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Economic growth and the proliferation of ICT infrastructures: which causes the other?

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ABSTRACT

This study explored the causal association between Information and Communications Technology (ICT) infrastructure development, measured by an ICT index, and the economic growth of 42 African economies between 2000 and 2019. Whether ICT development has contributed to real per capita GDP growth or ICT infrastructure expansion has just been a consequence of growth in real per capita GDP has been overlooked in prior studies concerning Africa. The econometric techniques used to analyse the data included robust second-generation tools to investigate cross-sectional dependence, slope homogeneity, and panel causality. The findings detected significant independence between the variables across countries, the slope was heterogeneous, and there was a long-run association between all of the economies in the sample. Dumitrescu and Hurlin's panel causality analysis indicated a unidirectional causal association between per capita income and the ICT index. The results also demonstrated that capital and employment were the leading causes of per capita GDP growth. The findings suggested that accelerating economic growth in developing economies was essential to promoting ICT investment.

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1. Introduction

Theoretical and empirical reasons exist to believe that ICT will promote economic growth (Stanley et al., 2018). According to Pradhan et al. (2014), ICT can impact real per capita GDP growth in four ways: first, by improving the quality of life; second, by improving the competitiveness of the performance of businesses; third, by diversifying the economy; and fourth, by retaining existing businesses. ICT has dramatically reduced transaction costs in financial services. With the rapid growth of ICT, new employment has been generated, e-business has been promoted, human capital has been developed, knowledge has been diffused, and externalities have been created (Adeleye & Eboagu, 2019). Thompson and Garbacz (2011) demonstrated that the

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deployment of ICT stimulated real per capita income indirectly by stimulating economic freedom, sociopolitical solidity, network externalities, and productive efficiency. Likewise, ICT has impacted growth indirectly by increasing revenue, enhancing employment opportunities, reducing transaction costs, quickening the formation of knowledge, reducing price variations and variances, and stimulating market efficiency (Haftu, 2019; Pradhan et al., 2022; Saba & Ngepah, 2022).

Additionally, ICT development has eliminated corruption, boosted social and political strength, and created positive externalities (Dewan & Kraemer, 2000; Thompson & Garbacz, 2011). Furthermore, ICT development has helped decrease inequality in the distribution of income (Chamayou, 2019), enabled the development of financial markets (Edo et al., 2019), and entry into schooling has also been expanded (Asmonga, 2019). For developing countries, expanding ICT will positively impact development since it will help them avoid some pre-required phases (leapfrogging). As a result of the expansion of ICT, it is no longer imperative to have specific fixed investments or human capital to drive rapid growth (Ding & Hynes, 2006; Steinmueller, 2001). A pessimistic perspective has suggested that ICT negatively impacts real per capita income. According to this perspective, ICT can lead to job displacement as automation and digitalisation replace human labour. This situation may lead to higher unemployment rates and lower real per capita income. Additionally, ICT can increase income inequality, as those with the skills to work in the ICT sector earn higher wages than those without such skills.

Many empirical studies have explored the impact of ICT services on real per capita income growth. An inclusive literature review of recent empirical results on the effect of ICT on real income growth was conducted by Vu et al. (2020). The authors found that although most studies had confirmed that ICT contributed to growth, some had not reached a conclusive verdict on the issue. It is worth noting that very few studies within the ICT-growth nexus have examined the possibility of reverse causality (a growth in per capita GDP causing an expansion of ICT services). A country's higher income levels may lead to an increased demand for ICT services and new investment in ICT infrastructure. That is to say, there is a likelihood of a two-way association between ICT development and income growth. Investigating the likelihood of a two-way link between ICT and income growth is imperative because it has significant policy implications. Examining the likelihood of a two-way relationship between the development of ICT and income growth is essential because it helps understand the complex dynamics between these two factors. If there is a robust causal relationship between the two, governments and policymakers can prioritise investment in ICT infrastructure to spur economic growth. By enhancing ICT capabilities, businesses can be more productive, innovative, and competitive, leading to economic growth. A comprehensive understanding of the link between ICT and income growth is also helpful in formulating informed policies. The government can create an environment conducive to economic growth by incentivising the adoption of ICT, the development of digital literacy, and the development of technology innovation. Policies that enhance broadband accessibility, support for tech startups, and digital skills education could boost the ICT ecosystem and lead to income growth. The main objective of this study was to determine whether this relationship existed in a group of developing countries in the Sub-Saharan Africa (SSA) region, given the importance of causal relationships between the two factors.

Considering the topic's importance and policy implications, the review of previous empirical studies revealed that most earlier studies had focused on ICT's one-way relationship with economic growth. Second, the econometric approaches and analysis methods failed to consider the possibility of cross-sectional dependence on the data. In a globalised and increasingly integrated world, shocks in one country may be transmitted to others. Therefore, it is expected that cross-section units will correlate. By overlooking this possibility, potentially false and skewed outcomes could be obtained (Coakley et al., 2006; Dogan et al., 2020; Khan et al., 2021; Pesaran, 2015). Third, in previous studies, when measuring ICT services, Internet and mobile phone usage have been frequently used, alternately, as proxies. Growing evidence has indicated that the effect of ICT diffusion on growth has depended mainly on the method of ICT measurement (Adeleye & Eboagu, 2019). A substitution effect, however, has been documented in several studies, particularly in African economies. Fixed telephones seem to be being replaced in Africa by mobile phones. A deficiency of fixed telephone lines in the African region has been the reason for the substitution effect because of a lack of extensive wired infrastructure. Therefore, it is unsurprising that the preceding analyses came to unreliable conclusions.

Against these drawbacks, the present study reexamined the ICT-per capita GDP growth nexus and has contributed to the existing literature in the following ways. First, until now, to the present study's author's knowledge, no practical analyses have addressed the possible causal association between ICT and growth in per capita income in the Sub-Saharan Africa (SSA) region. According to the World Bank, the SSA region had the highest percentage growth rate between 1990 and 2021. Specifically, the SSA region experienced a 69% change between 1990 and 2021 (from 2.45% to 4.23%). During the same period, the Middle East and North Africa (MENA) region underwent a −41% decline (from 12% in 1990 to 4.22% in 2021), while the East Asia and Pacific (EAP) region experienced a 41% increase (from 5.16% in 1990 to 7.27% in 2021). This remarkable growth in GDP has been accompanied by substantial growth in the provision of ICT infrastructure in the region. ICT infrastructure data from the World Bank database showed that the SSA region has grown significantly in delivering ICT services compared to other developing regions. For instance, between 1990 and 2020, internet users (% of the population) increased by 6000% in the SSA region compared to 2000% in Latin America and the Caribbean (LAC) and 3500% in the East Asia and Pacific (EAP) region. During the same period, Mobile cellular subscriptions (per 100 people) in the SSA region increased by 4700% compared to only 820% in the LAC and 2000% in the EAP regions. While most empirical studies have attributed, at least partly, such growth to the deployment of ICT infrastructure, no study has yet examined the possibility that income growth has been responsible for the expansion in investment in the ICT sector (Aker & Fafchamps, 2010; Albiman & Sulong, 2017; Hamilton, 2003). Specifically, this refers to whether a growing per capita income and developed ICT services can complement and strengthen each other, resulting in a mutually causal relationship. Bidirectional causality is argued from the standpoint that economic growth requires a solid ICT infrastructure, and ICT infrastructure is indispensable for GDP growth. To date, no empirical study has investigated the possibility that the two variables may be related in a two-way manner in the SSA region.

Second, the present study used previously overlooked robust econometric techniques to examine cross-sectional dependence, slope homogeneity, and panel causality. In a globalised and increasingly integrated world, shocks in one country may be transmitted to others. Thus, a correlation between cross-section units is expected. By overlooking this possibility, potentially false and skewed outcomes could be obtained (Coakley et al., 2006; Dogan et al., 2020; Khan et al., 2021; Pesaran, 2015). Hence, the present research has offered more efficient and reliable outcomes than the analyses found in the existing literature. Third, Internet and mobile phone usage have been frequently used, alternately, in earlier studies to measure ICT services. Growing evidence has proposed that the effect of ICT diffusion on growth has been mainly dependent on the measurement of ICT (Adeleye & Eboagu, 2019). A substitution effect, however, has been documented in several studies, particularly in African economies. Fixed telephones seem to be being replaced in Africa by mobile phones. A deficiency of fixed telephone lines in the African region is the reason for the substitution effect because of a lack of extensive wired infrastructure. Therefore, it is unsurprising that preceding analyses have come to unreliable conclusions. The present study incorporated three components into an ICT index (cellular mobile phone subscriptions (per 100 individuals), fixed broadband subscriptions (per 100 individuals), and internet access for persons (per 100 individuals)). Therefore, the comprehensive measurement of ICT development has better recognised the role of the deployment of ICT in income growth.

The current research employed the Solow (1956) neoclassical aggregate production function on data related to 42 African countries from 2000 to 2019. In addition to the ICT index, the production function included employment and capital stock variables. The results indicated a dependency between the variables across the countries included in the study. The results also revealed that all variables were integrated at order one, and the slope was heterogeneous. The cointegration testing detected a long-run correlation between the total sample of countries. Finally, the direction of causality between variables was investigated using the panel causality test proposed by Dumitrescu and Hurlin (DH) [2012]. Using the DH technique, heterogeneity and cross-sectional dependency problems can be overcome. The results showed a unidirectional causality relationship from per capita income to ICT services for the variables of interest. The findings implied that the witnessed economic progress in Africa over the last decades was not due to the observed massive expansion in ICT services. Capital stock and employment were crucial factors that might explain such progress in the GDP per capita.

The present study is structured as follows: the first section comprises the introduction, while Section 2 concisely reviews chosen appropriate literature. An outline of the study's practical methodology, model, technique of estimation, and data are given in Section 3. In Section 4, the results of the study are explained and interpreted. Finally, in Section 5, the conclusions are summarised.

2. Review of relevant theories and literature

Two contradictory perspectives have been presented concerning the effect of ICT on real per capita income. Those disputing the influence of ICT on income per capita growth have emphasised: “the puzzle of productivity” (Carr, 2003; Johnson, 1992), a theory that contends that productivity does not increase correspondingly or even decreases even with the expansion of the use of ICT services in businesses, industry, and the country. The opposite is also true, with various sources asserting that ICT investment can improve labour productivity or organisational efficiency, increasing real GDP per capita. ICT investment has also been attributed to “static economies of scale (e.g., industrialisation of information)” and “dynamic economies of scale (e.g., industrialisation of information),” as a result of this logic, Johnson (1992) applied it to their association between ICT infrastructure and growth in real income. The economy can gain from static economies of scale by reducing costs and improving the flexibility of ICT. It was also recognised by NIA. (2011) that ICT development has led to substantial technological change, improving the productivity of physical capital and the workforce, two of the most critical factors for efficiency.

On the other hand, the dynamic economy refers to increased productivity that increases business and industry through the enhanced division of labour in a social system. An ITU report (2010) agreed with this position. It indicated that ICT was critical to enhancing the productivity of industries since the process of decision-making and production efficiencies will be improved.

As previously noted, empirical studies exploring the direct impact of the proliferation of ICT services on growth in real income have been increasing whilst arriving at mixed results. This section focuses on empirical studies conducted in the SSA region that have analysed the impact of ICT services on growth. However, recent studies were reviewed regardless of the focus area when reviewing empirical analyses addressing the causal link between both variables. This action was because no empirical studies have yet addressed the likelihood of a causal connection between the two variables in the SSA region. Efforts to inspect the link between ICT development and per capita income in Africa in general and within the SSA region have confirmed, to some degree, the positive effect of ICT deployment on real per capita income in the region.

An example is Lee et al.’s (2012) study regarding the influence of the diffusion of ICT services (measured by landline and mobile cellular phones) on income per capita in 44 SSA region economies between 1975 and 2006. The findings from the GMM estimator indicated that only mobile cellular phones had significantly contributed to the economy’s growth. Furthermore, Chavula (2013) investigated the effects of the proliferation of ICT services (measured by mobile phones, landline telephones, and internet users) on the development of real income per capita in SSA region economies from 1990 to 2007. According to the results of an OLS analysis, each of the ICT measures impacted GDP per capita growth. Similarly, Donou-Adonsou et al. (2016) investigated the effect of the diffusion of ICT services (measured by mobile cellular and Internet users) on income per capita in 47 SSA economies from 1993 to 2012. The results from the GMM estimator showed that each measure promoted the economy’s growth. Albiman and Sulong (2016) examined the influence of ICT (measured by mobile phones, landlines, and Internet users) on real income growth in SSA region economies between 1990 and 2014. According to the GMM estimator results, the Internet and mobile phones caused an expansion in real per capita GDP. In their study, Asongu and Roux (2017) inspected the impact of ICT (based on landlines, mobile phones, and Internet users) on human development in 49 SSA region economies between 2000 and 2012. In the Tobit regressions of instrumental variables, human development was shown to be enhanced by ICT.

Similarly, Albiman and Sulong (2017) examined how the influence of ICT diffusion (measured by mobile cellular and Internet users) on the growth in real income in the SSA area differed according to the Country's development levels between 1990 and 2014. Next, nations in the SSA region were divided into 25 lower-income nations, 13 lower-middle-income nations, and seven upper-middle-income nations. The pooled Mean Group (PMG) method was applied, and the results showed that ICT's short- and long-run impacts on GDP per capita growth depended on income levels and the proxy used to measure ICT. Haftu (2019) inspected the effect of cellular mobile phones and Internet technology on GDP per capita development for forty SSA region economies from 2006 to 2015. Based on the results from the GMM technique, cellular mobile phones had a decisive effect on economic development; the usage of the Internet, on the other hand, had a negligible impact. Donou-Adonsou (2019) studied the effect of the proliferation of ICT services (measured by cellular mobile phones and Internet users) on real income growth in 47 SSA region economies between 1993 and 2015. The findings from the GMM technique showed that Internet use had a significant effect; however, mobile phones had a minimal impact on per capita GDP growth. Using the data from 48 SSA countries from 2004 to 2014, Tchamyou et al. (2019) examined how ICT stimulated income equality and real income growth. The findings from the GMM technique demonstrated that the effect of the proliferation of ICT services on per capita GDP growth and income inequality differed with levels of educational attainment. Compared to OECD economies, Myovella et al. (2020) inspected the proliferation of ICT services (measured by cellular mobile phones, landline phones, and Internet users) on the development of real income in the SSA region from 2006 to 2016. According to the GMM results, digitalisation contributed to real per capita income in both economic groups. However, the effect varied between the groups.

Regarding empirical studies on the likelihood of a two-way relationship between ICT development and real per capita income, Cronin et al. (1991) raised the idea of a bidirectional causality between the two variables by studying how causality works. As explained below, four causal nexuses may exist among ICT infrastructure and GDP per capita growth (Pradhan et al., 2018). According to the supply-leading hypothesis (SLH), ICT infrastructure is required for GDP per capita growth. As a result, the causality is from ICT services to GDP growth. According to this hypothesis, ICT services accelerate economic development by directly enhancing other infrastructure and production inputs, thus promoting per capita GDP. An alternative suggestion is the demand-following hypothesis (DFH), which argues that causality instead runs from real per capita growth to ICT services. ICT services are seen as a by-product or outcome of economic growth by advocates of the demand-following hypothesis.

According to this hypothesis, on the one hand, it is clear that ICT development has contributed significantly to economic growth in many countries. The increased use of computers, the Internet, and other digital technologies has enabled businesses to become more efficient and productive, leading to increased output and higher profits. This situation, in turn, has led to increased investment in ICT infrastructure and further technological development, creating a virtuous growth cycle.

On the other hand, it is also true that economic growth can lead to increased investment in ICT infrastructure. As countries increase their wealth, they have more resources to invest in new technologies, including ICT. In this sense, ICT infrastructure expansion can result from real per capita GDP growth. Finally, the neutrality hypothesis proposes that per capita income and ICT services are unrelated. The neutrality hypothesis argues that the two are unconnected in the development of the economy (Pradhan et al., 2018). Since then, several empirical studies have emerged that have tested this possibility but arrived at mixed findings. For instance, Shiu and Lam (2008) examined how ICT development and per capita GDP growth could be causally related in 22 provinces in China between 1978 and 2004. According to the findings, ICT development at the national level had a unidirectional relationship with real per capita income. The results indicated that only the territories in China's affluent Eastern region have causality from ICT development to per capita real income, but not those in the low-income Central and Western regions. Cieślik and Kaniewska (2004) examined how income levels and ICT services were related in Poland between 1989 and 1998 using panel data from 49 regions. A statistically substantial causal relationship was found between regional ICT infrastructure and per capita income. However, the causal chain ran from ICT to income. Based on a sample of ten Latin American economies between 1975 and 2003, Veeramacheneni et al. (2011) empirically analysed if there was a causal association between ICT development and per capita income. The findings revealed that while a bidirectional causality relationship was detected for some economies, a unidirectional causal connection that ran from ICT to an increase in real GDP per capita was observed in other economies. Pradhan et al. (2014) analysed the causal correlation between ICT services and per capita GDP for the G20 economies between 1991–2012. ICT development and economic development were associated in a bi-directional causal manner.

Likewise, Pradhan et al. (2016) investigated the causal association between ICT services, measured by an ICT index, and per capita GDP growth for 21 Asian economies between 1991 and 2012. The results showed that the exact nature of the causality varied by region. On the other hand, Latif et al. (2018) examined the dynamic correlation between ICT, FDI, GDP encompassing openness to trade, and globalisation for the BRICS economies from 2000 to 2014. According to the findings, the ICT index had a bi-directional causal association with income growth. Similarly, Sawng et al. (2021) explored the association between ICT investment and per capita income growth in South Korea between 1999 and 2016. The findings, using quarterly time-series data, showed that in the long run, the deployment of ICT services and income growth affected each other bi-directionally, except for the short-run case where a unidirectional causality was detected running from ICT to real per capita income growth.

Pradhan et al. (2021) also explored the long-run and short-run dynamics of real per capita income, financial inclusion, and ICT services growth in twenty Indian territories from 1991 to 2018. According to the Granger-causality procedure, a long-run bidirectional association between the variables existed. However, the causality in the short run was pushed towards ICT services from growth. In their study of 171 countries between 2000 and 2018, Saba and Ngepah (2022) explored the ICT diffusion-industrialisation-economic growth nexus. The study's conclusions indicated that ICT diffusion and economic growth were causally interconnected. Similarly, Pradhan et al. (2022) examined the causal relationships between institutional quality, real per capita income growth, and the deployment of ICT infrastructure for a group of emergent economies between 2005 and 2019. Despite a bidirectional association between the variables in the short run, the causality was from ICT to real per capita income growth in the long run.

In general, the reviewed studies that have examined ICT's impact on real per capita income growth in the SSA region have generally agreed, to a certain extent, that it positively affects African countries' per capita GDP growth. Internet use, landline, and mobile phone usage have been analysed alternately as measures of ICT services. Most importantly, no attempt has been made to assess the probability of two-way relationships between the variables as per the second set of reviewed studies. Specifically, previous empirical studies have predominantly focused on one-way relationships (i.e., from ICT to economic growth). The present study examined the causal relationship between the variables to investigate these outcomes.

Similarly, the present study incorporated the standard ICT measurements (Internet, mobile phones, and landline phones) into one index rather than using each individually. The present study specifically investigated the direction of causality between the two. The analysis sought to clarify whether the expansion of ICT infrastructures would lead to real per capita income growth or if it was an outcome of growth.

3. Methodology

The following steps were implemented to accomplish the present study's goals. The variables and the databases associated with each variable were first defined to construct the basic model. Secondly, tests were conducted for cross-sectional dependencies, unit roots, slope homogeneity, cointegration, and causality investigation.

3.1. The model

The present study followed Peprah et al. (2019), Wu et al. (2021), Oryani et al. (2021), and Nguyen and Doytch (2022) and used Solow's (1956) neoclassical aggregate production function (APF). The APF examines the relationship between total outputs and total inputs in producing final goods and services. The model took the subsequent general form:

$$Y_{it} = A_{it} \times (K_{it} L_{it}) \tag{1}$$

where Y_{it} refers to output, the k_{it} relates to capital and l_{it} denotes labour. A_{it} is the level of technological development, i indicates the country, and t denotes time. ICT was added into A_{it} Equation (2) to inspect ICT's influence on economic growth:

$$Y_{it} = f(K_{it} L_{it} ICT_{it}) \tag{2}$$

Equation (2) was then transformed by taking the natural logarithm:

$$LY_{it} = \alpha_0 + \alpha_1 LK_{it} + \alpha_2 LL_{it} + \alpha_3 LICT_{it} + \in_{it} \tag{3}$$

Based on Equation (3), Y denotes GDP per capita (constant 2010 US$). Based on the existing literature, K is capital measured by gross capital formation (constant 2010 US$) (Mendez & Kataoka, 2021; Oryani et al., 2021; Tabash et al., 2022; Yasmeen et al., 2021), L is total employment (Bulut & Muratoglu, 2018; Xin-Gang & Jin, 2022). ICT is the ICT index. This index consists of statistics concerning three ICT infrastructure types: cellular mobile phone subscriptions (per 100 individuals), fixed broadband subscriptions (per 100 individuals), and internet access for persons (per 100 individuals). The ICT index was constructed from the log of fixed broadband, internet users, and cellular mobile phone data using principal component analysis (PCA), as outlined by Ahmed and Le (2021) and Otoo and Song (2021). According to the results, COMP 1 clarified, on average, 82% of the variation in the original data for the economies in the study. The ICT index was derived from COMP1 (the PCA results are described in Tables A1 and A2 in the Appendix A). Data for all variables were gathered from the World Development Indicators (http://data.worldbank.org). The current study covered 41 Sub-Saharan African economies from 2000 to 2019 (As part of the Appendix A, Table A3 contains a list of the sampled countries). Examining the statistical properties of the variables prior to examining their relationships was helpful. Tables 1 and 2 present descriptive statistics and correlation matrixes.

Regarding ICT infrastructure, the aggregate data from the World Bank database showed considerable disparities between developing countries. In 2000, approximately one person per 100 people subscribed to fixed broadband services in the developing countries of the SSA, LAC, MENA, and EAP regions. However, by 2020, while the number of subscribers in the SSA region had remained the same, the number of subscribers had increased to 15 in the LAC region, 10 in the MENA region, and 25 in the EAP region. Internet users (% of the population) comprised only 1% in the SSA region, 3% in the LAC region, 1% in the MENA region, and 2% in the EAP region in 2000. Thirty per cent of the population in the SSA region had access to the Internet in 2020,

Table 1. Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
GDP per capita	820	2209.98	3010.541	208.075	20533
Capital	820	6.16E + 09	1.38E + 10	−6.30E + 09	9.00E + 10
Employment	820	6335181	8497577	122086	5.34E + 07
Fixed broadband subscriptions	820	0.443558	1.859311	3.07E-14	24.19534
Individuals using the Internet	820	9.299158	12.68688	0.0059021	70.84114
Mobile cellular subscriptions	820	46.18131	41.71649	3.60E-06	165.5991

Source: author's calculation.

Table 2. Correlation matrix.

Variables	GDP	Capital	Employment	ICT index
Log GDP	1			
Log Capital	0.35*	1		
Log Employment	−0.40*	0.48*	1	
Log ICT index	0.41*	0.31*	−0.0373	1

* denote significant at 1%.
Source: author's calculations.

Table 3. Cross-section independence analysis.

LGDP = f(LK,LL,LICT)	FE	RE
Pesaran's test	3.67*	10.02*
Friedman's test	12.03*	10.66*

*signify the rejection of the Ho of cross-sectional independence at 1%.
LK log of the capital, LL log of labour, LICT log of ICT.
Source: author's calculation.

compared to 73% in the LAC region, 74% in the MENA region, and 66% in the EAP region. In 2000, there were only two mobile subscribers per 100 people in the SSA region, compared to 11 in the LAC region, 2 in the MENA region, and 6 in the EAP region. In 2020, only 38 per 100 people in the SSA region subscribed to this service, compared to 102 in the LAC region, 106 in the MENA region, and 123 in the EAP region. Based on the data, the SSA region has lagged behind developing economies in other world regions. Among the correlation results in Table 3, the ICT index indicated a positive and noteworthy association with the real GDP per capita. Notably, the correlation between per capita GDP and each explanatory variable was below 50%.

3.2. Econometric methodologies

The first step was investigating the likelihood of dependent relationships between cross-sectional units (CD) to achieve the research objectives. One country's shocks may spread to others due to globalisation and increased integration. A cross-sectional correlation is likely to exist in such cases. CSD is crucial in empirical studies because ignoring it can lead to biased estimates and incorrect inferences. In particular, standard statistical techniques that assume independent and identically distributed (IID) data can yield incorrect standard errors and test statistics when CSD is present. This situation can lead to incorrect conclusions concerning the significance of variables, the magnitude of coefficients, and the validity of hypothesis tests (Coakley et al., 2006; Friedman, 1937; Pesaran, 2007, Pesaran, 2015). The Pesaran (2004) and Friedman (1937) tests were conducted to verify if the panel data were cross-sectionally dependent.

The study then examined the data's static properties in the second step. The analysis used second-generation unit root tests to account for the potential cross-sectional dependence (CSD) issue. First-generation Unit root tests, such as Levin et al. (2002) and Phillips and Perron (1988), did not consider CSD. More recently, unit root tests have been developed for heterogeneous panels and have started considering this issue. The present study used a well-known test that has been extensively used in recent studies: the augmented cross-sectional IPS (CIPS) test, suggested by Pesaran (2007). It was necessary to check the slope coefficients for homogeneity once the integration order had been verified as part of the last step. The slope coefficients may not be homogeneous because African countries are not homogeneous, and there is considerable variation in income levels and the availability of ICT infrastructure (Jiang et al., 2020). The likelihood that slopes might be homogeneous due to country-specific effects could not be overlooked. As discussed previously, early empirical studies had implicitly assumed that coefficients would be homogeneous across countries. The present study estimated slope homogeneity using Pesaran and Yamagata (2008) test.

Next, two tests were used to determine the long-run relationships between the variables. The first test was Westerlund's (2005) cross-sectional augmented cointegration test. Westerlund's cointegration test was preferred because its application was uncomplicated since it did not require any sequential data dependence correction. Most importantly, this test is robust in CSD and panel heterogeneity (Khan et al., 2021). According to the Monte Carlo simulations conducted by Westerlund (2005), the test works better with small samples, which was the case in this study. The rejection of the null hypothesis of no cointegration implied a long-run association in all or some panels. The Pedroni cointegration test (1999, 2004) was then applied to test the robustness of the analysis from the Westerlund (2005) cointegration test.

Ultimately, the direction of causality between variables cannot be inferred by cointegration. Thus, the analysis employed the panel causality test suggested by Dumitrescu and Hurlin (DH) [2012] to investigate these relationships and provide vital information to policymakers for performing effective, applicable policies. As a result of this analysis, Variable Z was considered to have 'Granger-caused' Variable Y if (and only if) it was possible to enhance the forecast of Y by considering lagged values of Z as well as lagged values of Y rather than not doing so (Granger, 1969). Heterogeneity and CSD were overcome using this technique. Similarly, this method is highly adaptable as it can be utilised irrespective of whether N < T or N > T. Similarly, it applies to unbalanced panels (Koçak & Şarkgüneşi, 2017). DH (2012) found that the test statistics remained comparatively robust using Monte Carlo simulations despite small data and CSD. DH suggested the subsequent linear version to test panel causality.

$$Y_{i,t} = \beta_i + \sum_{K=1}^{K} \varphi_i^{(k)} Y_{i,t-k} + \sum_{K=1}^{K} \delta_i^{(k)} X_{i,t-k} + \varepsilon_{i,t} \tag{4}$$

where $\delta i = (\delta_i^{(1)}, \delta_i^{(2)}, \delta_i^{(3)} ....\delta_i^{(k)})$, β_i country fixed effects, $\varphi_i^{(k)}$ is lag parameters, K is the lag length and $\delta_i^{(k)}$ is coefficient parameters. $\varphi_i^{(k)}$ and $\delta_i^{(k)}$ denote the differences between the units. In contrast to Weinhold's (1996) causality test, these coefficients are fixed over time. In contrast to Swamy (1970), the fixed effect model was used here. According to the DH causality test, the hypotheses are as follows:

$$\mathrm{H0} : \delta_i = 0, \lambda \mathrm{i} = 1, 2, ...\mathrm{N}$$

$$\mathrm{H1} : \delta_i = \mathrm{o}, \lambda \mathrm{i} = 1, ...\mathrm{N1}$$

$$\delta_{ii} \neq 0, \lambda \mathrm{i} = \mathrm{N1} + 1, \mathrm{N1} + 2......., \mathrm{N}$$

A homogeneous outcome is obtained by the DH causality test's null hypothesis (Ho), while the alternative hypothesis obtains a heterogeneous outcome. Therefore, the Ho of the DH panel causality test shows no causal relationships in the panel, while the alternative hypotheses (H1) assert that causal relationships occur in at least one unit. The Ho is rejected whenever the calculation likelihood value is less than the significance value. In the opposite case, Ho cannot be rejected. By calculating the Wald statistics for each unit, Dumitrescu and Hurlin have calculated the test statistic for each cross-section. They computed the Wald test statistic for the panel by computing the mean of these separable test statistics. The Wald test statistic for the panel was:

$$W_{N,T}^{Hnc} = \frac{1}{N}\sum_{i=1}^{N} W_{i,T} \tag{5}$$

4. Results and discussion

The results of Pesaran and Friedman's cross-sectional tests are presented in Table 3. Both tests consistently found a signal of unit dependency in the data. Ho rejected the hypothesis that cross-sectional units are independent of the entire variable set. Due to the lack of independence of each variable across sections, the first generation of unit root techniques was not applicable. The CIPS unit root test results for the panel are given in Table 4. All variables selected were integrated at order one, according to the results. The CADF test was implemented to ensure that the CIPS test analysis results obtained from Pesaran were robust. The CADF test belongs to the set of second-generation tools. The CADF test results have not been presented; however, they are obtainable upon request, and the outcomes of the CIPS test were substantiated.

The outcomes of Pesaran and Yamagata (2008) analysis of coefficient homogeneity are displayed in Table 5. The findings revealed that both tests' ($\acute{\Delta}$ and Δ adj) were

Table 4. Unit root test.

	Level		First difference	
All Variables	C	C + T	C	C + T
LGDP	−1.41	−1.99	−3.55*	−3.94*
LK	−1.62	−2.46	−3.90*	−4.02*
LL	−1.96	−2.07	−2.44*	−2.70**
LICT	−1.73	−1.91	−3.28*	−3.26*

*denotes the rejection of the null at 1%.
C refers to Constant, and T refers to time trend.
With C, critical values at 10%, 5%, and 1% are -2.03, -2.11, and -2,25, respectively.
With C + T, critical values at 10%, 5%, and 1% are -2.54, -2.62, and -2,76, respectively.
Source: author's calculation.

Table 5. Homogeneity of slope test.

Test	Statistic
Δ	9.68*
AdjΔ	11.71*

*denotes the rejection of the null of slope homogeneity at 1%.
Source: author's calculation.

statistically significant at the 1% level, signifying that the slope homogeneity hypothesis was rejected. This finding was expected since African countries are at different development levels, and there is variation in their ICT infrastructure. It was thus necessary to keep in mind, in the next step, that the variables were not unrelated across units; they were instead integrated at order one and were heterogeneous.

An analysis of long-run relationships is presented in Table 6. Both tests verified long-run associations between the variables for all panels.

Aydin (2019) stated that a series must be stationary when examining a causality association. Accordingly, the first difference for the variables integrated at I(1) was used (as shown in Table 5). In Table 7, DH's (2012) panel causality test results are presented using the bootstrap procedure, which mitigated the effect of cross-sectional dependence. First, it should be mentioned that the findings were robust for different lag lengths. The results identified capital and employment as the primary sources of growth in per capita income in these economies. Because the primary aim of the present study was to investigate the possibility of a two-way relationship between ICT and per capita GDP growth, the analysis focused mainly on findings related to that goal. The results showed a unidirectional causality relationship from growth in per capita GDP to ICT services, supporting the demand-following hypothesis (DFH). This finding implied that ICT development in Africa in recent decades was not reflected in the growth in per capita income. The results were consistent with Shiu and Lam (2008) for low-income countries in Europe. However, this study's findings contradicted with those of Cieślik and Kaniewska (2004), Veeramacheneni et al. (2011), Pradhan et al. (2014), Pradhan et al. (2016), Latif et al. (2018), Sawng et al. (2021), Pradhan et al. (2021), Saba and Ngepah (2022), and Pradhan et al. (2022). This study's findings differed from those of the previous studies because there were differences in the control variables, period, countries included, and methodology.

In contrast, the opposite was true; the shown growth in per capita income translated into an expansion in the development of ICT services. The present study's findings supported the demand-following hypothesis (DFH), which argues that causality

Table 6. Cointegration test.

Tests	Ho: No cointegration; Ha: All panels are cointegrated
Pedroni test	
Modified Phillips-Perron t	3.41*
Phillips-Perron t	−1.60**
Augmented Dickey-Fuller t	−1.88**
Westerlund test	
Variance ratio	−2.41*

* and **denote Ho of No cointegration rejection at 1% and 5%, respectively.
Source: author's calculation.

Table 7. Heterogeneous panel causality test.

The direction of the causality	W-bar	Z-bar	p-value
LICT → LGDP	1.90	−0.30	0.77
LGDP → LICT	3.65	4.99	0.000*
LK → LGDP	2.65	20.08	0.04**
LL → LGDP	2.93	2.99	0.000*

* and **denote significant at 1% and 5%, respectively.
Source: author's calculation.

instead runs from real per capita growth to ICT services. The deployment of ICT services is seen as a by-product or outcome of economic growth by supporters of the demand-following hypothesis. According to this hypothesis, more ICT infrastructure is required as an economy grows. However, the result was expected and was in line with several arguments. Among the reasons that ICT deployment has had negligible or no influence on per capita GDP growth in developing nations has been an inadequate level of investment, a lack of human skills, and ineffective policies (Dewan & Kraemer, 2000; Niebel, 2018). The expansion of ICT services was necessary. However, it was insufficient to generate growth in per capita income. World Bank Group (2016) showed that the correct understanding of the relationship between contemporary technologies and elements critical for emerging nations is vital to maximise the growth of ICT services. These factors were called "analogue complements" and were broken down into three parts: regulations, accountable institutions, and better training. The finding implied that the observed expansion in ICT services in Africa contributed nothing to millions of people's living standards over recent decades. Without promoting the capacity of the economy to observe ICT services and translate them into productive use, the argument of "leapfrogging" through ICT development discussed above will not take place in Africa. The present study's findings suggested that physical capital has driven economic growth in the SSA region, which accorded with the neoclassical economic model. The results of this study also suggested that employment was the second key factor driving regional economic growth. Therefore, per capita GDP was expected to grow by providing more regional employment opportunities.

4.1. Robustness checking

To ensure robustness, the present analysis re-estimated the causal analysis using composite indices for ICT constructed by the African Development Bank. Among the fundamental indicators applied in the formation of this index were: (1) entire phone subscriptions, fixed line + cellular mobile), (2) internet subscribers, (3) fixed broadband (wired) users, (4) bandwidth (Mbps) worldwide over the Internet). The Score for the index ranged between 0 and 100, with low scores suggesting poor functionality. The results, which are not reported here but available upon request, show that causality ran in the same direction as in Table 7.

5. Conclusion and policy implications

In 2015, the African Development Bank (AFDB) reported that the mobile telecom industry had experienced a period of high development from 2005 to 2010, marked by the entry of additional operators, the development of additional coverage, and the growth of broadband speeds. Likewise, contemporary undersea and overland cable schemes were established from 2010 to 2015, providing massive further capacity throughout coastal Africa while permitting mobile firms to integrate. Additionally, the private sector has invested heavily, and public-private partnerships have emerged in some nations, fostering economic development. At the same time, data has shown that Africa has also witnessed remarkable growth in per capita GDP since the early 1990s. Thus, the current study sought to answer whether there was any causal association between the two. Previous studies in Africa have focused on whether ICT services have had a significant influence on per capita GDP growth while ignoring the possibility of a reverse impact. The current study has contributed to the contemporary literature on the ICT-growth nexus in the SSA region by first exploring whether or not there was a causality association between the two variables. Secondly, the present study employed previously overlooked robust techniques for CSD, slope homogeneity, and panel causality. Thirdly, previous studies that have concentrated on the ICT-economic growth nexus in Africa have tended only to use one or two components of ICT services (mobiles, telephones, Internet). The current study built an ICT index that included these three components. Therefore, the function of ICT investment in GDP expansion was recognised using an inclusive measurement of ICT.

The current research employed the Solow (1956) neoclassical aggregate production function on data related to 42 African countries from 2000 to 2019. The results showed a unidirectional causality relationship from per capita income to ICT services for the variables of interest. The findings implied that the witnessed economic progress in Africa over recent decades was not due to the observed massive expansion in ICT services. Capital stock and employment were crucial factors that might explain such progress in the GDP per capita. The absence of feedback from ICT development to growth may have been due to the lack of absorptive capacity (regulations, accountable institutions, and improved skills). This situation might have translated the ICT infrastructure development into the increased production of final goods and services, constituting the possible justification for the findings. Thus, it will be hard for African countries to benefit from their growing ICT services to expand the standard of living and reduce the poverty rate unless more resources are allocated to promote the absorptive capacity of their economies. The outcomes of the present study propose that the SSA region countries need to implement policies and strategies to accumulate physical capital and generate more jobs. Such a strategy will increase per capita income, which will, in turn, stimulate demand for ICT services. As the demand for ICT services grows, more investment will be made in the sector. SSA region countries can implement various policies and strategies to accumulate physical capital and generate more jobs. Some of these include *encouraging foreign investment*: SSA countries can create favourable conditions for foreign direct investment (FDI) to increase capital inflows into the region. Tax incentives, streamlined regulations, and improved infrastructure help achieve this.

Governments can also support their growth by developing local businesses through loans, subsidies, and mentorship programs. This situation will increase entrepreneurship and stimulate job creation. Likewise, *investing in infrastructure*: Building roads, bridges, ports, and other essential infrastructure can attract investment and create jobs in the construction sector. As well as *improving education and training,* providing education and training programs can equip citizens with the skills necessary to participate in the modern economy, creating a more skilled labour force.

Similarly, *promoting exports*: Encouraging local businesses to expand their markets and exports can help increase demand for local products and create jobs. Likewise, encouraging technological innovation: Investing in research and development and promoting innovation can lead to new businesses and industries, increasing economic growth and creating jobs. It is critical to note that the specific policies and strategies appropriate for an SSA country will depend on its unique economic conditions and goals.

Even though the study's findings were not optimal for these countries, they have indicated the need for further study. The coefficients of each variable were not estimated in this study. However, fresh approaches to investigation that handle the issues of CSD and heterogeneity are becoming available, for example, the CS-ARDL and Dynamic Common Correlated techniques. Firstly, it should be noted that such new methods involve a much larger time series (T) than the cross-section (N), which was not possible in the present research (in this study's case, $N < T$). Secondly, they have not been evaluated for reliability yet. ICT development could also be measured using different sources in future studies. It has been suggested that the lack of high-quality micro- and macro-level data on ICT infrastructure in developing countries may contribute to the minor influence of ICT deployment on the GDP growth in such economies.

Moreover, the present study used a simple production function, which could be extended by introducing additional variables reflecting the economy's absorption capacity. Future research might consider other control variables or specifications of the initial model. In addition, the present study agreed with Vu et al. (2020), who argued that ICT-growth research should move from validating a positive influence on GDP per capita growth to explaining how and why ICT affects economic growth in direct or indirect ways. The effect of the global digital revolution on growth can be enhanced by identifying critical factors for policymakers on which to focus. In addition, the current study focused on the impact of the availability of ICT services on growth. It might be interesting to study the effect of accessibility and affordability of ICT services on economic growth in the SSA region.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix A

Table A1. Principal component analysis.

Component	Eigenvalue	Proportion	Cumulative
Comp1	2.47228	0.8241	0.8241
Comp2	0.352562	0.1175	0.9416
Comp3	0.175154	0.0584	1

Source: author's calculation.

Table A2. Principal component analysis.

Variable	Comp1	Comp2	Comp3	Unexplained
Log broadband	0.5539	0.8226	0.1285	0
Log Internet	0.5941	−0.2824	−0.7532	0
Log mobile	0.5833	−0.4935	0.6451	0

Source: author's calculation.

Table A3. List of the countries included.

Angola	Kenya
Benin	Lesotho
Botswana	Liberia
Burkina Faso	Madagascar
Burundi	Malawi
Cabo Verde	Mali
Cameroon	Mauritania
Central African Republic	Mauritius
Chad	Mozambique
Comoros	Namibia
Congo, Dem. Rep.	Niger
Congo, Rep.	Nigeria
Cote d'Ivoire	Rwanda
Equatorial Guinea	Senegal
Eritrea	South Africa
Eswatini	Sudan
Gabon	Tanzania
Gambia, The	Togo
Ghana	Uganda
Guinea	Zimbabwe
Guinea-Bissau	

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