.000	0.000	0.246	0.000	0.004	0.101	0.000	0.251	0.003
Obs	1387	1387	1387	760	760	760	266	266	266	361	361	361

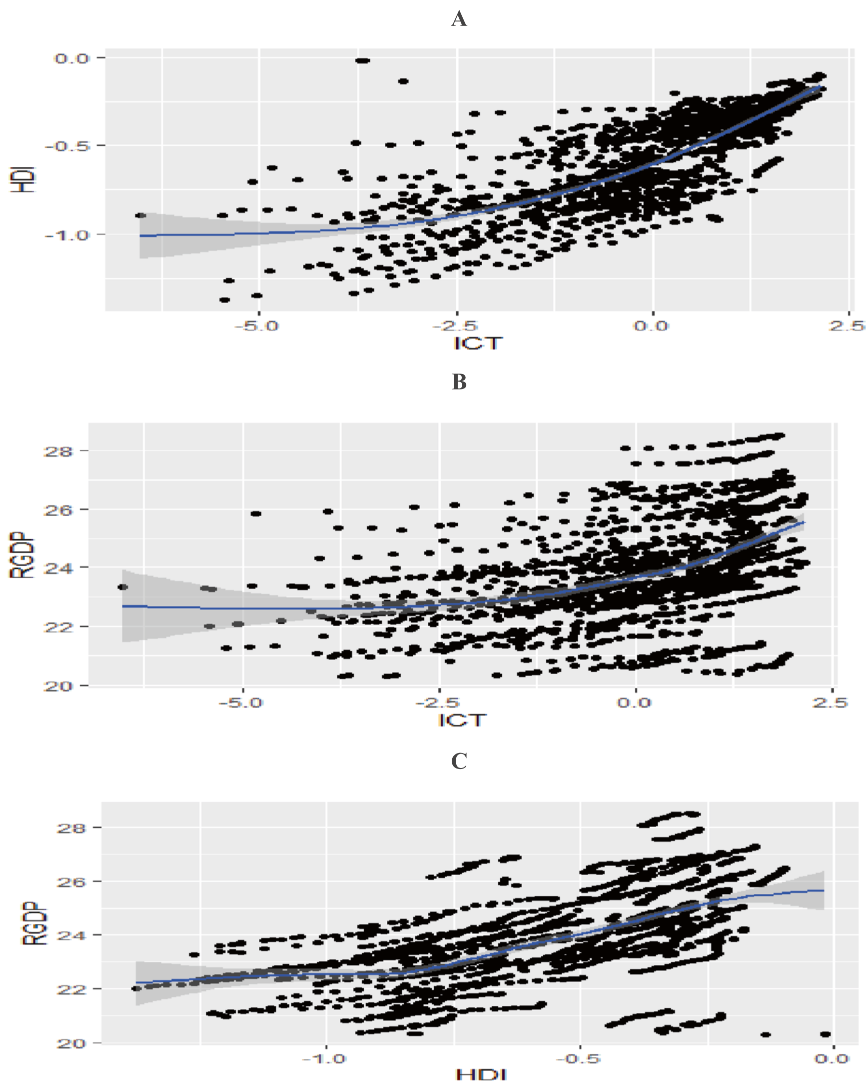


Fig. 3 **A** Scatter plots for the linear relationship between ICT diffusion and development for the entire sample; **B** scatter plots for the linear relationship between ICT diffusion and economic growth for the entire sample; **C** scatter plots for the linear relationship between economic growth and development for the entire sample; **D** scatter plots for the linear relationship between ICT diffusion and development for the regions; **E** scatter plots for the linear relationship between ICT diffusion and economic growth; and **F** scatter plots for the linear relationship between economic growth and development

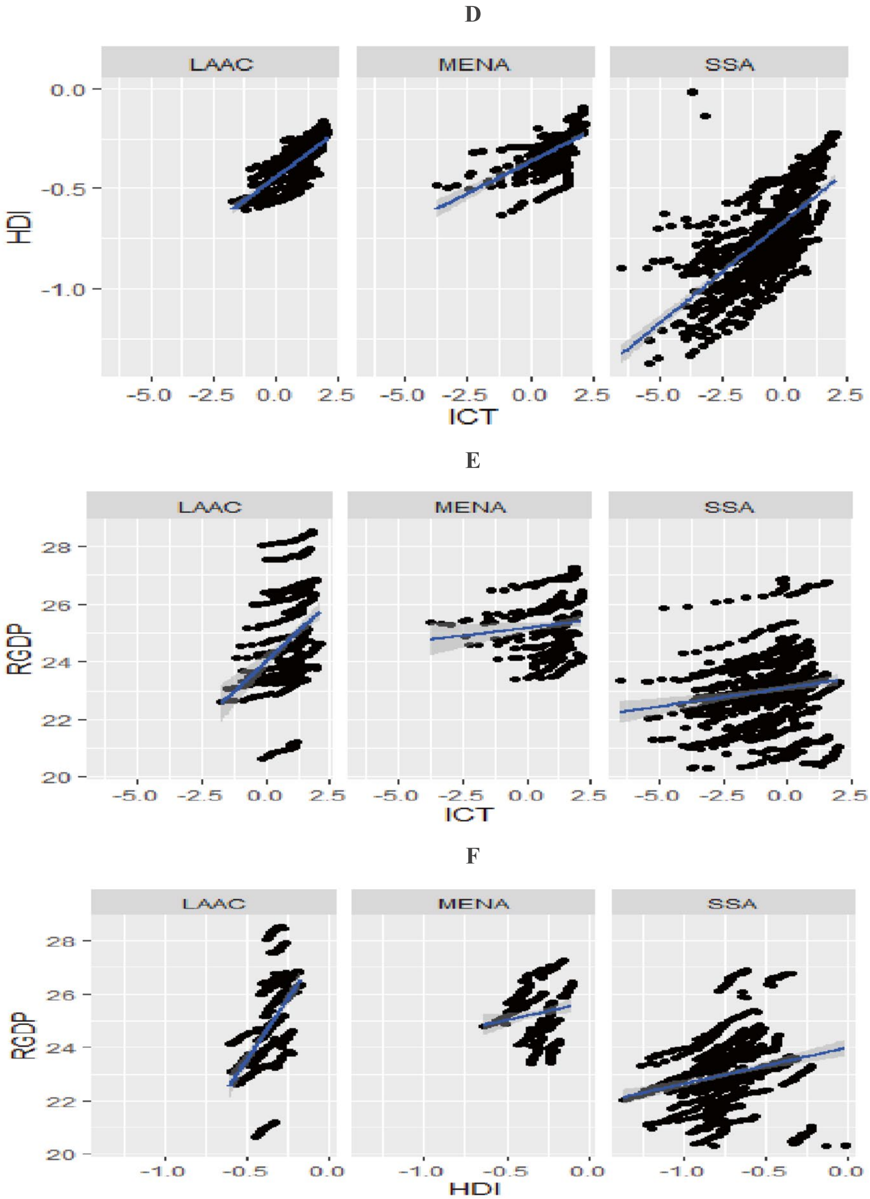


Fig. 3 (continued)

Table 5 Panel unit root test results

Series	Model	LLC	IPS	Breitung
Entire sample				
ICT	Constant	−73.3096 (0.000)***	−57.7973 (0.000)***	
	Constant and trend	−52.7371 (0.000)***	−38.7423 (1.000)	10.3846 (1.000)
RGDP	Constant	−27.610 (0.200)	−12.6413 (1.000)	
	Constant and trend	−13.3748 (0.310)	−6.97492 (0.000)***	10.6936 (1.000)
HDI	Constant	−41.0383 (0.000)***	−25.2327 (1.000)	
	Constant and trend	−3.85297 (1.000)	13.3773 (1.000)	−3.18522 (1.000)
ΔICT	Constant	−2.41387 (0.007)***	−2.01458 (0.022)**	
	Constant and trend	−7.85411 (0.000)***	−13.0209 (0.000)***	−12.1718 (0.000)***
ΔRGDP	Constant	−12.40895 (0.000)***	−8.45676 (0.000)***	
	Constant and trend	−10.9251 (0.000)***	−14.2321 (0.000)***	−12.9571 (0.000)***
ΔHDI	Constant	−8.30218 (0.000)***	−10.0987 (0.000)***	
	Constant and trend	−23.8723 (0.000)***	−34.2909 (0.000)***	−37.2770 (0.000)***
SSA				
ICT	Constant	−21.293 (0.000)***	−13.117 (0.000)***	
	Constant and trend	0.4684 (0.680)	11.446 (1.000)	20.8940 (1.000)
RGDP	Constant	−18.792 (0.000)***	−9.408 (0.000)***	
	Constant and trend	10.635 (1.000)	15.748 (1.000)	13.941 (1.000)
HDI	Constant	−24.718 (0.000)***	−13.2595 (0.000)***	
	Constant and trend	19.308 (1.000)	24.288 (1.000)	−6.977 (0.000)***
ΔICT	Constant	2.533 (0.000)***	1.350 (0.000)***	
	Constant and trend	5.716 (0.000)***	−7.222 (0.000)***	−9.747 (0.000)***
ΔRGDP	Constant	3.433 (0.000)***	4.201 (0.000)***	
	Constant and trend	−4.922 (0.000)***	0.907 (0.000)***	−3.918 (0.000)***
ΔHDI	Constant	11.837 (0.000)***	7.593 (0.000)***	
	Constant and trend	5.882 (0.000)***	1.010 (0.000)***	4.916 (0.000)***
MENA				
ICT	Constant	−11.510 (0.000)***	−7.872 (0.000)***	
	Constant and trend	−6.584 (0.000)***	0.016 (0.506)	4.612 (1.000)
RGDP	Constant	−5.759 (0.000)***	−0.639 (0.2614)	
	Constant and trend	−0.939 (0.1740)	0.282 (0.6111)	−0.041 (0.484)
HDI	Constant	−5.663 (0.000)***	−0.927 (0.177)	
	Constant and trend	−0.049 (0.480)	2.128 (0.983)	2.679 (0.996)
ΔICT	Constant	−3.309 (0.000)***	−1.843 (0.000)***	
	Constant and trend	−0.463 (0.000)***	−1.216 (0.000)***	−1.020 (0.000)***
ΔRGDP	Constant	−6.449 (0.000)***	−6.072 (0.000)***	
	Constant and trend	−7.082 (0.000)***	−6.153 (0.000)***	−2.266 (0.012)**
ΔHDI	Constant	−9.510 (0.000)***	−8.268 (0.000)***	
	Constant and trend	−10.325 (0.000)***	−8.338 (0.000)***	−5.051 (0.000)***
LAAC				
ICT	Constant	−9.208 (0.000)***	−5.766 (0.000)***	
	Constant and trend	−3.432 (0.000)***	2.957 (0.9984)	3.892 (1.000)

Table 5 (continued)

Series	Model	LLC	IPS	Breitung
RGDP	Constant	−2.625 (0.004)***	1.710 (0.9563)	
	Constant and trend	−1.377 (0.084)*	−0.692 (0.2446)	1.457 (0.928)
HDI	Constant	−2.962 (0.001)***	1.790 (0.963)	
	Constant and trend	0.746 (0.772)	1.85280 (0.968)	0.577 (0.718)
ΔICT	Constant	−5.362 (0.000)***	−2.542 (0.005)***	
	Constant and trend	−7.933 (0.000)***	−5.291 (0.000)***	−3.964 (0.000)***
ΔRGDP	Constant	−9.376 (0.000)***	−7.226 (0.000)***	
	Constant and trend	−9.883 (0.000)***	−5.456 (0.000)***	−5.434 (0.000)***
ΔHDI	Constant	−14.297 (0.000)***	−12.429 (0.000)***	
	Constant and trend	−14.145 (0.000)***	−11.226 (0.000)***	−10.764 (0.000)***

Null: Unit root (assumes common unit root process): Levin, Lin, and Chu (t*) and Breitung (t-stat). Null: Unit root (assumes individual unit root process): and Im, Pesaran and Shin (W-stat)

***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$ are significance levels respectively

Author's computations

Table 6 Cross-sectional dependence test results

Test	Variables	Entire Sample	SSA	MENA	LAAC
Pesaran	ICT	215.487*** (0.000)	114.302*** (0.000)	39.745*** (0.000)	55.863*** (0.000)
	RGDP	194.093*** (0.000)	107.953*** (0.000)	27.822*** (0.000)	52.210*** (0.000)
	HDI	179.377*** (0.000)	100.455*** (0.000)	20.218*** (0.000)	53.511*** (0.000)
Frees	ICT	62.354*** (0.000)	33.204*** (0.000)	11.489*** (0.000)	16.575*** (0.000)
	RGDP	58.565*** (0.000)	32.489*** (0.000)	9.895*** (0.000)	14.640*** (0.000)
	HDI	55.771*** (0.000)	30.670*** (0.000)	8.085*** (0.000)	15.650*** (0.000)
Friedman	ICT	1251.622*** (0.000)	667.594*** (0.000)	236.693*** (0.000)	329.834*** (0.000)
	RGDP	1177.313*** (0.000)	655.263*** (0.000)	195.131*** (0.000)	309.088*** (0.000)
	HDI	1096.200*** (0.000)	627.447*** (0.000)	142.866*** (0.000)	319.823*** (0.000)

1: Friedman (1937) test for cross-sectional dependence using Friedman's $\chi 2$ distributed statistic, 2: Frees (1995) for cross-sectional dependence by using Frees' Q distribution (T-asymptotically distributed), 3: Pesaran (2004) cross-sectional dependence in panel data models test

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$ are significance level respectively at denote rejection of null hypothesis

Author's computations

Table 7 Panel unit root results with cross-sectional dependence

	Entire sample		**SSA**		**MENA**		**LAAC**	
	Constant	Constant and trend	Constant	Constant and trend	Constant	Constant and trend	Constant	Constant and trend
Level								
ICT	−2.135	−2.341	−2.122	−2.408	−2.408*	−2.403	−2.821***	−2.972***
RGDP	−1.817	−1.869	−1.282	−1.306	−1.808	−2.057	−1.774	−1.889
HDI	−1.846	−1.875	−1.468	−1.736	−2.126	−1.808	−1.704	−1.834
1St Diff								
ΔICT	−3.413***	−3.700***	−3.738***	−3.790***	−3.513***	−3.903***	−3.483***	−3.892***
ΔRGDP	−3.191***	−3.570***	−3.111***	−3.570***	−2.658***	−2.961***	−2.909***	−3.182***
ΔHDI	−3.319***	−3.953***	−3.008***	−3.736***	−3.212***	−3.910***	−3.920***	−4.338***

***, ** and * denote statistically significant at the 1%, 5%, and 10% level respectively. The critical values of CIPS test at 10%, 5%, and 1% significance levels are:−2.11,−2.2, and−2.38 for intercept, and−2.63,−2.72, and−2.88 for intercept plus trend, respectively

Author's computations

it suggests the need for a panel cointegration test to establish the long-run relationship between the variables.

Panel Cointegration Result Analysis

Based on the fact that the variables follow the same order of integration, we deemed it fit to execute the first- and second-generation panel cointegration tests, namely the Johansen-Fisher and Westerlund (2007) tests. Before examining the long-run equilibrium relationship between ICT diffusion, growth, and development, we first determined the optimum lag length for the entire sample and the regions under investigation. The results of the optimum lag length are not reported to save space but can be made available upon request. The Johansen-Fisher test for cointegration results in Table 8 show that both the trace and maximum Eigen-value test statistics supported the cointegration of 6, 6, 4, and 2 for the entire sample, SSA, MENA, and LAAC, respectively. Thus, at least the 6, 6, 4, and 2 vectors of the cointegrating equations had the presence of panel cointegration for the entire sample: SSA, MENA, and LAAC, respectively. Given the first-generation panel cointegration test results, we can confidently say that there is a long-run equilibrium relationship among the three variables in the entire sample and the regions. However, due to the evidence of cross-sectional independence in our panel data, we further implemented the Westerlund (2007) second-generation panel cointegration test for a robustness check. Table 9 presents the Westerlund (2007) cointegration test results. We found that the null hypothesis of no cointegration was rejected at the 10% significance level, which confirmed the existence of a long-run equilibrium relationship between the variables for the entire sample and the regions. This further confirmed the reliability and robustness of the cointegration results for drawing inferences. The cointegration results implied that the variables were important to the improvement of one another in the long run, as also revealed by the PVAR results. The reasons for the interdependence of long-run relationships may be due to the mutual reinforcement between ICT diffusion and economic growth and development in developing countries.

Panel Causality Result Analysis

This section analysed the causal relationship between ICT, RGDP, and HDI by using the PVAR Granger causality test for the entire sample, SSA, MENA, and LAAC. In Table 10, the results suggested strong evidence of bidirectional causality between ICT and RGDP, ICT, and HDI, RGDP, and HDI in the entire sample, and SSA. For MENA, the results suggested strong evidence of bidirectional causality between ICT and RGDP, while unidirectional causality runs from ICT to HDI and from RGDP to HDI. For LAAC, the results suggested strong evidence of bidirectional causality between ICT and RGDP, ICT, and HDI, while unidirectional causality ran from RGDP to HDI. The null hypothesis of no causality was rejected for the entire sample, SSA, MENA, and LAAC. The

Table 8 Johansen Fisher panel cointegration test results

			Variables: ICT diffusion, growth and development							
			Trace test			**Maximum eigenvalue test**				
Regions	H_0	H_1	λ-trace statistic	0.05 critical value	*p*-value	H_o	H_1	λ-max statistic	0.05 critical value	*p*-value
Entire sample	$r = 0$	$r \geq 1$	274.342***	29.797	0.000	$r = 0$	$r \geq 1$	184.418***	21.132	0.000
	$r \leq 1$	$r \geq 2$	89.924***	15.495	0.000	$r \leq 1$	$r \geq 2$	56.415***	14.265	0.000
	$r \leq 2$	$r \geq 3$	33.509***	3.841	0.000	$r \leq 2$	$r \geq 3$	33.509***	3.841	0.000
SSA	$r = 0$	$r \geq 1$	184.297***	29.797	0.000	$r = 0$	$r \geq 1$	100.186***	21.132	0.000
	$r \leq 1$	$r \geq 2$	84.110***	15.495	0.000	$r \leq 1$	$r \geq 2$	56.064***	14.265	0.000
	$r \leq 2$	$r \geq 3$	28.046***	3.841	0.000	$r \leq 2$	$r \geq 3$	28.046***	3.841	0.000
MENA	$r = 0$	$r \geq 1$	124.551***	29.797	0.000	$r = 0$	$r \geq 1$	99.169***	21.132	0.000
	$r \leq 1$	$r \geq 2$	25.383***	15.495	0.001	$r \leq 1$	$r \geq 2$	23.859***	14.265	0.001
	$r \leq 2$	$r \geq 3$	1.523	3.841	0.217	$r \leq 2$	$r \geq 3$	1.523	3.841	0.217
LAAC	$r = 0$	$r \geq 1$	96.307***	29.797	0.000	$r = 0$	$r \geq 1$	91.979***	21.132	0.000
	$r \leq 1$	$r \geq 2$	4.328	15.495	0.875	$r \leq 1$	$r \geq 2$	4.301	14.265	0.826
	$r \leq 2$	$r \geq 3$	0.026	3.841	0.870	$r \leq 2$	$r \geq 3$	0.027	3.841	0.870

*Rejection of the null hypothesis of no cointegration at least at the 10% level of significance. Probabilities are computed using asymptotic chi-square distribution

Author's computations

Table 9 Westerlund panel cointegration test results

Statistic	Value	Z-value	p-value	Robust p-value
Entire sample				
G_t	−1.956	−4.681***	0.000	0.000
G_a	−5.612	0.331**	0.630	0.020
P_t	−21.729	−10.328***	0.000	0.000
P_a	−6.538	−7.041***	0.000	0.000
SSA				
G_t	−2.053	−3.999***	0.000	0.000
G_a	−5.381	0.505***	0.693	0.000
P_t	−17.020	−8.405***	0.000	0.000
P_a	−6.545	−5.155***	0.000	0.000
MENA				
G_t	−2.025	−2.297**	0.011	0.000
G_a	−4.680	0.782*	0.783	0.080
P_t	−9.499	−4.511***	0.000	0.000
P_a	−5.470	−2.268***	0.012	0.000
LAAC				
G_t	−1.711	−1.369**	0.086	0.050
G_a	−5.994	−0.136**	0.446	0.020
P_t	−7.579	−2.630**	0.004	0.010
P_a	−5.108	−2.320**	0.010	0.010

*, **, and *** represent significance at the 1%, 5%, and 10% levels respectively; number of replications to obtain bootstrapped p-values is set to 100; bandwidth is selected according t-o the data depending rule $4(\frac{T}{100})^{2/9} \approx 3$ recommended by Newey and West (1994); Barlett is used as the spectral estimation method

Author's computations

individual chi square-value statistics were significant. These results implied the existence of causality among the series.

The bidirectional causality result between ICT diffusion and RGDP was consistent with the findings in the studies of Lam and Shiu (2010), Saidi et al. (2018), and David (2019a). The bidirectional causality between the variables suggested the need to account for endogeneity problems in our regression model; hence, we applied the proposed PVAR in the GMM framework by Abrigo and Love (2016) in the next estimated models.

PVAR Result Analysis

Table 11 presents the PVAR results. Firstly, the entire sample result for the economic growth (RGDP) equation revealed that at a 1% significance level, both ICT diffusion and the level of development (HDI) are positive to RGDP, respectively. This suggests that if ICT diffusion increases by 1%, economic growth will increase by 0.01% in the developing countries under study. If the level of development rises by 1%,

Table 10 Panel VAR-Granger causality Wald test, chi square-value results

Model	Null hypothesis	chi^2	*p*-value	Direction of relationship observed	Conclusion
Entire sample					
1	ICT ↛ RGDP	33.057	0.000***	ICT ↔ RGDP	Bidirectional causality
	RGDP ↛ ICT	2.919	0.088*		
2	ICT ↛ HDI	6.632	0.010***	ICT ↔ HDI	Bidirectional causality
	HDI ↛ ICT	12.279	0.000***		
3	RGDP ↛ HDI	17.311	0.000***	RGDP ↔ HDI	Bidirectional causality
	HDI ↛ RGDP	8.041	0.005***		
SSA					
1	ICT ↛ RGDP	37.102	0.000**	ICT ↔ RGDP	Bidirectional causality
	RGDP ↛ ICT	2.773	0.096*		
2	ICT ↛ HDI	11.249	0.001***	ICT ↔ HDI	Bidirectional causality
	HDI ↛ ICT	25.222	0.000***		
3	RGDP ↛ HDI	7.123	0.008***	RGDP ↔ HDI	Bidirectional causality
	HDI ↛ RGDP	2.918	0.088*		
MENA					
1	ICT ↛ RGDP	159.319	0.000***	ICT ↔ RGDP	Bidirectional causality
	RGDP ↛ ICT	41.781	0.000***		
2	ICT ↛ HDI	143.271	0.000***	ICT → HDI	Unidirectional causality
	HDI ↛ ICT	0.291	0.590		
3	RGDP ↛ HDI	2.978	0.084***	RGDP → HDI	Unidirectional causality
	HDI ↛ RGDP	1.562	0.211		
LAAC					
1	ICT ↛ RGDP	16.888	0.000***	ICT ↔ RGDP	Bidirectional causality
	RGDP ↛ ICT	8.123	0.004***		
2	ICT ↛ HDI	13.613	0.000***	ICT ↔ HDI	Bidirectional causality
	HDI ↛ ICT	10.074	0.002***		
3	RGDP ↛ HDI	19.985	0.000***	RGDP → HDI	Unidirectional causality
	HDI ↛ RGDP	0.979	0.322		

↔ and → denote bidirectional and unidirectional causality respectively. ↛ denote H_o: Excluded variable does not Granger cause equation variable. Here the H_1 is excluded variable does Granger cause equation variable

*$p<0.1$; **$p<0.05$; ***$p<0.01$

Author's computation

economic growth will rise by 0.5%. As the policy implications of these results are to promote economic growth by 0.01%, there is a need to increase ICT diffusion by 1% in developing countries. The result suggests that there is a need to enact policies that will speed up the rate of ICT diffusion meant to promote growth. The result of the positive impact of ICT diffusion on growth is consistent with the findings of Osotimehin et al. (2010), Pradhan et al. (2016a, b), Latif et al. (2018), and David (2019a). The result of the development equation revealed that at a 1% significance

Table 11 Panel VAR results

	RGDP(t − 1)	ICT(t − 1)	HDI(t − 1)
Entire sample			
ICT(t)	0.018 (0.088)*	0.951 (0.000)***	0.006 (0.000)***
RGDP(t)	0.734 (0.000)***	−0.437 (0.000)***	−0.019 (0.005)***
HDI(t)	0.537 (0.000)***	0.697 (0.010)**	0.934 (0.000)***
SSA			
ICT(t)	0.013 (0.000)***	0.958 (0.000)***	0.016 (0.000)***
RGDP(t)	0.883 (0.000)***	−0.548 (0.044)**	0.032 (0.088)*
HDI(t)	0.185 (0.008)***	0.972 (0.036)**	0.697 (0.000)***
MENA			
ICT(t)	0.127 (0.000)***	0.895 (0.000)***	0.001 (0.590)***
RGDP(t)	0.551 (0.000)*	0.435 (0.000)**	0.008 (0.211)***
HDI(t)	−0.631 (0.084)***	−3.259 (0.000)**	0.878 (0.0000)***
LAAC			
ICT(t)	0.051 (0.004)**	0.835 (0.000)***	0.014 (0.002)***
RGDP(t)	0.473 (0.000)**	−0.406 (0.000)***	−0.024 (0.322)***
HDI(t)	1.725 (0.000)***	1.803 (0.000)***	0.881 (0.000)***

*$p<0.1$; **$p<0.05$; ***$p<0.01$ p values in parenthesis; The error terms include country-specific effect

Author's computations

level, ICT diffusion is positive to the level of development. This suggests that if ICT diffusion increases by 1%, the level of development will rise by 0.01%, implying that ICT contributes to the level of development in the full sample. Secondly, for the three regions a similar interpretation holds, although the magnitude of causation of ICT diffusion and development in the economic growth equation and the magnitude of causation of ICT diffusion and RGDP in the development equation differ.

Thirdly, the results of the ICT diffusion equation for the entire sample and the two regions (i.e. SSA and LAAC) revealed that growth is negatively significant to the ICT diffusion at a 5% significance level at most. This suggests that if growth increases by 1%, the ICT diffusion will fall by−0.437,−0.548, and−0.406% for the entire sample—SSA and LAAC respectively. This implies that the gains from production are to some extent not properly being channelled towards the advancement of the ICT sector in the SSA and LAAC. The results for the entire sample, SSA, and LAAC show that the ICT equation revealed that at a 1% significance level, the level of development is positive to ICT diffusion. This implies that the level of development has supported the ICT sector in SSA and LAAC. It is worth noting that the impact of ICT diffusion is more pronounced on growth in the MENA region when compared to the other regions. This could result from all countries in the MENA region rigorously pursuing policies that are in support of digitalisation, which is meant to further growth and development (Göll & Zwiers, 2019). The result for MENA also points to the potential and preparedness of the region to uptake technology and innovation more generally, when compared to SSA and LAAC. For SSA, the impact of ICT diffusion is more pronounced on development when compared

Fig. 4 **A** Stability condition for the entire sample; **B** stability condition for sub-Saharan African countries ▶ (SSA); **C** stability condition for the Middle East and East African countries (MENA); and **D** stability condition for the Latin American and the Caribbean countries (LAAC)

to the other two regions. According to Nadiri and Nandi (2003) "ICT infrastructure has experienced radical, technical and productivity change in the region; and it has attracted large amounts of investment capital from the public and private sectors from both domestic and foreign investors in the region; and its rapid diffusion has been propelled by sharply reduced costs and increased capacity". Hence, this could be the driving force behind the impact of ICT on the process of development in SSA, despite the political and socioeconomic challenges plaguing the region.

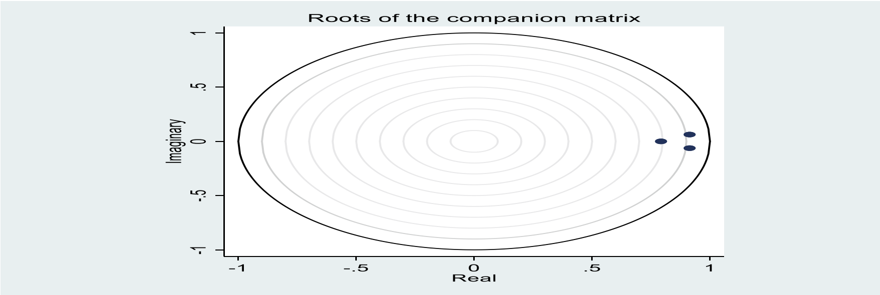
Stability Condition Test

In order not to embark on a fruitless analysis, we tested the validity of our PVAR models by performing the stability condition test. Figure 4 shows that our models are correctly specified and that all our estimated results can be relied upon, as the eigenvalues lie within the unit circle. This implies that all the four estimated panel models have stationary roots (Abrigo & Love, 2016; Hamilton, 1994; Lutkepohl, 2005). The results in Table 12 further support Fig. 4, as each of the eigenvalue's moduli for the entire sample and the three regions together are less than 1. Therefore, this satisfies the condition of the eigenvalue stability test.

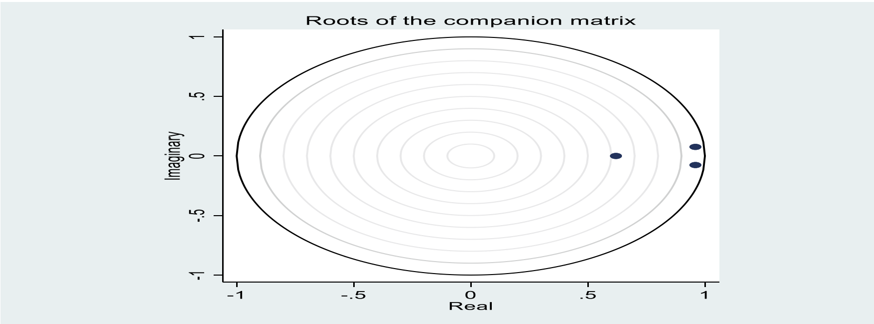
Variance Decomposition and Impulse Response Analysis

In addition to the cointegration, the Granger causality, and PVAR tests, this study also utilised FEVDs and IRFs analysis of the unrestricted VAR estimation process using orthogonalized Cholesky ordering technique. These two methods were used to further explain the magnitude of the causation among the variables. By investigating differences in the values of one variable that can be explained by the other variable, FEVD tests/measures the strength of the causal relationship (Shahbaz, 2012), while IRF measures the effect of a shock to a predictor variable on the predicted variable (Koop et al., 1996). Table 13 presents the variance decompositions of the variables for 10 periods, in which one-fourth of the periods (i.e. period 5) is assumed to be the short run, and period 10 is the long run. For the entire sample, Panel A, the response of ICT diffusion to shocks in itself in the short run would cause 0.908% fluctuations, but 0.801% fluctuations in the long run to ICT. In the short run, shocks in growth (RGDP) and development (HDI) respectively cause 0.087% and 0.005% fluctuations in ICT diffusion, while in the long run, shocks in RGDP and HDI cause 0.194% and 0.005% variations in ICT diffusion, respectively. This implies that ICT diffusion is highly sensitive to shocks in economic growth when compared to the levels of development in developing countries, while a similar interpretation holds for panels B and C for the entire sample.

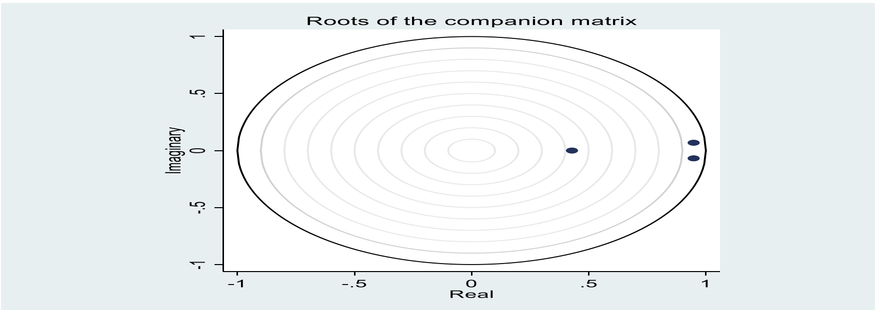
A


Roots of the companion matrix
Imaginary
Real
-1
-.5
0
.5
1

B


Roots of the companion matrix
Imaginary
Real
-1
-.5
0
.5
1

C


Roots of the companion matrix
Imaginary
Real
-1
-.5
0
.5
1

D

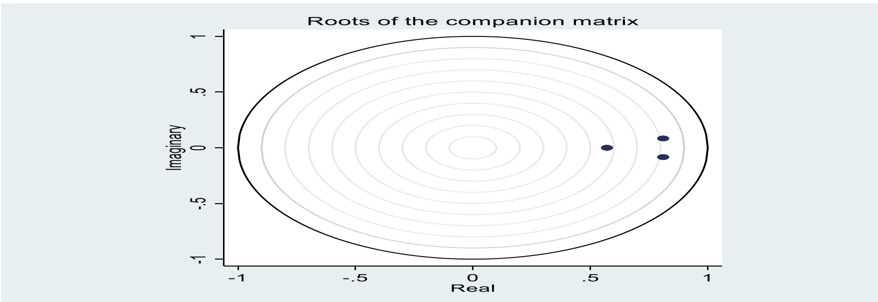

Roots of the companion matrix
Imaginary
Real
-1
-.5
0
.5
1

Table 12 Eigenvalue stability condition

	Real	Imaginary	Modulus
Entire sample			
1	0.914	0.063	0.916
2	0.914	−0.063	0.916
3	0.792	0.000	0.792
SSA			
1	0.959	−0.076	0.962
2	0.959	0.076	0.962
3	0.620	0.000	0.620
MENA			
1	0.948	−0.068	0.950
2	0.948	0.068	0.950
3	0.428	0.000	0.428
LAAC			
1	0.810	0.084	0.814
2	0.810	−0.084	0.814
3	0.570	0.000	0.570

For SSA, panel D shows that the response of ICT to shocks in itself revealed that at period 5, in the short run, own shocks cause 0.664% fluctuations, but 0.351% fluctuations in the long run to ICT in SSA. In the short run, shocks in RGDP and HDI cause 0.312% and 0.024% variations in ICT diffusion, respectively. In the long run, shocks in RGDP and HDI cause 0.630% and 0.018% variations in ICT diffusion, respectively. In panel E, own shocks of RGDP accounted for 0.981% fluctuation in the short run but 0.950% variations in the long run. In the short run, shocks in ICT and HDI cause 0.015% and 0.004% variations in RGDP, respectively, while in the long run, shocks in ICT and HDI cause 0.040% and 0.010% variations in RGDP, respectively. Panel F shows the response of HDI to its own shocks and shocks in RGDP and ICT diffusion in SSA. The empirical results identified that own shocks of HDI cause 0.365 and 0.327% variations in the short run and long run respectively. In the short run, shocks in ICT diffusion and RGDP cause 0.128% and 0.365% variations in HDI respectively, while in the long run, shocks in ICT diffusion and RGDP cause 0.240% and 0.327% variations in HDI, respectively.

For MENA, panel G shows that the response of ICT diffusion to shocks reveals that in both the short run and long run (i.e., periods 5 and 10), own shocks will cause 0.770 and 0.463% fluctuations in ICT, respectively. In panel H, own innovations of RGDP accounted for 0.762% fluctuation in RGDP in the short run but caused 0.563% variation in the long run. In the short run, shocks in ICT and HDI cause 0.198% and 0.041% fluctuations in RGDP, respectively, while in the long run, shocks in ICT and HDI cause 0.227% and 0.210% variations in RGDP, respectively. Panel I empirical results identified that own shocks of HDI cause 0.502% variations in HDI in the short run but 0.448% fluctuation in the long run. In the short run, shocks in ICT diffusion and RGDP cause 0.065% and 0.433% fluctuations in

Table 13 Variance decomposition results

Entire sample									
	Panel A: variance decomposition of ICT:			Panel B: variance decomposition of RGDP:			Panel C: variance decomposition of HDI:		
Period	ICT	RGDP	HDI	ICT	RGDP	HDI	ICT	RGDP	HDI
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	1.000	0.000	0.000	0.006	0.994	0.000	0.008	0.172	0.820
2	0.986	0.012	0.001	0.012	0.983	0.005	0.016	0.141	0.843
3	0.963	0.034	0.003	0.019	0.964	0.017	0.028	0.116	0.856
4	0.935	0.060	0.004	0.028	0.939	0.033	0.041	0.097	0.862
5	0.908	0.087	0.005	0.039	0.909	0.052	0.055	0.084	0.861
6	0.881	0.113	0.006	0.052	0.877	0.071	0.070	0.075	0.855
7	0.857	0.137	0.006	0.065	0.846	0.089	0.085	0.070	0.845
8	0.836	0.158	0.006	0.078	0.816	0.106	0.100	0.068	0.832
9	0.817	0.177	0.005	0.092	0.788	0.120	0.114	0.069	0.818
10	0.801	0.194	0.005	0.104	0.764	0.132	0.127	0.072	0.802
SSA									
	Panel D: variance decomposition of ICT:			Panel E: variance decomposition of RGDP:			Panel F: variance decomposition of HDI:		
Period	ICT	RGDP	HDI	ICT	RGDP	HDI	ICT	RGDP	HDI
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	1.000	0.000	0.000	0.005	0.995	0.000	0.042	0.459	0.499
2	0.948	0.044	0.007	0.007	0.993	0.001	0.061	0.495	0.443
3	0.859	0.125	0.016	0.009	0.990	0.001	0.082	0.512	0.406
4	0.760	0.219	0.021	0.012	0.986	0.002	0.104	0.515	0.381
5	0.664	0.312	0.024	0.015	0.981	0.004	0.128	0.507	0.365
6	0.580	0.396	0.024	0.019	0.976	0.005	0.152	0.493	0.355
7	0.507	0.469	0.024	0.024	0.970	0.006	0.177	0.476	0.347
8	0.446	0.532	0.022	0.029	0.964	0.007	0.200	0.459	0.341

Table 13 (continued)

Entire sample									
	Panel A: variance decomposition of ICT:			Panel B: variance decomposition of RGDP:			Panel C: variance decomposition of HDI:		
Period	ICT	RGDP	HDI	ICT	RGDP	HDI	ICT	RGDP	HDI
9	0.394	0.585	0.020	0.034	0.957	0.008	0.221	0.444	0.335
10	0.351	0.630	0.018	0.040	0.950	0.010	0.240	0.433	0.327
MENA									
	Panel G: variance decomposition of ICT:			Panel H: variance decomposition of RGDP:			Panel I: variance decomposition of HDI:		
Period	ICT	RGDP	HDI	ICT	RGDP	HDI	ICT	RGDP	HDI
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	1.000	0.000	0.000	0.068	0.932	0.000	0.044	0.362	0.594
2	0.951	0.024	0.025	0.106	0.892	0.002	0.048	0.391	0.561
3	0.894	0.032	0.074	0.142	0.850	0.008	0.053	0.410	0.537
4	0.834	0.028	0.137	0.173	0.806	0.021	0.059	0.423	0.518
5	0.770	0.022	0.208	0.198	0.762	0.041	0.065	0.433	0.502
6	0.703	0.019	0.278	0.215	0.717	0.068	0.072	0.440	0.488
7	0.636	0.021	0.343	0.226	0.674	0.100	0.079	0.445	0.476
8	0.573	0.027	0.401	0.230	0.634	0.136	0.086	0.449	0.465
9	0.515	0.036	0.449	0.231	0.597	0.173	0.093	0.451	0.456
10	0.463	0.048	0.489	0.227	0.563	0.210	0.100	0.452	0.448
LAAC									
	Panel J: variance decomposition of ICT:			Panel K: variance decomposition of RGDP:			Panel L: variance decomposition of HDI:		
Period	ICT	RGDP	HDI	ICT	RGDP	HDI	ICT	RGDP	HDI
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	1.000	0.000	0.000	0.116	0.884	0.000	0.037	0.248	0.715

Table 13 (continued)

Entire sample									
	Panel A: variance decomposition of ICT:			Panel B: variance decomposition of RGDP:			Panel C: variance decomposition of HDI:		
Period	ICT	RGDP	HDI	ICT	RGDP	HDI	ICT	RGDP	HDI
2	0.964	0.009	0.027	0.134	0.805	0.062	0.053	0.207	0.739
3	0.920	0.023	0.057	0.147	0.710	0.143	0.069	0.178	0.753
4	0.884	0.037	0.079	0.158	0.629	0.213	0.083	0.158	0.759
5	0.858	0.050	0.093	0.167	0.569	0.263	0.096	0.144	0.760
6	0.839	0.061	0.100	0.176	0.527	0.297	0.107	0.135	0.758
7	0.827	0.069	0.104	0.183	0.498	0.319	0.115	0.129	0.755
8	0.819	0.076	0.105	0.189	0.479	0.332	0.122	0.126	0.752
9	0.813	0.082	0.105	0.194	0.466	0.340	0.127	0.125	0.748
10	0.809	0.086	0.105	0.198	0.458	0.344	0.131	0.124	0.745

Orthogonalised Cholesky ordering used

Author's computations

Fig. 5 **A** Entire sample impulse responses; **B** sub-Saharan Africa (SSA) impulse responses; **C** Middle East and North African countries (MENA) impulse responses; **D** Latin American and Caribbean countries (LAAC) impulse responses; note: We computed the IRFs using the PVAR coefficients. In order to take into account, the standard errors of these coefficients, we used the Monte Carlo simulation, in which the parameters of the model are re-calculated 200 times using the estimated coefficients and their variance–covariance matrices as underlying distribution. The 5th and 95th percentiles from the resulting distribution were then used to generate the lower and upper bounds of the impulse response functions ▶

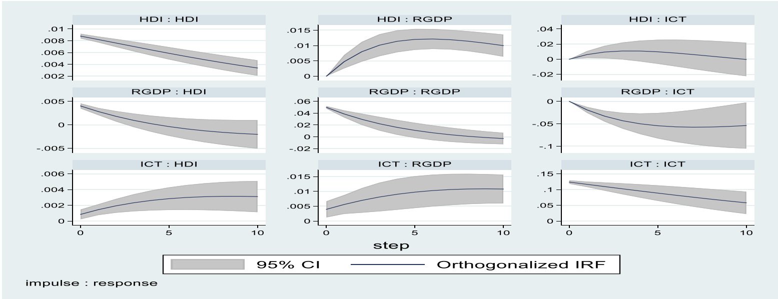
HDI, respectively, while in the long run, shocks in ICT and RGDP cause 0.100% and 0.452% variations in HDI, respectively. A similar interpretation holds for the LAAC region. In summary, the MENA region's economic growth is more sensitive to shock in ICT diffusion when compared to the rest of the regions, while the SSA region's levels of development are more sensitive to shock in ICT diffusion when compared to the rest of the regions.

To further explain the magnitude of the causation between the variables, we estimated the IRFs for the entire sample and the three regions. Figure 5 reports the summary of the IRF outcome for the full sample and the regions. The IRF plots show that a positive shock in ICT diffusion leads to (i) a steady fall in growth for the entire sample and a sharp fall in growth for SSA and MENA and (ii) a steady rise and fall in the levels of development in the entire sample, SSA, and LAAC, but a sharp fall in development in MENA. It is also noteworthy that a shock in growth leads to a rise in the level of development in the entire sample and SSA, but a steady fall in development in MENA and LAAC. However, these shocks are short-lived, but they can be observed in the entire sample and in each of the regions under study. Most shocks have a noticeable influence on one another/the economy in the first 5 years only, and they are fully absorbed within 10 years.

Policy, Theoretical, and Managerial Implications and Discussion

The findings suggest that policies designed to boost ICT (mobile phones, Internet, telephones) penetration will increase economic growth and development for all the regions, considering the post-2015 sustainable development agenda. This is important because previous empirical literature identified ICT as a crucial factor that could influence some of the drivers of economic growth and development, such as foreign investment, business efficiency, and educational and technical opportunities for the labour force, etc. (Hussain et al., 2021; Tsang et al., 2011). The degree of positive responsiveness of economic growth and development to ICT varies across regions. Therefore, as mentioned earlier, our findings consolidate the need to promote ICT penetration and/or adoption for increased economic growth and development for the regions under study. The SSA, MENA, and LAAC governments should formulate, implement, evaluate, and review policies that enable universal access mechanisms via low pricing and sharing schemes and increase the infrastructure needed for ICT penetration meant for growth and development. These are suggested options that policymakers could consider for

A


HDI : HDI
HDI : RGDP
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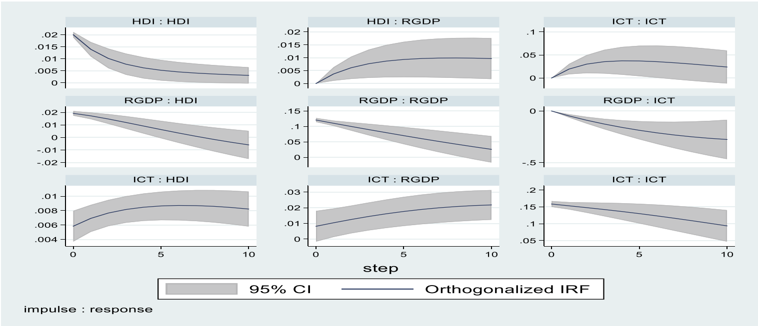
ICT : HDI
ICT : RGDP
ICT : ICT
step
95% CI
Orthogonalized IRF
impulse : response

B


HDI : HDI
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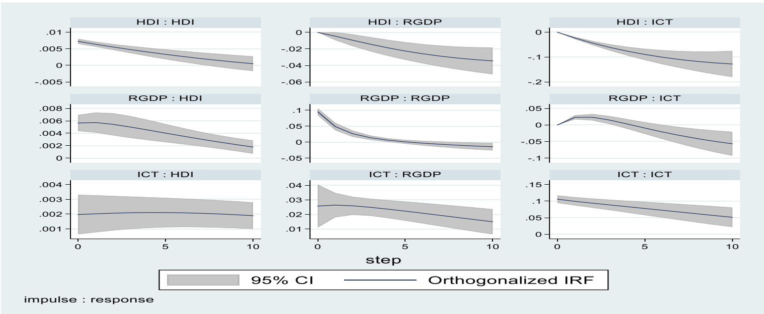
Orthogonalized IRF
impulse : response

C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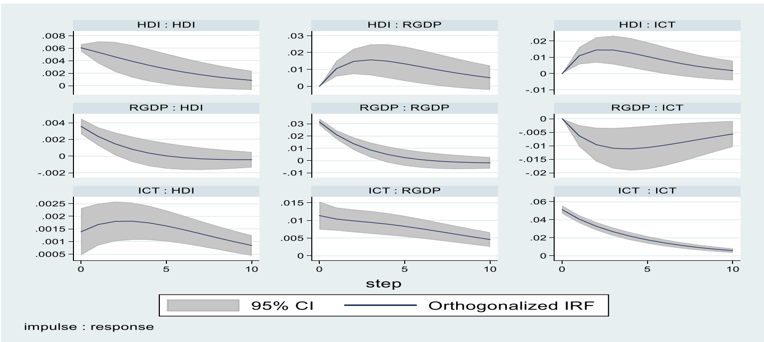
impulse : response

D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step
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Orthogonalized IRF
impulse : response

the regions but are not direct policy implications resulting from the findings of this study because they are outside the scope of the study but, at the same time, are essential.

In addition, the policy implications of these results are that if the governments in the regions are interested in promoting and accelerating long-run levels of economic growth and development, accessibility and affordability of ICT services must be given priority in their policy aims and objectives. Due to the mutual causality results reported, ICT growth and development should be overhauled concurrently, given that the regions are somewhat behind in ICT development when compared to developed countries (Saba & David, 2020). Given the negative and significant impact of growth on ICT and development in the LAAC region, we recommend that growth policies should be carefully formulated and implemented in order not to hamper ICT and developmental goals. This is because ICT investors are sensitive to the economic performance and developmental state of every country/region. For SSA, the MENA, and LAAC regions, policies that enhance the rapid spread of Internet access penetration, fixed line penetration, and the affordability of mobile devices should be encouraged in the three regions to further accelerate growth and development. The governments of the regions should formulate and implement policies that will encourage competition in the ICT sector. This is because the ICT sector could be a breeding ground for high prices/costs in ICT services, hence discouraging investment that could boost the economy. Since there is a long-run equilibrium relationship between ICT, growth, and development in the regions, we suggest that bearing the future in mind, policies in the regions should not only consistently facilitate mobile, Internet, and telephone growth and encourage competition in ICT markets, but also regularly review growth and development policies at the same time. To improve the standard of living, ICT diffusion has become inevitable because of its degree of backward and forward linkages to the economy. Hence, there is a need to continuously promote inclusive and holistic policies that will enhance digital capacities and provide whatever is necessary for growth and development in the SSA, MENA, and LAAC regions.

Furthermore, the policy implications of our results are that an appropriate ICT infrastructure strategy will encourage feasible ICT diffusion in the SSA and LAAC regions, which may drive the processes of economic growth that support economic development. The establishment of better-quality ICT service and infrastructure is more critical in the two regions. Therefore, policymakers and managers of telecom businesses should accommodate sufficient support to further establish ICT infrastructures and expand their penetration. Since the results indicate a negative impact of ICT on economic growth at the panel level, ICT infrastructures within the context of Internet access, mobile phones, and fixed telephones should be one of the top priorities in the countries' development strategies. The governments of the developing countries should foster and promote the usage of ICT infrastructure in everyday life and in businesses as a first and most essential step towards accelerating the information age. According to Kurniawati (2021), the increased use of ICT infrastructure, particularly the components that form the composite index, can promote technological innovation and diffusion, e-government and e-commerce, better decision-making in businesses, households, and the economy as a whole, increased demand, lower production costs and make changes to the economy's structure and international trade. The results reveal that ICT infrastructure usage could contribute to balanced regional economic growth development, most especially for the regions that are running behind in terms of their growth and development at the international level. In a way, the results reveal that Internet users, mobile phone users, and fixed-telephone subscribers are crucial in achieving sustainable economic growth and development, despite this not being directly investigated by the study. Therefore, effective and efficient digital programs and services that will promote and maintain high-speed/quality ICT infrastructure/services need to be executed.

In terms of the theoretical implications in the literature, the growth theory endogenizes the sources of economic growth and development to production, which is attributed to investments in technology. According to Barros (1993), the potential for such investments signals the presence of increasing returns to scale in the production processes. Therefore, going by the panel results of this study, the significant negative impact of technology (ICT) implies that the production process of the developing regions under investigation enjoys limited increasing returns to scale. Thus, there is a continuous need for investment in the region's ICT infrastructures. This is important because investment in ICT infrastructure is often seen as producing positive externalities and contributing to private incentives to invest in new technology in the economies (Barros, 1993). However, more emphasis is needed to be placed on this in the SSA and LAAC regions in terms of investing in ICT infrastructure so that the regions can enjoy increasing returns to scale in their production process. An encompassing ICT policy framework that focuses on connectivity and access, usage, and the legal and regulatory framework, would contribute greatly to growth and development. The results of variance decomposition and impulse response analysis suggest that the theories that underlie the ICT-growth-development nexus need to account for moments of shock in the economy.

Although this study is not directly linked to managerial issues, since managers operate in an economy where the use of ICT infrastructure has become indispensable, the study also has implications for managers. As ICT infrastructure plays an important role in explaining growth and development on a regional level, managers must take ICT infrastructural development levels into account when choosing a location in which to develop their businesses. The managerial challenges associated with the use of ICT depend on levels of growth and development; hence, managers must be mindful of the economic performance and development of the regions, since economic growth leads to increased revenues and profitability. For business managers, the facilitation of ICT infrastructure occasioned by the Internet, mobile phones, and fixed-line telephones that provide different services will result in higher productivity by allowing for better supply chain management (Aker & Mbiti, 2010; Njoh, 2018).

The variance decomposition and impulse response analysis indicate that policymakers and managers need to be conscious of "shocks" that may occur in the economies, which are still vulnerable to shocks. For example, the regions depend on primary commodities which make up about 80% and 54% of SSA and LAAC's merchandise exports, respectively. According to Bertschek et al. (2019), massive economic and social consequences of economic crises/shocks include business failure, job losses, and decreased productivity, which may affect growth and development levels. Therefore, to reduce these costs, policymakers and managers need to be aware of what makes their firms and the economy more resilient. ICT has been identified as helping when shocks occur in an economy (Bertschek et al., 2019; Jovanovic & Rousseau, 2005). According to the Bertschek et al. (2019) study, managers using ICT in a competent way can possibly deal with economic shocks more flexibly through easier reorganisation of their production processes. For example, this was practically evident when there was a hard lockdown that brought economic activity to almost a complete shutdown during the COVID-19 pandemic. Therefore, policymakers should promote the use of ICT infrastructures/services, while managers should use it as a potent source of a firms' resilience during shocks, when economic and developmental activities are disrupted.

Conclusion

This study has empirically investigated the nexus between information and communication technology (ICT) diffusion, economic growth (RGDP), and development in a panel of 73 countries, over the period 2000–2018. The countries were divided into three regions (sub-Saharan Africa (SSA), the Middle East and North Africa (MENA), and Latin America and the Caribbean (LAAC), based on the World Bank classification of regions. We focused on this theme firstly because previous research has predominantly paid attention to the relationship between ICT and economic growth, without finding an innovative measure for ICT diffusion and the dynamic role it might play in promoting growth, and hence, economic development. Secondly, some studies have used the traditional panel vector autoregression (PVAR) model introduced by Sims (1980), which does not consider endogeneity problems that may exist between the series. Thirdly, this study was inspired by the fact that most of the empirical literature on the nexus between ICT and growth has focused mainly on developed economies, with very little literature paying attention to developing countries, especially in SSA, MENA, and LAAC. Considering this, we have contributed to the literature by playing a greater role in filling the gap that exists in the SSA, MENA, and LAAC regions, especially in this period, as SSA, MENA, and LAAC have become regions where global ICT/telecommunication services/markets are growing rapidly (International Telecommunications Union (ITU), 2019). The ICT indicators are measured by three different ICT variables which comprise mobile lines, fixed lines, and Internet access penetration via the principal component method. Stationarity, cointegration, and causality of the data were examined to gain insight into the degree of relationship that may exist between ICT diffusion, economic growth, and development. The study used estimation approaches that controlled for endogeneity, cross-section dependence, and unobserved heterogeneity problems that may exist in panel data.

The results from the panel cointegration test suggest a long-run equilibrium relationship between the variables. Bidirectional causality dominated the relationships between the three variables in the entire sample and the regions (except the unidirectional causality running from ICT to development in MENA, and growth to development in MENA and LAAC). These findings imply (i) that the developing countries, particularly SSA, with bidirectional causality can pursue ICT, growth and development aims and policy objectives concurrently; (ii) ICT objectives and policies should be made and pursued based on the level of growth of the economy of these regions; (iii) in MENA, where ICT causes development, ICT could be an argument for economic development; and (iv) the regions with bidirectional causal relationships can integrate and create synergy by making both ICT and growth policy decisions when pursuing developmental objectives. The main PVAR results suggest that (i) at the full sample, SSA, MENA, and LAAC levels, ICT diffusion has a positive and significant impact on growth and development, respectively; (ii) at LAAC level, growth has a negative and significant impact on ICT and development, which suggests the inability of the former to drive the latter in the region (except in MENA, where positive impact was reported).

This study contributes to the theory of economic development via the empirical results obtained. These results validate the new theory of economic development founded on both endogenous interpretation and the neo-Schumpeterian perspectives of economic development (Asongu & Le Roux, 2017; Howells, 2005). According to Romer (1990), progress in technology can simultaneously be both exogenous and endogenous. Therefore, it has been established in the literature and in this study that a mutual causality could exist between ICT/technology and economic growth and development (Asongu & Le Roux, 2017). Considering this as evidence that the investments/engagements made by economic agents through the mobilisation of critical resources linked with human capital have resulted in ICT/technology, it has positively and significantly promoted economic growth/development, which is in line with the new growth models (see Romer, 1990). Given that the effect of ICT on economic growth and development varies from region to region, this study further validates Romer's assertion that the benefits from technology enjoyed by many countries are heterogeneous (or varying). This implies that ICT development could lead to disequilibrium in economic growth and development processes that elicit cross-country differences in economic development (see Verspagen, 1992). Therefore, realistic policies that enable adequate monitoring of ICT development for each region should be formulated and implemented, thus ensuring that no region is left behind.

The findings reported in this study are an initial assessment, using the new ITU, United Nations, and World Development Indicators dataset that allowed us to extend empirical investigation into the complex ICT diffusion-economic growth and development nexus for the three regions. Given that PVAR in the GMM framework is a newly developed estimation technique, future research should analyse the causal effect between each of the ICT indicators/variables and economic growth and development by applying a similar methodological approach to that used in this study, which will differentiate the income groups of different countries, based on World Bank classification.

It is important to mention that the manuscript has not been published elsewhere in part or in entirety and is not under consideration by another journal.

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Declarations

Ethical Approval This article does not contain any studies with human participants or animals performed by any of the author(s).

Consent for Publication This manuscript is an original work and has been done by the author(s). CSS, NN, and NMO are aware of its content and approve its submission. The author(s) have given consent for this article to be submitted for publication in *Journal of the Knowledge Economy*.

Conflict of Interest The authors declare no competing interests.

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