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THE NEXUS BETWEEN ICT DIFFUSION, FINANCIAL DEVELOPMENT, INDUSTRIALISATION AND ECONOMIC GROWTH: EVIDENCE FROM SUB-SAHARAN AFRICAN COUNTRIES

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Abstract

This study examines the nexus between ICT diffusion, financial development, industrialisation, and economic growth using a novel panel VAR approach in the generalized method of moments (GMM) estimation. Different proxies were used to measure the mentioned variables, instead of the popular measures employed in previous literature. Based on panel data covering 45 countries from 2000 to 2018, the empirical results suggest that there is bidirectional causality between: ICT diffusion and economic growth; financial development and industrialisation; financial development and economic growth; industrialisation and economic growth. The findings further provide evidence that financial development, levels of industrialisation, and economic growth are not significant or positive predictors of ICT diffusion. The study's implications for policy are profound, suggesting that SSA governments should adopt a holistic approach to economic policy development, integrating ICT, financial, and industrial policies to harness these interdependencies effectively.

Keywords: ICT diffusion; financial development; industrialisation; economic growth; Sub-Saharan African countries

1. Introduction

As Information and Communication Technology (ICT) permeates every sector of the economy, its past, present, and potential future impacts on Africa's economy cannot be overstated, despite the challenges it faces (Liu et al., 2022; Adeleye et al., 2022; Asongu and Odhiambo, 2023). Studies examining the relationship between ICT/telecommunication infrastructure and economic growth conclude that there is a positive correlation between these variables (for example, Ng'ambi, 2006; Andrianaivo and Kpodar, 2011; Myovella et al., 2020; David, 2019a, 2019b; Nchofoung and Asongu, 2022; Albiman and Sulong, 2017; Owoeye et al., 2022; Tchamyou et al., 2019a; Adeleye and Eboagu, 2019; Ofori and Asongu, 2021; Haftu, 2019; Bilan et al., 2019; David and Grobler, 2020). Furthermore, some studies have reported negative or mixed effects (for example, Ishida, 2015; Yousefi, 2011; Lee et al., 2005; Hassan and Islam, 2005). Prominent factors identified in the empirical literature that could influence financial development levels across countries include poverty and inequality, income, inflation, FDI, productivity, institutions, and trade openness (for example, Levine, 1997; Beck, 2002; Beck et al., 2007; Alfaro et al., 2009; Bittencourt, 2011; Hodler, 2011; Tchamyou et al., 2019a). While other factors have been considered in the literature, ICT as a potential driver of financial development, industrial development, and growth has not received much attention in the context of Africa. Focusing on Africa is crucial, given that it is a developing region with a pressing need to leverage ICT/telecommunication services for financial development, industrialisation, and growth.

Most financial development studies, whether they focus on the effect of ICT diffusion or other macroeconomic variables, seldom explore the impact of ICT diffusion on the complex multidimensional nature of financial development. Examining the effect of ICT diffusion on the multidimensional aspects of financial development has become essential in Africa. This is because the global financial sector supports the ICT/Telecommunication and industrial sectors through loans and technical assistance (World Bank, 2017; Udoh and Ogbuagu, 2012). As Africa's economy becomes more integrated with the global economy, its businesses and citizens increasingly need access to financial services to compete effectively. Since ICT and financial services can complement each other, ICT is a way to increase financial access. ICTs can facilitate financial inclusion, and the financial services sector drives communications and network technology (World Bank, 2012). Many financial companies have integrated ICT/telecommunication services with internal process modernization to offer enhanced services such as mobile cash transfers, remittances, and bill payments (Cheng et al., 2021).

Most empirical studies use the ratio of private credit to GDP or stock market capitalization to GDP as proxies for financial development. Following previous literature, we use these indicators. Our study builds on research by Yartey (2008), Ahmad and Schreyer (2016), Pradhan et al. (2016), Nguyen et al. (2020), Mignamissi (2021), Alraja et al. (2023), Alshubiri et al. (2023). but differs in several ways. Given the above discussion, although there has been substantial examination of the ICT-growth nexus, several gaps persist in the African context. Previous studies have largely focused on developed economies, with only a few exploring the impacts of ICT in African regions or on the process of industrialisation within developing contexts. This leaves a gap in understanding how ICT influences economic dynamics specifically in Africa, where different socio-economic conditions may alter these relationships. Secondly, most existing literature does not sufficiently address how ICT diffusion interplays with financial development and industrialisation concurrently, especially in African countries. There is a particular need to explore these relationships in depth, considering Africa's ongoing struggles with financial accessibility and industrial development. Thirdly, there is a notable deficiency in studies considering the multifaceted aspects of financial development influenced by ICT. Many analyses simplify financial development to one or two metrics, which may not fully capture the broad effects of ICT on the financial sector. On this basis, this study used three metrics to capture financial development.

Based on the research gaps identified in the literature, has ICT diffusion contributed to financial development in Africa (considering the three metrics identified in this study), as well as industrialisation and economic growth concurrently? We seek to answer this research question in this study. Therefore, the contribution of this study lies in its advancement of previous methodologies by employing a novel panel VAR (PVAR) approach within a GMM framework, which addresses endogeneity issues. This methodological innovation enables a more robust analysis of ICT diffusion and financial development, as well as industrialisation and economic growth, within the context of Africa. Unlike previous studies that might have limited their analyses to fewer countries or shorter time frames, this research expands its scope to include a larger sample size of 45 African countries over an extended period from 2000 to 2018. This expanded scope is designed to enhance the generalizability and relevance of the findings, making them more applicable across different African contexts and providing deeper insights into the transformative potential of ICT in the region.

This study further contributes to the literature by providing a holistic economic evaluation. By integrating ICT with financial development and industrialisation within its analytical framework, the study offers a comprehensive view of the economic impact of ICT. This is particularly relevant for policy-making in Africa, where these areas are crucial for sustainable economic development and catching up with global economic standards. This research fills a crucial gap by emphasizing the role of industrialisation, an often under-explored area in ICT-related economic studies, particularly in the context of African economies. By doing so, it aligns with historical economic theories that regard industrialisation as a primary engine of growth (Kaldor, 1966, 1967) and examines how ICT can facilitate this process. According to Prakash (2019), "*industrialisation supported by ICT could be a chosen pathway for regional growth/development and integration into global markets for goods and services.*" Hence, the role of ICT in promoting financial development, industrialisation, and economic growth cannot be overemphasized (Lerner, 2010; Saba et al. 2023a; Saba and Ngepah, 2021).

The findings of this study underscore the need for SSA countries to adopt a holistic and integrated approach to policymaking that considers the interconnectedness of economic sectors. By fostering a coordinated development strategy, SSA countries can enhance resilience against economic shocks, improve the efficiency of investments, and ultimately achieve sustainable economic growth. Additionally, there is a critical need to build capacity and infrastructure that supports such integrated policy initiatives, ensuring that all sectors are adequately prepared to contribute to and benefit from economic advancements.

The remaining sections of this article are structured as follows: Section 2 reviews related literature; Section 3 focuses on the methodology; Section 4 presents the empirical results and discussion; and Section 5 provides the conclusion and policy recommendations.

2. Literature review

Given the clear impact of ICT on economic and financial growth and its long-term development (Grace et al., 2003; Hye et al., 2023; Al-Malki et al., 2023), and due to its economic, financial, and social repercussions across various sectors, ICT is one of the most significant industries for governments. As global economies become more digitalised, it is crucial to investigate the role of ICT in the complex, multidimensional nature of financial development in Africa to guide policy direction. Since ICT enables easy access to information, improved bank credit, and the transfer of funds/remittances (Asongu, 2013). Since ICT enables easy access to information, improved bank credit, and the transfer of funds/remittances (Asongu, 2013), prior studies measured ICT by mobile phone penetration. For example, Donner and Tellez (2008) found that: (i) users with bank accounts can store value (currency) accessible through a handset; (ii) they can convert their cash into and out of the stored value account; and (iii) they can transfer stored value between different banks and accounts.

Demombynes and Thegeya (2012) investigates the mobile-finance nexus and identify two types of mobile savings: (i) basic mobile savings and (ii) partially integrated mobile savings systems. The former involves using a standard mobile money system, while the latter involves accessing a bank account through a mobile phone, which depends on establishing a traditional account at a physical bank (Asongu, 2013). Asongu (2013) examines the nexus between mobile phone penetration and financial development in a sample of 52 African countries. He finds a growing role of informal finance and suggests that mobile phone penetration may not be positively reflected at a macroeconomic level by traditional financial development indicators. Bansal (2014) investigates the relationship between ICT diffusion and banks' operational levels. The study's findings reveal that formal commercial banks were able to reduce transaction costs and boost managerial efficiency through the national electronic financial inclusion system, ATMs, and other technologies. Using a quantile regression approach, Asongu and Acha-Anyi's (2017) study investigates the role of ICT in the conflicts of financial intermediation for financial access across 53 African countries from 2004 to 2011. The study's results show that ICT has a positive threshold impact on the banking system and a negative threshold impact on the financial system.

Studies examining the nexus between ICT and financial development/inclusion include Andrianaivo and Kpodar (2011), Onaolapo (2015), Asongu and Acha-Anyi (2017), Mushtaq and Bruneau (2019), Lashitew et al. (2019), Karakara and Osabuohien (2019), Razzaq et al. (2024), among others. Although these studies focused on different countries/regions, they consistently found that ICT penetration, in various ways, boosts financial inclusion/development. For example, Yartey (2008) examines the ICT-financial structure-financial development nexus in 76 emerging and advanced countries from 1990 to 2003. The study uses the dynamic GMM estimator to achieve its objective. The findings indicate that measures of financial development (such as credit and stock market development) promote ICT diffusion, whereas the financial structure is influenced by ICT diffusion. Using a data that spans from 2018 to 2019, Aziz and Naima's (2021) study explores financial inclusion and the use of digital technologies, proposing a comprehensive framework for digital financial inclusion. Their findings show that the social dynamics of financial engagement with new technologies require moving beyond a simple individualistic adopter/non-adopter binary framework and a 'supply-oriented' financial infrastructure. Marszk and Lechman (2021) examines the impact of ICT on the diffusion of financial innovations in European countries from 2004 to 2019. Using panel and country-specific regression models, their findings indicate that ICT penetration facilitated the development of innovative financial products across the study's countries. Additionally, while ICT significantly influenced the diffusion of exchange-traded funds, the development of these markets remains limited across the countries examined.

Alshubiri's (2020) study examines the effect of ICT price baskets on financial development in Gulf Cooperation Council (GCC) countries from 2008 to 2016, using econometric methods like GMM and fixed effects to analyze data on domestic credit and market capitalization. The findings indicate varying impacts of ICT prices across countries, with a positive correlation between ICT prices and stock market development particularly noted. Conversely, Nguyen et al.'s (2020) research investigates the influence of internet and mobile usage on financial development across 109 economies from 1998 to 2017, employing techniques such as Granger causality and GMM. Their results show a complex relationship where internet usage negatively affects financial institutions but positively impacts financial markets, with a generally positive effect of internet and mobile usage on financial development indices.

Literature examining the nexus between ICT and bank performance can be grouped into micro studies (*inter alia*: Delgado et al., 2007; Onay and Ozsoz, 2013; Scott et al., 2017) and macro studies (*inter alia*: Sassi and Goaied, 2013; Beck et al., 2016). Del Gaudio et al. (2021) study the impact of mobile, internet, and ICT diffusion on the profits and risk of financial distress in the EU-28 banking industry from 1995 to 2015. The results show that ICT has a positive impact and contributes to the overall financial stability of the banking industry. Studies examining the ICT-economic growth-development nexus alongside other explanatory variables (such as FDI, trade, inequality etc.) include Hofman et al. (2016), Appiah-Otoo and Song (2021), Abdulqadir and Asongu (2022), Saba et al. (2023), Asongu and Odhiambo (2020), Hussain et al. (2023), Nkemgha et al. (2023), Behera et al. (2024), among others.

Using a panel of 123 countries between 2002 and 2017, Appiah-Otoo and Song (2021) examines the economic growth effect of ICT by comparing rich and poor countries. The findings reveal that ICT supports economic growth in both types of countries and that the benefits of ICT revolution in poor countries outweigh those in rich countries. In a similar study to that of Appiah-Otoo and Song (2021), using a growth accounting approach, Hofman et al. (2016) examined economic and sectoral productivity issues in Latin America from 1990 to 2013. The study finds that improved labor factors have reduced the GDP per capita gap with the US, but poor labor productivity and a widening ICT capital gap counteract human capital improvements in Latin America. ICT's contribution is minimal, while capital is the main growth driver in transportation and communications, supported by high ICT investment. Focusing on Latin America and the Caribbean (LAAC), sub-Saharan Africa (SSA), and the Middle East and North Africa (MENA) using a comparative approach, Saba et al.'s (2023) study examines the ICT-economic growth-development nexus for these three regions during the period 2000–2018. The study finds that ICT diffusion positively influences growth and development across regions, with a notably stronger impact on growth in MENA. It highlights the importance of understanding the relationship between ICT diffusion, economic growth, and development, suggesting that policymakers and telecom managers should enhance ICT infrastructure to promote sustainable and inclusive growth.

Abdulqadir and Asongu (2022) examines the economic growth asymmetric effect of internet access in SSA countries and conclude that the internet has a threshold effect of 3.55% on economic growth, using the two-step system-GMM approach. Using the GMM method and focusing on 25 SSA countries for the period 1980–2014, Asongu and Odhiambo (2020) examines the ICT-FDI-economic growth nexus and finds that ICT modulates FDI to induce overall positive net effects on economic growth dynamics. Hussain et al.'s (2023) study, based on innovation diffusion theory, finds that ICT and finance are crucial for sustainable economic development in 102 developing countries. Their study utilized Driscoll–Kraay (D-K), Generalized Linear Model (GLM), Feasible Generalized Least Squares (FGLS), and Difference GMM approaches to obtain consistent results. In a different study, Nkemgha et al. (2023) find heterogeneous positive net effects of financial development and human capital on industrialisation when these factors interact with infrastructure for 33 African countries during the period 2003–2019 using the system GMM methodology. Behera et al. (2024) examines the ICT-growth nexus by considering the role of institutional quality, foreign direct investment, financial development, and innovation in 13 emerging economies between 2000 and 2020. Using the fixed effects, Panel Corrected Standard Error (PCSE) and D-K models, they discovered that the use of ICT significantly boosts growth independently of institutional quality and FDI, while its moderating effects with financial development and R&D expenditures are beneficial to growth.

Research gap

This review of the literature suggests that while considerable progress has been made in understanding the role of ICT in economic and financial development, further research is needed to unravel the nuanced impacts across different economic settings and to explore new models that better capture these dynamics. The current research landscape calls for studies that bridge these gaps with innovative methodologies and broader, more inclusive data analysis, particularly in under-researched regions and sectors. Furthermore, the literature shows that previous research has mainly focused on the relationships between ICT and economic growth, financial development and economic growth, and the combined impact of ICT and financial development on economic growth. However, these studies have not developed innovative measures for ICT diffusion and financial development, nor have they examined their dynamic roles in promoting industrialization and economic growth in the context of 45 African countries from 2000 to 2018. This study fills this research gap by analyzing the ICT diffusion-financial development-industrialisation-economic growth nexus using the novel PVAR-GMM method, which addresses endogeneity issues.

3. Methodology and data

3.1 Empirical Strategy and Panel VAR model in GMM estimation framework

In this study, we employed a panel VAR[4] in a GMM (PVAR-GMM) estimation framework, an extension of the traditional panel vector autoregression (VAR) model introduced by Sims (1980), to explore the nexus between ICT diffusion, financial development, industrialisation, and growth. Following the models of Sassi and Goaied (2013), Cheng et al. (2021), and Saba and Ngepah (2021), we utilised economic growth model incorporating ICT diffusion, financial development, and industrialisation.

This methodology (i.e., PVAR-GMM) offers several advantages that justify its use for the study, as follows:

1. All variables in the model are treated as independent and endogenous, without concern for the direction of causality.

2. Each variable is explained by its own lags and the lagged values of other variables.

3. It is not a single-equation model, unlike other models.

4. It accommodates unobserved individual heterogeneity.

5. It improves asymptotic results and simplifies the choice of suitable instrumental variables.

6. The model can be estimated regardless of whether the variables are cointegrated, due to the GMM framework.

7. It minimizes data loss typically associated with first-difference transformations.

This method enhances estimate efficiency and effectively addresses the issue of weak instruments, common in dynamic panel data models. Canova and Ciccarelli (2004) simplified the general presentation of the PVAR model, as given below;

$$y_{i,t} = Z_0\psi_{i,t} + V_1 y_{i,t-1} + \cdots + V_\varphi y_{i,t-\varphi} + \varepsilon_t \quad (1)$$

Where $y_{i,t}$ is a $K \times 1$ vector of a K panel data variables, $i = 1, \dots, I, \psi_{i,t}$ is a vector of deterministic terms, Z_0 is the associated parameter matrix, and the $V's$ are a $K \times K$ parameter matrices attached to the lagged variables $y_{i,t-\varphi}$. The lag order (VAR order) is denoted by φ, while the error term is ε_t. Four variables are included in the model: financial development (FDEV), manufacturing value-add as a percentage share of GDP (MAV), information and communication technology (ICT) diffusion, and real GDP (proxy for economic growth (RGDP)). The four variables in a PVAR model are represented as:

$$\begin{bmatrix} 1\ \psi_{12}\ \psi_{13}\ \psi_{14} \\ \psi_{21}\ 1\ \psi_{23}\ \psi_{14} \\ \psi_{31}\ \psi_{32}\ 1\ \psi_{14} \\ \psi_{41}\ \psi_{42}\ \psi_{43}\ 1 \end{bmatrix} \begin{bmatrix} \Delta MAV_{i,t} \\ \Delta ICT_{i,t} \\ \Delta RGDP_{i,t} \\ \Delta FDEV_{i,t} \end{bmatrix} = \begin{bmatrix} \psi_{10} \\ \psi_{20} \\ \psi_{30} \\ \psi_{40} \end{bmatrix} + \begin{bmatrix} V_{11}\ V_{12}\ V_{13}\ V_{14} \\ V_{21}\ V_{22}\ V_{23}\ V_{14} \\ V_{31}\ V_{32}\ V_{33}\ V_{14} \\ V_{41}\ V_{42}\ V_{43}\ V_{44} \end{bmatrix} \begin{bmatrix} \Delta MAV_{i,t-\rho} \\ \Delta ICT_{i,t-\rho} \\ \Delta RGDP_{i,t-\rho} \\ \Delta FDEV_{i,t-\rho} \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \end{bmatrix} \quad (2)$$

Where $y_{i,t}$ is a four-variable vector including 4 endogenous variables which all influence one another: FDEV, MAV, ICT and RGDP. The 4×4 matrix *W* contains the coefficients of contemporaneous relationships between the four variables. The GMM estimator is used to obtain consistent estimates of the parameter in Eq. (2). We consider the forward orthogonal deviations or Helmert transformation to the first-difference transformation to remove the panel-specific fixed effects in the panel VAR model. This is because fixed effects are usually correlated with the regressors due to lags of the dependent variables (Arellano and Bond 1991;

[4]The latest STATA pvar programs used for this study was made available by Abrigo and Love (2016) and it has been used by other researchers.

Blundell and Bond 1998). Unlike the first-difference transformation, the forward orthogonal deviations would minimize loss of data and allow the panel VAR model to yield efficient estimates due to its capability to overcome weak instrumentation (Abrigo and Love 2016; Arellano and 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 (henceforth, FEVD) and impulse response function (henceforth, IRF) models, this paper follows the IRFs and FEVDs framework provided by Abrigo and Love (2016)[5] which was an extension of Hamilton's (1994) and Lutkepohl's (2005) approaches. The use of IRFs and FEVDs within the PVAR-GMM framework allows us to dynamically explore the impact of shocks and innovations within the system, providing insights into the temporal effects of economic policies or external shocks.

3.2 Data

This study used annual panel data spanning from 2000 to 2018 for 45 Sub-Saharan African countries. A summary of the dataset can be found in Table 1 below, while Table 2 lists the countries used in this study.

Table 1: **Summary of Dataset**

Variables	Indicators	Variable description	Source of data
MAV	Industrialisation	Manufacturing value-added as a percentage share of GDP as a proxy for industrialisation. We used this measure by following previous studies such as Gui-Diby and Renard (2015), Marconi et al. (2016), Saba and Ngepah (2020) among others.	World Bank's World Development Indicators (WDI) database.
FDEV	Financial development	The financial development index was calculated using principal component analysis based on three variables: M3 to GDP, the ratio of private sector credit to GDP, and the total value of stock traded to GDP.	World Bank's World Development Indicators (WDI) database.
RGDP	Real gross domestic product	Real GDP (constant 2010 US$) serves as a proxy for economic growth.	World Bank's World Development Indic.ators (WDI) database.
ICT	Information and communication Technology	ICT diffusion is captured by a composite index of ICT indicators (which comprises of three indicators) by applying principal components method/analysis (PCA). 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); and (iii) percentage of Individuals using the Internet (percentage of population with access to the internet).	International Telecommunication Union database.

Note: To compose the composite index ICT, we follow the study conducted by David (2019) and Bera (2019). Similarly, to compose the composite index of financial development, we follow the study of Sassi and Goaied (2013) and Cheng et al. (2021).

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

Table 2: List of Selected Sub-Saharan African countries

Angola	Cabo Verde	Côte d'Ivoire	Ethiopia	Guinea-Bissau	Malawi	Namibia	Senegal	Tanzania
Benin	Cameroon	Dem. Rep. of the Congo	Gabon	Kenya	Mali	Niger	Seychelles	Togo
Botswana	Central African Rep.	Equatorial Guinea	Gambia	Lesotho	Mauritania	Nigeria	Sierra Leone	Uganda
Burkina Faso	Chad	Eritrea	Ghana	Liberia	Mauritius	Rwanda	South Africa	Zambia
Burundi	Congo (Rep. of the)	Eswatini	Guinea	Madagascar	Mozambique	Sao Tome & Principe	Sudan	Zimbabwe

4. Empirical results and discussion

4.1 Principal component and descriptive statistics results analysis

Before analysing the study, we first estimate the ICT diffusion and financial development variables using the principal component analysis/method (PCA/M). Given the significant correlation (at least at the 1% significance level) between the ICT and financial development indicators, we proceed with applying PCA to these indicators. The results in Table 3 are supported by Figures 1 and 2 (scree plots). Following the rule of thumb, we retained component 1, which has an eigenvector >1 and a loading exceeding 0.40 in absolute value for both ICT and financial development (Saba and David, 2020). We disregarded the remaining components as they did not meet the condition.

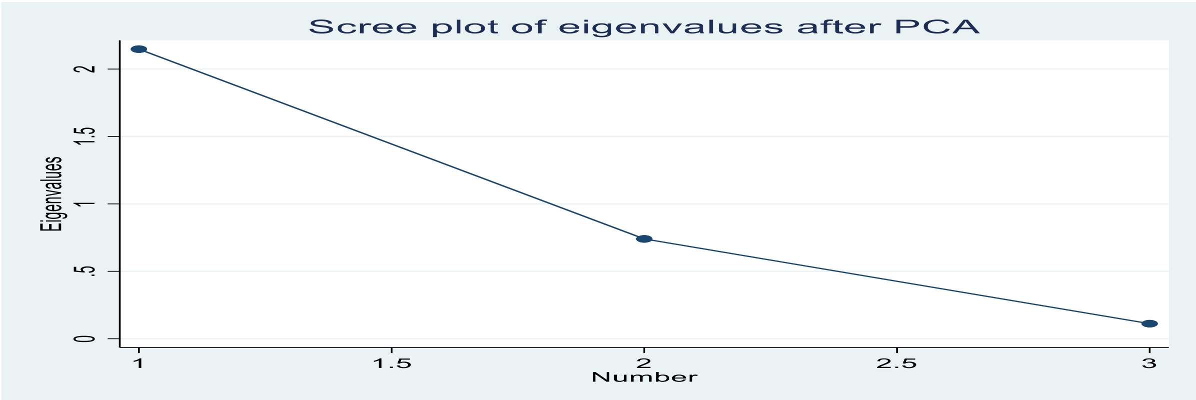
Table 3: Principal component and Correlation matrix results

Panel (A): Principal component results for ICT variable				
Component	Eigenvalue	Difference	Proportion	Cumulative
Component 1	2.148	1.407	0.716	0.716
Component 2	0.740	0.628	0.247	0.963
Component 3	0.112	-	0.037	1.000
Principal components (eigenvectors) results				
Variable	Component 1	Component 2	Component 3	Unexplained
Fixed-telephone	0.437	0.891	0.124	0
Mobile-telephone	0.622	-0.399	0.674	0
Internet access	0.649	-0.218	-0.729	0
Retained eigenvectors results				
Variable	Component 1	Unexplained		
Fixed-telephone	0.437	0.589		
Mobile-telephone	0.622	0.169		
Internet access	0.649	0.095		
Correlation matrix results				
Variables	Fixed-telephone	Mobile-telephone	Internet access	
Fixed-telephone	1.000			
Mobile-telephone	0.331*** (0.000)	1.000		
Internet access	0.456*** (0.000)	0.877*** (0.000)	1.000	
Panel (B): Principal component results for Financial Development				
Component 1	2.549	2.1873	0.850	0.850
Component 2	0.362	0.2736	0.121	0.971
Component 3	0.088	-	0.030	1.000
Principal components (eigenvectors) results				
Variable	Component 1	Component 2	Component 3	Unexplained
Stock traded share of GDP	0.544	0.821	0.177	0
Private sector credit share of GDP	0.604	-0.236	-0.762	0
M3 to GDP	0.583	-0.521	0.623	0
Retained eigenvectors results				
Variable	Component 1	Unexplained		
Stock traded to GDP	0.544	0.2465		
Ratio of private sector credit to GDP	0.604	0.07141		
M3 to GDP	0.583	0.1326		
Correlation matrix results				

Variables	Stock traded to GDP	Ratio of private sector credit to GDP	M3 to GDP
Stock traded to GDP	1.000		
Ratio of private sector credit to GDP	0.755*** (0.000)		
M3 to GDP	0.636*** (0.000)	0.822*** (0.000)	1.0000

Note: ****p* < 0.01; ***p* < 0.05; **p* < 0.1, p-value in parentheses. **Source:** Author's computations

A: ICT Diffusion



B: Financial development

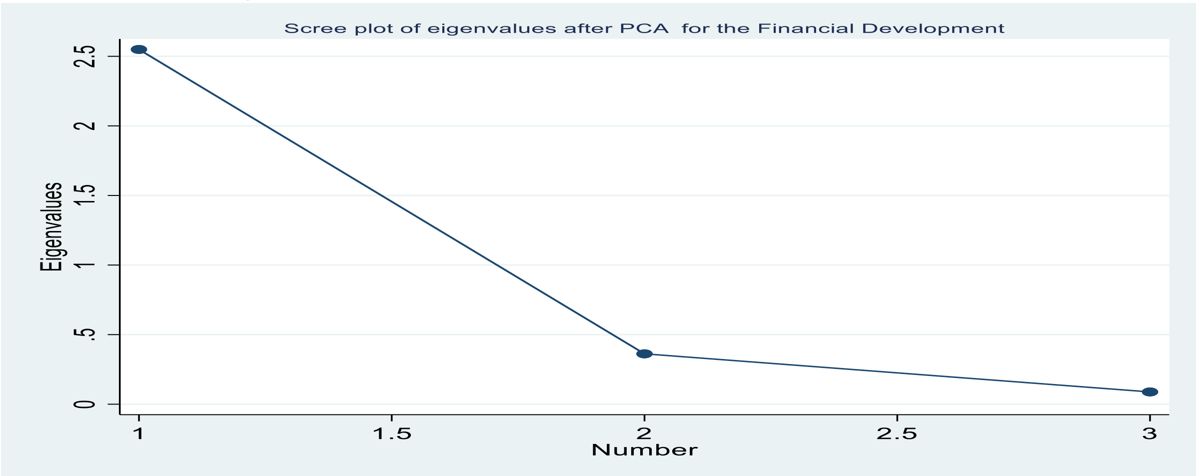


Figure 1: (**A**) ICT diffusion scree plot; and (**B**) financial development scree plot

Table 4 presents the descriptive statistics for the variables. For SSA, the mean (or median) values for ICT, financial development (FDEV), industrialisation (MAV), and real GDP (RGDP) are approximately 0.804, 4.08E-09, 2.499, and 24.574 (or 0.709, -0.127, 2.463, 24.212), respectively. The maximum and minimum values for these variables range between 26.874 and -3.220. The skewness values are both positive and negative, indicating a distribution that is positively and negatively skewed. The Jarque-Bera statistics suggest that the residuals of the variables are not normally distributed at least at the 5% significance level.

Table 4: Descriptive statistics results

Statistics	ICT	FDEV	MAV	RGDP
Mean	0.804	4.08E-09	2.499	24.574
Median	0.709	-0.127	2.463	24.212
Maximum	2.836	2.390	3.561	26.874
Minimum	-3.059	-3.220	1.733	20.883
Std. Dev.	1.302	1.596	0.418	1.671
Skewness	-0.704	-0.014	0.922	0.036
Kurtosis	3.489	1.741	3.743	1.740
J-Bera	9.079	6.467	16.165	6.494
Prob.	0.012	0.039	0.000	0.038
Obs	98	98	98	98

Source: Author's computations

4.2 Panel causality results analysis

This study utilised the panel VAR Granger causality test, to examine the causal relationship between ICT diffusion, financial development, industrialisation and economic growth. In Table 5, the results suggest strong evidence of bidirectional causality between: (i) ICT diffusion and growth; (ii) financial development and industrialisation; (iii) financial development and growth; and (iii) industrialisation and growth. While the results further suggest that unidirectional causality runs from: (i) financial development to ICT diffusion; and (ii) industrialisation to ICT diffusion.

According to this study, the bidirectional causal relationship between ICT diffusion and economic growth shows that as SSA nations' economies expand and become more technologically linked, it enables further ICT adoption and investment. This illustrates ICT's dual role in promoting and facilitating economic progress. The reciprocal relationship between ICT and growth is supported by earlier research, such as that by Czernich et al. (2011). The discovery of a bidirectional causal relationship between financial development and industrialisation suggests that, while financial markets and institutions in SSA are crucial for expanding the industrial sector by providing capital, industrialisation can also enhance financial markets by increasing the number of investment opportunities and diversifying the financial services available. This is consistent with the findings of Da Rin and Hellmann (2002), Akçay (2019), and Shahbaz et al. (2018), who demonstrated that the financial sector plays a crucial role in the industrial process.

This bidirectional relationship underscores the crucial role of financial development in facilitating economic growth and, conversely, how economic growth can further stimulate financial development. This finding aligns with studies by Blackburn and Hung (1998), Blackburn et al. (2005), Wolde-Rufael (2009), and Musamali et al. (2014), which observed that financial development both results from and drives economic growth. However, the results of this study contradict the findings of Ram (1999), De Gregorio and Guidotti (1995), and Ang (2008), among others. The mutual causality between industrialisation and economic growth emphasizes the traditional view that industrialisation is a key engine for economic growth. This relationship has been extensively documented in the literature, including by Szirmai (2012), who highlighted the transformative role of industrialisation in modern economic development.

The unidirectional causality from financial development to ICT diffusion indicates that a well-developed financial sector is crucial for promoting ICT by supplying the necessary financial resources for ICT investments. This finding contradicts the results of Yartey (2008), Comin and Nanda (2019), and Alshubiri et al. (2019). Additionally, the unidirectional causality from industrialisation to ICT diffusion suggests that industrial growth may drive increased ICT adoption, as industries aim to enhance efficiency and productivity through technology in SSA. This justified the use of a panel causality test based on the GMM estimator, which addresses endogeneity issues in the panel VAR model through instrumentation (Abrigo and Love, 2016).

Table 5: Panel VAR-Granger causality Wald test, Chi square-value results

Model	Null hypothesis	chi2	p-value	Direction of relationship observed	Conclusion
1	ICT↛ FDEV	2.301	0.129	FDEV→ICT	Unidirectional causality
	FDEV ↛ ICT	29.894***	0.000		
2	ICT↛ MAV	0.001	0.977	MAV→ICT	Unidirectional causality
	MAV ↛ ICT	5.179**	0.023		
3	ICT↛RGDP	38.776***	0.000	ICT ↔ RGDP	Bidirectional causality
	RGDP↛ ICT	7.555***	0.006		
4	FDEV↛ MAV	21.044***	0.000	FDEV↔MAV	Bidirectional causality
	MAV↛ FDEV	9.602***	0.002		
5	FDEV ↛RGDP	4.079**	0.043	FDEV↔RGDP	Bidirectional causality
	RGDP↛ FDEV	18.565***	0.000		
6	MAV↛RGDP	20.347***	0.000	MAV↔RGDP	Bidirectional causality
	RGDP↛ MAV	6.911***	0.009		

Note: ↔ and → denote bidirectional and unidirectional causality respectively. ↛ denote $\mathbf{H_o}$: Excluded variable does not Granger cause equation variable. Here the $\mathbf{H_1}$ is excluded variable does Granger cause equation variable. *** p<0.01, ** p<0.05, * p<0.1. **Source:** Author's Computations

4.3 Panel VAR in GMM results analysis

Table 6 presents the panel-VAR results. Firstly, the ICT equation reveals that, at the 1 percent significance level, both financial development and industrialisation are negatively related to ICT diffusion and statistically insignificant. This suggests that a 1 percent increase in financial development and industrialisation will not impact the rate of ICT diffusion in SSA. Conversely, if economic growth increases by 1 percent, ICT diffusion will decrease by 0.31 percent. The policy implications of these results are that to promote ICT diffusion in SSA by 0.01 percent, significant transformations in the financial and industrial sectors are needed. Additionally, policies in these sectors must be ICT-friendly. ICT has a positive and significant impact on financial development and economic growth.

Financial development has a negative and significant effect on industrialization and economic growth. This impact of financial development on economic growth in SSA aligns with findings by Ram (1999), Cheng et al. (2021), and Arcand et al. (2012). Several factors may explain this negative impact in SSA, including: (i) high interest rates leading to increased long-term risks (Yong et al., 2009); (ii) bank risks due to lower capital holdings and excessive lending (Nijskens and Wagner, 2011); and (iii) investors seeking higher returns from short-term investments due to excessive stock market liquidity, which results in inadequate monitoring of company performance and subsequently hinders economic growth (Bhide, 1993). The results reveal that ICT development boosts growth by enhancing the efficiency of information transmission and dissemination, consistent with the findings of Vu (2011) and Sassi and Goaied (2013). Furthermore, the results indicate that ICT is crucial for growth in sub-Saharan Africa (SSA) as it connects the region internally and links it with global industrial and economic systems through virtual communication and electronic coding.

The significant and negative impact of industrialisation on economic growth indicates that Kaldor's (1966, 1967) hypothesis of the manufacturing sector serving as an engine of growth does not hold in SSA. This is consistent with the findings of Saba and Ngepah (2021). This could be due to numerous challenges facing the sector, as highlighted in Shaaba and Nicholas's (2018) study, including *"infrastructure bottlenecks, insufficient productive capabilities, lack of skilled workers, underdeveloped financial markets, and high levels of income inequality."* The poor performance of the industrial sector in SSA might be a reason why it does not receive sufficient support from the financial sector. This lack of support could explain the significant and negative impact of financial development on industrialisation. Economic growth is positively and significantly related to industrialisation, while ICT diffusion is negatively and significantly related to industrialisation. This suggests that the industrialisation process in SSA has not been adequately supported by ICT, contributing to the challenges in adopting a viable pathway for regional growth and development and in integrating into global markets for goods and services. Figure 2 indicates that our models are correctly specified and that all estimated results are reliable, as the eigenvalues lie within the unit circle. This implies that all four estimated panel models have stationary roots. The results in Table 7 further support Figure 2, as each country's eigenvalue modulus is within the acceptable range.

Table 6: Panel VAR results

	ICT $(t-1)$	FDEV $(t-1)$	MAV $(t-1)$	RGDP $(t-1)$
ICT (t)	1.005*** (0.000)	0.5493*** (0.000)	-0.127** (0.023)	0.038*** (0.006)
FDEV (t)	-0.101 (0.129)	0.331*** (0.000)	-0.216*** (0.002)	-0.087*** (0.000)
MAV (t)	-0.004 (0.977)	0.974*** (0.000)	0.907*** (0.000)	-0.089*** (0.009)
RGDP (t)	-0.314*** (0.000)	-0.2915*** (0.000)	0.497*** (0.000)	0.896*** (0.000)

*** p<0.01, ** p<0.05, * p<0.1. *p* values in parenthesis; The error terms include country-specific effect. **Source:** Author's Computations

Table 7: Eigenvalue stability condition

	Real	**Imaginary**	**Modulus**
1	0.859	-0.215	0.886
2	0.859	0.215	0.886
3	0.710	0.347	0.791
4	0.710	-0.347	0.791

Source: Author's Computations

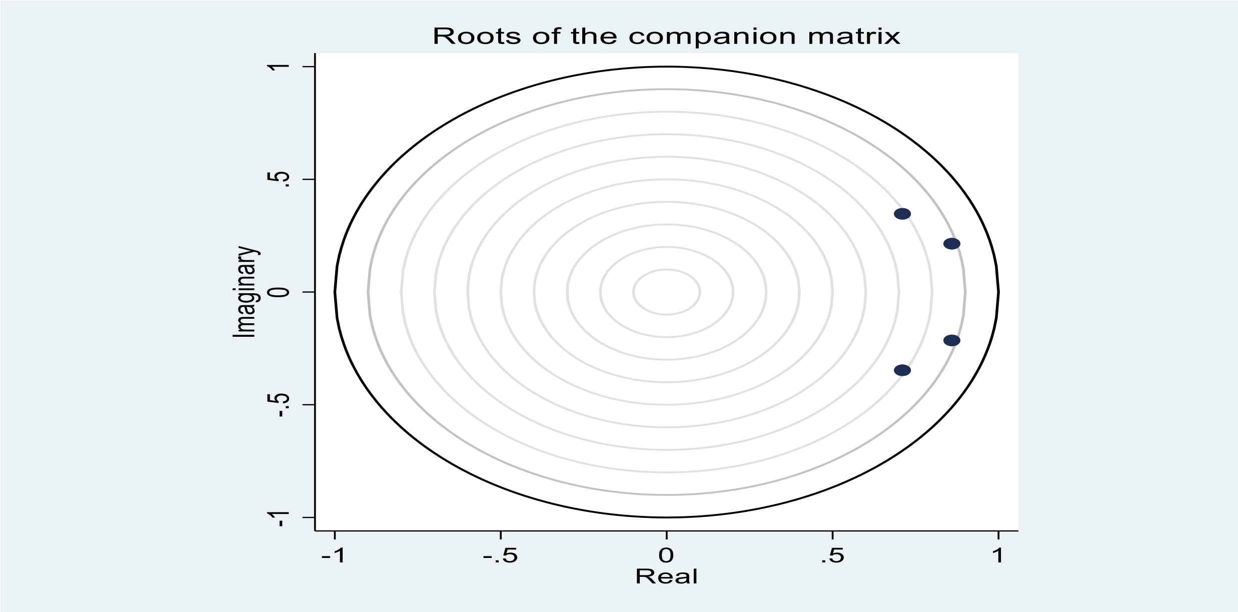


Figure 2: **(**A**)** Stability condition test

4.4 Variance decomposition and impulse response analysis

In addition to the previous estimations, this study also utilizes forecast error variance decompositions (FEVDs) and impulse response functions (IRFs) analysis from the unrestricted VAR estimation process using the orthogonalized Cholesky ordering technique. Table 8 presents the variance decomposition of the variables over 10 periods, with period 5 representing the short run and period 10 the long run. In summary: (i) ICT diffusion is more sensitive to shocks in RGDP compared to financial development and industrialisation; (ii) financial development is more sensitive to shocks in industrialisation compared to ICT diffusion and RGDP; (iii) industrialisation is more sensitive to shocks in ICT diffusion compared to financial development and RGDP; (iv) RGDP is more sensitive to shocks in ICT diffusion and industrialisation compared to financial development. We estimated the IRFs for SSA to further explain the magnitude of the causation between the variables. Figures 3 report a summary of the IRF outcomes. The IRF plots indicate that a positive shock in ICT diffusion leads to: (i) a steady decline in growth; (ii) an initial decline followed by a rise in industrialisation; and (iii) an initial rise followed by a decline in financial development. A similar interpretation applies to shocks in financial development, industrialisation, and economic growth. Although these shocks are short-lived, they significantly impact the economy, particularly in the first five years, and are fully absorbed within ten years.

RGDP's sensitivity to shocks in both ICT and industrialisation but less to financial development suggests that in the context of SSA, economic growth is more directly influenced by ICT and industrial capacity building than by the sophistication of financial markets. The endogenous growth theory, which posits that economic growth is primarily generated from within a system as a result of internal processes such as investments in human capital, innovation, and knowledge (Romer, 1986; Lucas, 1988; Hall and Jones, 1999), supports the findings of this study. The sensitivity of RGDP to ICT diffusion and industrialisation could be seen as manifestations of endogenous growth factors, where ICT and sectoral growth stimulate broader economic growth. Furthermore, Schumpeterian growth theory which emphasizes the role of technological innovation and its diffusion as a key component of economic development and growth (Schumpeter, 1942). The observed impacts of ICT shocks on RGDP and industrialisation fit well within this framework, highlighting the transformative power of technology.

Table 8: **Forecast-error variance decomposition results**

	Impulse variable			
Response variable and Forecast horizon	ICT	FDEV	MAV	RGDP
ICT				
0	0.000	0.000	0.000	0.000
1	1.000	0.000	0.000	0.000
2	0.969	0.028	0.000	0.002
3	0.949	0.041	0.004	0.006
4	0.941	0.038	0.010	0.011
5	0.937	0.031	0.014	0.018
6	0.931	0.027	0.015	0.027
7	0.926	0.025	0.013	0.036
8	0.920	0.023	0.012	0.045
9	0.912	0.022	0.014	0.052
10	0.901	0.022	0.019	0.058
FDEV				
0	0.000	0.000	0.000	0.000
1	0.080	0.920	0.000	0.000
2	0.118	0.831	0.051	0.000
3	0.117	0.759	0.124	0.000
4	0.101	0.741	0.157	0.001
5	0.099	0.744	0.154	0.004
6	0.107	0.742	0.144	0.008
7	0.116	0.731	0.142	0.012
8	0.119	0.717	0.149	0.014
9	0.117	0.707	0.161	0.015
10	0.116	0.701	0.169	0.015
MAV				
0	0.000	0.000	0.000	0.000
1	0.070	0.002	0.928	0.000
2	0.169	0.209	0.615	0.007
3	0.262	0.309	0.410	0.019
4	0.345	0.325	0.296	0.033
5	0.409	0.303	0.241	0.047
6	0.445	0.272	0.224	0.059
7	0.451	0.254	0.228	0.067
8	0.436	0.253	0.241	0.070
9	0.416	0.264	0.251	0.069
10	0.402	0.277	0.255	0.067
RGDP				
0	0.000	0.000	0.000	0.000
1	0.000	0.001	0.172	0.827
2	0.001	0.330	0.073	0.596
3	0.002	0.421	0.089	0.488
4	0.026	0.347	0.217	0.411
5	0.106	0.250	0.341	0.303
6	0.223	0.212	0.364	0.202
7	0.337	0.206	0.317	0.140
8	0.433	0.198	0.258	0.111
9	0.507	0.183	0.210	0.100
10	0.560	0.163	0.178	0.099

Source: Author's Computations

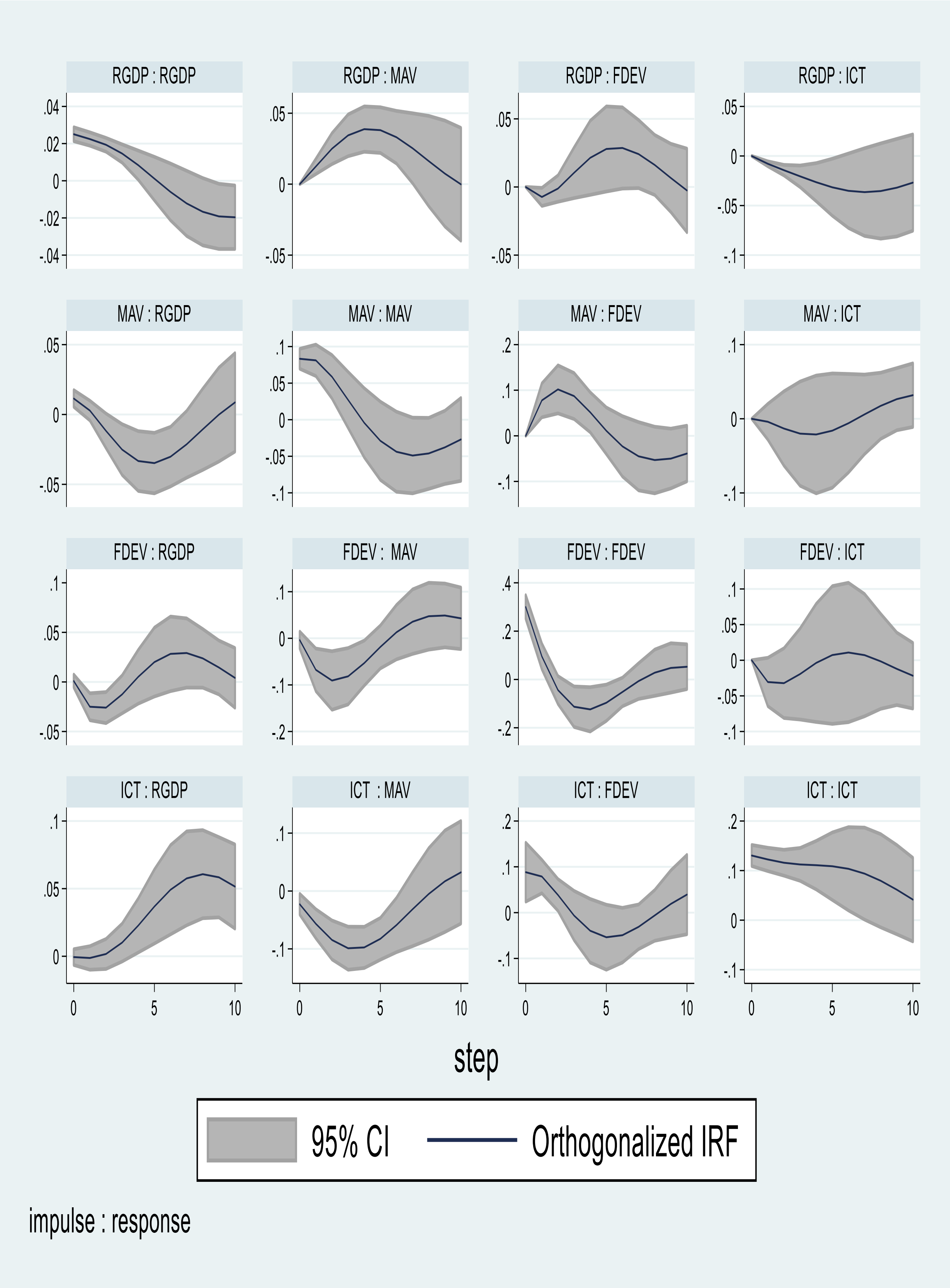


Figure 3: (**A**) impulse responses for the variables

5. Conclusion and policy recommendations

We analyse the ICT diffusion-financial development-industrialization-growth nexus for 45 African countries from 2000 to 2018. Our precise quantitative analysis utilizes novel panel VAR models within a generalized method of moments (GMM) estimation framework, addressing endogeneity issues. This study differs from previous literature by measuring ICT diffusion using a composite index of ICT/telecommunications indicators, including mobile lines, fixed lines, and internet access penetration, calculated via the principal component method. Financial development is measured through stock traded to GDP, private sector credit as a share of GDP, and M3 to GDP.

The causality results suggest that there is unidirectional causality from: financial development to ICT diffusion; and industrialisation to ICT. While a bidirectional causality between: ICT and RGDP; financial development and industrialisation; financial development and RGDP; and industrialisation and RGDP. The bidirectional causality results imply interdependence and mutual reinforcement between: ICT and growth; financial development and growth; and industrialisation and growth across SSA. These sectors are bidirectionally causal, meaning that policies in one sector can significantly impact the others. Due to this interdependence, individual policy interventions in Sub-Saharan African nations may be less effective unless they consider the synergistic effects across the financial, industrial, and economic sectors. Therefore, this study recommends developing an integrated policy framework that aligns ICT, financial, and industrial sector development to mutually reinforce each other, thereby enhancing overall economic growth. To improve industrial and financial services and leverage feedback effects to boost overall economic activity, government policies should focus on making targeted investments in ICT infrastructures such as mobile-cellular telephone, internet access penetration etc. The governments in the region should foster greater collaboration among the government, private sector, and international bodies operating in these sectors to streamline efforts in these interlinked areas.

The results demonstrate that while ICT positively impacts economic growth, financial development has occasionally had a detrimental effect on industrialisation and economic progress. This suggests potential misalignments and inefficiencies in financial policies that hinder the region's industrial development. Therefore, we recommend reforming financial policies to lower interest rates and reduce the cost of capital to support industrial and technological investments that will boost growth without negatively impacting the financial sector. To mitigate the negative impact of financial development on industrialisation and growth, it is crucial to address both the supply and demand sides of credit constraints. Policies should be implemented to regulate financial credit and corporate debt, focusing on controlling their excessiveness and expansion within the economy. Additionally, there is a need for policies that enhance financial sector regulation to ensure stability and promote long-term investments in the ICT and industrial sectors, rather than encouraging speculative short-term gains that may arise from these sectors. Government policies in the region should also include the implementation and evaluation of skill development programs to boost productivity in the industrial sector, ensuring that workforce skills align with industry needs of the 21st century.

The sensitivity of economic variables to shocks in ICT diffusion, financial development, and industrialisation suggests that unexpected changes in one can significantly affect the innovation of the others. The analysis shows that ICT shocks have a profound short-term impact on growth and industrialisation, which can either be negative or positive. Therefore, governments should develop economic stabilization tools to manage and mitigate the impacts of shocks in key sectors such as ICT and finance, as revealed in this study.

Governments and policymakers in the region should prioritize long-term strategic planning in economic policies to mitigate and leverage the effects of these shocks. There is also a need for the government to implement and reinforce robust monitoring and evaluation mechanisms to track the impact of shocks and adjust policies related to the ICT, financial, and industrial sectors accordingly, in order to maintain economic stability and growth.

One significant limitation of this study is the use of a financial development index calculated using principal component analysis based on M3 to GDP, the ratio of private sector credit to GDP, and the total value of stock traded to GDP, rather than employing the comprehensive measure of financial development developed by the International Monetary Fund (IMF). Although the chosen metrics were relevant and tailored to the context of SSA, they may not capture all dimensions of financial development as comprehensively as the IMF's measure. However, the IMF's measure presents data availability challenges for the SSA region. This might limit the generalizability of the findings to other regions of the world with different economic characteristics. Therefore, for future directions, it is recommended that research expands to include other regions such as Middle East & North Africa, Latin America & Caribbean, and Europe & Central Asia. Additionally, considering other economic blocs may provide a broader insight into ICT-financial development-industrialisation-economic growth nexus. This approach will enable a more global perspective on the interdependencies and effects of financial development, enhancing the robustness and applicability of the research findings. Future studies should also consider using the comprehensive IMF measure of financial development to allow for comparisons across different international contexts and to address the gaps identified in this study regarding the depth of financial development analysis.

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