



Exploring the Moderating impact of ICT Infrastructure on Trade Openness-Sectoral Growth Nexus in Sub-Saharan Africa (SSA)

BAMIDELE O. OSHINOWO, OLUWASEYI A. ADELOWOKAN,
ADEDAMOLA A. SIYANBOLA, JIMOH S. OGEDE
Olabisi Onabanjo University, Ago Iwoye, Nigeria

Abstract. This study examines the moderating role of Information and Communication Technology (ICT) infrastructure in the relationship between trade openness and sectoral growth in Sub-Saharan Africa (SSA). Using balanced panel data for 26 SSA countries from 1992 to 2023, sourced from the Penn World Table, African Development Bank, International Monetary Fund, and World Bank Development Indicators, the analysis employs the Pooled Mean Group–Autoregressive Distributed Lag (PMG/ARDL) approach. Results show that, in the long run, trade openness has a negative and significant impact on agricultural, industrial, and, in most cases, service sector growth. ICT infrastructure positively influences industrial and service sectors but has limited direct effects on agriculture. Interaction terms between trade openness and ICT variables are predominantly negative and significant, suggesting that higher trade openness reduces the growth-enhancing effects of ICT. In the short run, trade openness, ICT, and their interactions are largely insignificant across sectors. Foreign direct investment emerges as a consistent short-term driver of agricultural growth, while labour force dynamics significantly affect short-term industrial and service performance. The findings underscore the need for policies that integrate ICT expansion with complementary infrastructure, skills development, and targeted trade strategies. Strengthening domestic capacity, enhancing productivity, and ensuring inclusive access to ICT can enable trade openness to translate into sustainable growth across sectors in SSA.

1. Introduction

The relationship between trade openness and economic growth has been a cornerstone of development economics discourse, particularly for emerging economies seeking to integrate into the global marketplace. In sub-Saharan Africa (SSA), this relationship takes on added complexity as countries

navigate the structural transformation from predominantly agricultural economies toward more diversified industrial and service-oriented sectors. Classical trade theory emphasizes that liberalization enhances efficiency by reallocating resources according to comparative advantage, thereby stimulating growth through greater market access, technology transfer, and capital inflows. However, the empirical evidence from SSA remains mixed. Some studies find that trade openness positively contributes to growth by attracting foreign direct investment (FDI) and expanding productive capacity (Çınar & Nulambe, 2018), while others highlight that openness alone often fails to generate sustained growth without supportive institutions and complementary policies (Osuma & Nzimande, 2024).

Nevertheless, the advent of the digital age has fundamentally altered the dynamics of international trade and sectoral development. Information and Communication Technology (ICT) infrastructure has emerged as a critical moderating factor that can either amplify or constrain the benefits derived from trade openness. This technological revolution has created new pathways for economic integration, enabling countries to participate in global value chains, reduce transaction costs, and facilitate knowledge transfer. Recent scholarship has further underscored the sectoral heterogeneity of trade's impact, demonstrating that agricultural sectors may experience productivity gains from export opportunities, yet remain vulnerable to global price volatility. Manufacturing and services, by contrast, tend to benefit more from openness when combined with technological upgrading and skills development. In view of the foregoing, ICT infrastructure has emerged as a critical enabler, reducing transaction costs, improving access to global markets, and facilitating knowledge spillovers. Evidence from SSA demonstrates that economies with more advanced ICT ecosystems derive stronger growth dividends from trade liberalization, particularly through expanded

intra-regional trade and service exports (Kapingura & Sanusi, 2024; Dumor et al., 2023). This suggests that the trade-growth nexus in SSA is increasingly conditional on complementary factors such as ICT penetration, human capital development, and institutional quality, all of which shape the region's ability to translate openness into sustained structural transformation. However, the extent to which ICT infrastructure influences the trade openness-growth nexus remains underexplored, particularly in the context of SSA's unique economic landscape.

Sub-Saharan Africa presents a compelling case study for examining these relationships due to its distinctive characteristics: rapid technological adoption amid persistent infrastructure gaps, diverse sectoral compositions ranging from resource-dependent to service-oriented economies, and varying degrees of integration into global markets. The region has witnessed remarkable growth in mobile phone penetration and internet usage, yet significant disparities exist in ICT infrastructure development across countries. This heterogeneity provides a natural laboratory for investigating how technological capabilities moderate the relationship between trade policies and sectoral growth outcomes.

Recent empirical evidence reveals conflicting findings regarding the trade openness-growth relationship across different economic sectors. While studies by Shahbaz et al. (2017) demonstrate that trade openness enhances financial development in some emerging economies, others like Tahir et al. (2019) find that trade liberalization positively impacts agricultural and industrial sectors while adversely affecting service sectors. These mixed results underscore the importance of considering sectoral heterogeneity and the role of enabling factors such as ICT infrastructure in shaping trade-growth dynamics. The theoretical foundation for examining ICT's moderating role rests on the premise that technological infrastructure serves as an enabler of trade benefits by reducing information asymmetries, lowering transaction costs, and facilitating market access. From a neoclassical growth perspective, ICT infrastructure enhances total factor productivity (TFP) and enables more efficient allocation of resources across sectors. Endogenous growth theory further suggests that ICT adoption fosters innovation and knowledge spillovers, which can amplify the positive effects of trade openness on sectoral development.

However, the interaction between trade openness and ICT infrastructure is not uniformly positive across all sectors. Recent studies indicate that while ICT development generally promotes economic growth, its

interaction with trade policies may produce sector-specific outcomes. For instance, Huang et al. (2024) found that ICT development significantly boosts economic performance in both short and long run, but the magnitude of this effect varies depending on the level of trade integration. Similarly, empirical literature by Wang et al. (2023) suggests that ICT diffusion enhances inclusive growth, but this relationship is contingent on complementary factors including trade policies and financial inclusion. The agricultural sector, which remains a significant component of many SSA economies, faces unique challenges and opportunities in the digital trade era. Mobile phone adoption and internet connectivity can enhance market information access, improve supply chain efficiency, and facilitate direct marketing channels for smallholder farmers. However, the benefits may be constrained by limited rural electrification, inadequate digital literacy, and insufficient integration with formal market systems. The industrial sector presents different dynamics, where ICT infrastructure can facilitate participation in global value chains, enable technology transfer, and support manufacturing efficiency improvements. However, the interaction effects may be more complex, as increased trade openness combined with inadequate technological capabilities could lead to deindustrialization pressures. The service sector, increasingly recognized as a driver of modern economic growth, is particularly dependent on ICT infrastructure for its expansion and integration into global markets.

Despite the growing importance of these relationships, there remains a significant research gap in understanding how ICT infrastructure specifically moderates the trade openness-sectoral growth nexus in SSA. Most existing studies examine these relationships in isolation or focus on aggregate economic outcomes, failing to capture the nuanced sectoral dynamics that characterize structural transformation processes. Furthermore, the methodological approaches used in previous studies often overlook the potential for cross-sectional dependence and heterogeneity that are characteristic of panel data from African economies. This study addresses these gaps by empirically examining the moderating role of ICT infrastructure in the relationship between trade openness and sectoral growth across 26 SSA countries over the period 1992-2023. Specifically, the research investigates how different components of ICT infrastructure, including internet penetration, mobile subscriptions, and fixed-line telephone density, as well as the influence the effectiveness of trade policies in promoting growth across agricultural, industrial, and service sectors.

The study contributes to the existing literature in several ways. First, it provides sector-specific evidence on the trade openness-growth relationship, moving beyond aggregate analyses to capture the heterogeneous impacts across different economic activities. Second, it explicitly models the moderating role of ICT infrastructure using interaction terms, allowing for a more nuanced understanding of how technological capabilities influence trade benefits. Third, it employs advanced panel data techniques that account for cross-sectional dependence and heterogeneity, addressing methodological limitations in previous studies. Finally, it offers policy-relevant insights for SSA countries seeking to maximize the development benefits of trade liberalization through strategic investments in ICT infrastructure.

The remainder of the paper is organized as follows: Section 2 provides a review of the relevant literature, Section 3 outlines the data and methodology, Section 4 presents the empirical results and analysis, and Section 5 concludes with policy implications and recommendations for future research.

2. Literature Review

2.1 Trade Openness and Sectoral Growth

Trade openness has emerged as a fundamental factor influencing economic growth across various sectors, particularly in developing economies. Shahbaz et al. (2017) conducted a comparative analysis of financial development in India and China, highlighting the role of trade openness in shaping economic trajectories. Their findings suggest that while trade openness enhances financial development in India, it has a counterproductive effect in China. This divergence underscores the importance of contextual factors in understanding how trade policies can differentially affect sectoral growth within emerging economies. Tahir et al. (2019) further explored the sectoral implications of trade openness, revealing that it positively impacts the agricultural and industrial sectors while adversely affecting the service sector. This understanding of sectoral dynamics is crucial for policymakers, as it indicates that trade strategies should be tailored to the specific needs and capacities of different sectors to maximize overall economic growth. The negative impact on the service sector suggests that trade policies may inadvertently favor traditional sectors over more modern service-oriented industries. Monyela and Saba (2024) examined the relationship between trade liberalization and economic growth in South Africa, particularly in the BRICS countries. Their research employed a Vector Error

Correction Model (VECM) to establish a long-run equilibrium relationship among trade openness, GDP growth, and economic development. The study found a significant positive association between trade openness and GDP growth in the post-BRICS period, reinforcing the notion that trade liberalization can serve as a catalyst for economic expansion. This finding is particularly relevant for emerging economies seeking to enhance their growth trajectories through increased integration into the global economy. Huang et al. (2024) focused on the impact of financial development and trade openness on China's economic growth from 1990 to 2021. Their analysis employed various econometric techniques, revealing that trade openness significantly boosts economic development in both the short and long run. This validates the trade-led growth hypothesis and emphasizes the importance of fostering an open trade environment to stimulate sectoral growth. Varriale et al. (2024) investigated the role of renewable energy consumption, technological innovation, and export diversification in the economic growth of seven emerging economies known as the E-7. Their findings indicate that trade openness has a negative and significant effect on economic growth, which contrasts with the generally positive associations found in other studies. This highlights the complexity of the trade-growth nexus and suggests that trade policies must be carefully crafted to align with broader economic objectives, particularly with renewable energy and technological advancement. Asada (2022) analyzed Thailand's outward-oriented industrialization strategy, emphasizing the role of foreign direct investment (FDI) and trade openness in driving economic growth. The study found that trade openness and human capital development positively contributed to Thailand's GDP growth in the long run, while FDI inflows had a negative impact. This finding underscores the importance of human capital in maximizing the benefits of trade openness, suggesting that investments in education and skills development are essential for sustaining growth in an increasingly globalized economy. The foregoing demonstrates that trade openness generally promotes growth in agriculture and industry, its effects on the service sector can be detrimental. Moreover, the impact of trade policies is often mediated by other variables, such as financial development, human capital, and technological innovation.

2.2 ICT Infrastructure and Sectoral Growth

The role of Information and Communication Technology (ICT) infrastructure in fostering economic growth across various sectors has garnered significant attention in recent years. This literature review

synthesizes findings from multiple studies to elucidate the relationship between ICT infrastructure and sectoral growth, particularly in developing regions and industrialized economies. Bahrini and Qaffas (2019) conducted a panel analysis of selected developing countries in the Middle East and North Africa (MENA) and Sub-Saharan Africa (SSA) regions, revealing that while fixed telephone services lagged, mobile phones, Internet usage, and broadband adoption emerged as pivotal drivers of economic growth from 2007 to 2016. Their findings underscore the necessity for policymakers to enhance ICT infrastructure investments to harness these technologies' potential for economic advancement. The study highlights that the MENA region outperformed SSA in Internet usage and broadband adoption, suggesting a regional disparity in ICT development that could influence overall economic performance. In a contrasting framework, Kurniawati (2020) explored the interconnections among ICT, innovation, globalization, and economic growth in OECD countries from 1996 to 2017. Utilizing sophisticated econometric methodologies, the study found that ICT and innovation positively contributed to economic growth, with strong endogenous relationships observed among ICT usage, innovation, and globalization. This suggests that developed economies have yet to fully capitalize on ICT infrastructure expansion, indicating a need for continued investment in technology and innovation to sustain economic growth.

Huang et al. (2024) scrutinized the impact of financial development, ICT, labour force, and trade openness on China's economic growth from 1990 to 2021. Their findings revealed that while financial and ICT development positively influenced economic growth, adverse shocks in ICT could also spur growth, indicating a nuanced relationship. This highlights the importance of a balanced approach to ICT investment, where potential negative impacts are mitigated through strategic planning and policy formulation. In the framework of South Africa, Semenya and Ogujiuba (2024) identified inefficiencies in various sectors, including ICT, as significant barriers to economic growth since the 1980s. Their analysis pointed to the need for increased public infrastructure investment and research and development financing to stimulate growth. This study reinforces the notion that ICT infrastructure is not merely a facilitator of growth but a critical component that requires comprehensive governmental support and strategic investment to overcome historical inefficiencies. Matsvai and Hosu (2024) examined the impact of ICT on agricultural development in South Africa from 1995 to 2022. Their findings indicated that mobile phone subscriptions and

Internet usage positively affected agricultural output and total factor productivity (TFP) in both the short and long run. However, they also noted that fixed telephone subscriptions had a negative impact on TFP in the long run, suggesting that the type of ICT infrastructure deployed can significantly influence sectoral growth outcomes. The study advocates for the digitalization of the agricultural sector to leverage ICT's potential fully.

Wang et al. (2023) critically analyzed the connection between ICT diffusion and inclusive growth in top African nations. Their research employed an improved Generalized Method of Moments (GMM) technique to assess the interactive impacts of trade openness, foreign direct investment (FDI), and financial inclusion on inclusive growth. The study concluded that while ICT diffusion significantly enhances inclusive growth, inflation acts as a hindrance. This finding highlights the importance of creating a conducive environment for ICT development, which is essential for achieving broader societal benefits beyond mere economic expansion. Lastly, Vu (2024) utilized growth accounting to quantify the contributions of the ICT manufacturing sector to value-added and labour productivity growth across 13 industrialized economies from 2000 to 2015. This analysis underscores the critical role of the ICT manufacturing industry in driving economic performance in developed countries, suggesting that sustained investment in this sector is vital for maintaining competitive advantage in a rapidly evolving global economy. In conclusion, the literature indicates that ICT infrastructure enhances sectoral growth across various regions and economies. While the positive impacts of ICT on economic growth are well-documented, the studies also reveal complexities and potential drawbacks that necessitate careful consideration in policy formulation. As such, policymakers need to prioritize investments in ICT infrastructure while addressing accompanying challenges to maximize the benefits of ICT in fostering sustainable and inclusive economic growth.

2.3 The Moderating Role of ICT on Trade Openness and Sectoral Growth Nexus

The interplay between information and communication technology (ICT) infrastructure, trade openness, and sectoral growth has garnered significant attention in recent research, highlighting its multifaceted implications for economic growth. Xiao et al. (2024) explore the relationship between technological innovation and income inequality, revealing that while technological advancements can enhance communication and operational efficiency,

they may inadvertently exacerbate income disparities, particularly in developed economies. This underscores the importance of robust ICT infrastructure as a moderating factor that can either buffer or amplify the effects of trade openness on sectoral growth. In the perspective of Mediterranean countries, Demircan Çakar et al. (2021) investigate the impact of innovation on carbon emissions from the transportation sector, emphasizing the role of ICT in facilitating sustainable practices. Their findings suggest that innovation, particularly in developed nations, correlates positively with carbon emissions when driven by trademark increases, indicating that ICT infrastructure can influence the environmental outcomes of trade activities. This relationship highlights the potential for ICT to mediate the effects of trade openness on sectoral growth by promoting environmentally friendly innovations. Furthermore, Danish (2019) examines the nexus between ICT and carbon emissions, considering the moderating effects of international trade and foreign direct investment (FDI). The study finds that both international trade and FDI intensify the positive impact of ICT on CO₂ emissions, suggesting that robust ICT infrastructure is crucial in shaping the environmental and economic dynamics of trade. This evidence points to the need for further research into how ICT infrastructure can effectively moderate the relationship between trade openness and sectoral growth, particularly in the framework of sustainable development.

3. Methodology

3.1 Data and Variables

The study employs panel data from 26 Sub-Saharan African (SSA) countries covering the period 1992–2023, drawing from robust international datasets including the Penn World Table, African Development Bank (ADB) database, International Monetary Fund (IMF) statistical database, and World Bank Development Indicators (WDI). Data availability dictated the choice of economies and periods. Exogenous variables to the sectoral growth process are included in the study. The major variables of interest are trade openness, sectoral output growth, and ICT infrastructure. The sectoral economic growth measures the contribution of agricultural, manufacturing and service sector toward GDP respectively. This is in line with Tahiret al., (2019).

The dependent variables of interest are sectoral growth rates: agriculture, industrial, and services, which capture the structural transformation pathways of SSA economies. The key independent variable is trade openness, measured as the ratio of total trade (exports plus imports) to GDP, widely used in growth empirics to assess integration into the global economy. A moderating variable, ICT infrastructure index, is constructed as a composite indicator of internet penetration, mobile subscriptions, and fixed-line telephone density. ICT acts as a technological enabler that may amplify or constrain the benefits of trade openness by lowering transaction costs, improving market access, and fostering innovation (Kapingura & Sanusi, 2024).

The study account for heterogeneity and capture the structural drivers of long-run growth in Sub-Saharan Africa (SSA) by incorporating control variables. These variables reflect both neoclassical growth theory and endogenous growth perspectives, ensuring that sectoral growth dynamics are not mis-attributed solely to trade openness or ICT infrastructure. In this study, GDP per capita serves as a measure of the initial level of development and economic well-being. Human capital, typically measured through education is a cornerstone of endogenous growth theory. Higher levels of education enhance productivity, facilitate technology adoption, and improve the efficiency of labour and capital utilization. Labour participation rates on the other hand capture the demographic and labour market dynamics of growth. SSA is characterized by a young and rapidly expanding population, but with significant underemployment and informal sector dominance. Hence, including labour participation, the model accounts for the quantity dimension of growth. Foreign Direct Investment (FDI) represents a critical channel for capital inflows, technology transfer, and integration into global value chains. In SSA, FDI has historically been directed towards resource extraction, but recent trends show diversification into manufacturing and services. The inclusion of FDI as a control variable recognizes its role in augmenting domestic investment and fostering structural transformation. Empirical evidence confirms that trade openness, when coupled with FDI inflows, enhances productivity and growth outcomes in SSA (Babatunde, 2011). Table 1 presents a summary of the variable sources and measurements.

Table 1: Data Description, Measurement, and Sources

Variables	Description	Data Sources
Sectoral output growth (<i>y</i>)	Agriculture, manufacturing, and services sectors	WDI (2024)
ICT infrastructure (<i>ict</i>)	ICT infrastructure index	Author compilation
Mobile users (<i>mcs</i>)	Mobile cellular subscriptions (per 100 people)	WDI, ITU (2024)
Fixed telephone users (<i>fts</i>)	Fixed telephone subscriptions per 100 people	WDI, ITU (2024)
Individual internet (<i>iui</i>)	% of the population using the Internet	WDI, ITU (2024)
Trade openness (<i>to</i>)	Ratio of total trade to GDP	WDI (2024)
Human capital investment (<i>k</i>)	Gross fixed capital formation to GDP	WDI (2024)
Labour participation (<i>lb</i>)	Ratio of the labour force to working-age population	WDI (2024)
Foreign direct investment (<i>fdi</i>)	Foreign direct investment to GDP (% of GDP),	WDI (2024)
Income (<i>inc</i>)	Gross domestic product per capita	WDI (2024)

Source: Author's Compilations (2025)

Furthermore, the study measured the ICT infrastructure using ICT infrastructure index. This index was created using the Principal Component Analysis (PCA) technique by allowing us condense a large dataset into a smaller set while keeping the original information's quality. The composite index incorporated variables such as individuals using the Internet (% of population), mobile cellular subscriptions (per 100 people), and fixed telephone subscriptions (per 100 people). The study measured the eigenvalues of each component, and components with eigenvalues greater than one were retained as they explained a significant amount of the dispersion in the principal component. The results of the principal components of the ICT infrastructure index, derived from the three variables included in the model, are presented in Table 2.

Table 2: Principal Component Analysis for ICT Infrastructure

Principal Components	ICT infrastructure index			Proportion	Cumulative Proportion	Eigen value
	Component Matrix					
	IUI	MCS	FTS			
First PC	0.6564	-0.2462	0.7131	0.6530	0.6530	1.9591
Second PC	0.6486	-0.2987	0.7001	0.2779	0.9309	0.8336
Third PC	0.3854	0.9220	0.0364	0.0691	1.000	0.2071

Source: Author's compilation (2025)

3.2 Theoretical Framework and Model specification

The analysis builds on the neoclassical growth model (Solow, 1956; Swan, 1956), in which output depends on capital, labour, and technology. ICT infrastructure is treated as a component of technological capability, potentially enhancing total factor productivity (TFP) and facilitating sectoral structural transformation. This fundamental neoclassical production function, applicable to a single sector, is represented as follows:

$$Y_t = AK_t^\alpha L_t^{1-\alpha} \tag{1}$$

where Y represents the sector's total output; A denotes total factor productivity (TFP), which represents technology and efficiency. K signifies the capital stock in the sector; L represents the labour force employed in the sector; α is the output elasticity of capital, indicating the share of output attributed to capital. Consequently, to analyze the impact of trade openness and ICT infrastructure on sectoral growth, the study incorporates two additional variables, TO and ICT into equation (1). Expanding and modifying the analysis in equation (1), it now encompasses the impacts of trade variables on sectoral growth, resulting in the following formulation:

$$Y_t = AK_t^\alpha L_t^{1-\alpha} TO_t^\theta \tag{2}$$

The study argues that A in equation (2) represents technology, resource endowments, and policy framework which differ across countries. Thus, in order to capture the different initial levels of technology efficiency across countries, a measure of ICT infrastructure is added to the model to become:

$$Y_t = A.K_t^\alpha L_t^{1-\alpha} TO_t^\theta ICT_t^\gamma \tag{3}$$

The natural logarithm of both sides is taken in order to linearize the equation (3):

$$\ln Y_t = \ln A + \alpha \ln K_t + (1-\alpha) \ln L_t + \theta \ln TO_t + \gamma \ln ICT_t \quad (4)$$

The model presented in equation (3.4) above places its emphasis on four key variables: sectoral output (Y), capital (K), labour (L), ICT infrastructure (ICT), and trade openness (TO). Also, α represents the elasticity of output with respect to physical capital (K_t), $1-\alpha$ represents the elasticity of output with respect to labour (L_t), θ represents the elasticity of output with respect to trade openness (TO_t), and γ represents the elasticity of output with respect to ICT infrastructure (ICT_t). This signifies that, at any given point in time, the economy possesses specific quantities of capital, labour, trade activity, and ICT infrastructure, all of which are typically combined to generate sectoral output. As a result, this study specifies the following model:

$$Y_{it} = a_0 + a_1 TO_{it} + a_2 ICT_{it} + a_3 L_{it} + a_4 K_{it} + a_5 Z_{it} + \mu_i + \varepsilon_{it} \quad (5)$$

where; Y_{it} is the sectoral output under investigation which are the agriculture, manufacturing, and service sectors. TO_{it} is trade openness, ICT_{it} is the ICT infrastructure index, Z is a vector of control variables, ε_{it} is the idiosyncratic error term; μ_i represents unobservable country specific effects and it is time invariant, i and t are the cross-sectional and time series components respectively, and a_0 is the fixed effect intercept. Further, the study establishes the relationship between the term interacting ICT infrastructure with trade openness is stated as follows:

$$Y_t = \rho_0 + \rho_1 k_{it} + \rho_2 to_{it} + \rho_3 ict_{it} + \rho_4 (ict \times to)_{it} + \rho_5 lb_{it} + \Omega ctv_{it} + v_{it} \quad (6)$$

Where: Y is sectoral growth; k denotes capital investment; to represents trade openness; ict denotes ICT infrastructure; and lb is labour force participation rate. Other control variables (ctv) in a row vector form are: gross domestic product per capita (inc); and foreign direct investment (fdi). The stochastic term is represented by v ; t denotes time; ρ_0 is

constant; and ρ_{1-5}, Ω are the coefficients of the variables. The net effect of the interactive variable in equation (7) is calculated as:

$$\frac{\partial(y_t)}{\partial(to_t)} = \rho_2 + \rho_4 ict \quad (7)$$

This revealed the net effect of trade openness on sectoral growth at the average value of ICT infrastructure. It equally denoted the financial elasticity of sectoral growth at the mean value of ICT infrastructure. Afterwards, the interaction of ICT infrastructure and trade openness on sectoral growth are conditional on the parameters: ρ_2 and ρ_4 in equation (7). Thus, if the net effect value is negative, it means that ICT infrastructure and trade openness are substitute, while complement if the net effect value is positive. Similarly, it suggests that trade openness has a favourable impact on sectoral economic growth, and the ICT infrastructure improves and supplements the direct impact if $\rho_2 > 0$ and $\rho_4 > 0$. Also, trade openness contributes positively to sectoral economic growth, but the ICT infrastructure acts as a drag, leaking out the beneficial impact if $\rho_2 > 0$ and $\rho_4 < 0$.

3.3 Estimation Techniques

To comprehensively examine the impact of trade openness and ICT infrastructure on sectoral growth across 26 SSA countries spanning from 1991 to 2022, pooled mean group (PMG) techniques was employed to achieve objectives 1, 2 and 3. The examination of the relationship among trade openness, ICT infrastructure, and sectoral economic growth is conducted in four steps. First, the data set was tested for the existence of cross-sectional dependence, which is a common issue in cross country analysis. Second, second-generation unit root tests-augmented IPS (CIPS) developed by Pesaran (2007) which is the average of individual cross-sectional augmented ADF (CADF) statistics, and CADF test for stationarity, were employed since there may be unit root problems when the large time dimension exists. Third, the panel co-integration test was used to control the long-run relationship among variables. Fourth, panel Autoregressive Distributive Lag Approach (ARDL) with second-generation estimators (i.e., PMG.ARD) was applied. The PMG/ARDL model allows for capturing both short-run and long-run dynamics, accounting for potential endogeneity, and accommodating heterogeneous country-specific effects. This approach is suitable when the long-run equilibrium relationship is expected to be similar across countries, but the short-run adjustment may differ. The panel ARDL model estimation is specified as:

$$Y_{it} = \alpha_{1i} + \beta_{1i}TREND_t + \sum_{k=0}^a \lambda_{11ij} Y_{it-1} + \sum_{k=0}^{m1} \lambda_{12ij} TO_{it-1} + \sum_{k=0}^{m2} \lambda_{13ij} ICT_{it-1} + \sum_{k=0}^{m3} \delta\lambda_{14ij} L_{it-1} + \sum_{k=0}^{m4} \lambda_{15ij} K_{it-1} + \sum_{k=0}^{m5} \lambda_{16ij} Z_{it-1} + \mu_{1it} \quad (8)$$

where $i = 1, 2, \dots, "n"$ represents the number of countries; $t = 1, 2, \dots, "t"$ is the number of periods; set of explanatory variables stands as previously defined with the $b \times 1$ vector of endogenous variables ($b = 6$); λ_{xij} are $k \times 1$ coefficient vectors. δ_{1i} is the vector of scalars, and μ_{it} is an error term distributed with a zero mean and a finite variance. Thus, the study modelled the short-run dynamic nexus among the selected variables, equation (9) is written as follows:

$$\Delta Y_{it} = \alpha_{1i} + \beta_{1i}TREND_t + \sum_{k=0}^a \lambda_{11ij} \Delta Y_{it-1} + \sum_{k=0}^{m1} \lambda_{12ij} \Delta TO_{it-1} + \sum_{k=0}^{m2} \lambda_{13ij} \Delta ICT_{it-1} + \sum_{k=0}^{m3} \delta\lambda_{14ij} \Delta L_{it-1} + \sum_{k=0}^{m4} \lambda_{15ij} \Delta K_{it-1} + \sum_{k=0}^{m5} \lambda_{16ij} \Delta Z_{it-1} + \lambda_{12ij} TO_{it-1} + \lambda_{13ij} ICT_{it-1} + \delta\lambda_{14ij} L_{it-1} + \lambda_{15ij} K_{it-1} + \lambda_{16ij} Z_{it-1} + \mu_{1it} \quad (9)$$

where α_{1i} is the intercept, λ_{2i} , δ_{2xij} , $x = 1, \dots, 4$, and λ_{2wi} , $w = 1, \dots, 4$, are the parameters estimate, and μ_{2it} is the disturbance term. The above model is a prototype of Pesaran et al. (2001).

4. Results and Discussion

This section unfolds with the presentation and discussion of the empirical estimations, offering insights into the findings derived from the specified empirical models outlined in Section 3. It details the outcomes of pre-estimations and main estimation techniques. Subsequently, the section delves into an extensive discussion of the estimation results, providing thorough explanations and interpretations.

4.1. Summary Statistics, Correlation and Variance Factor Analysis (VIF)

Table 3 present the presents the results of the summary statistics. These findings reveal key characteristics of trade openness, ICT infrastructure, and sectoral economic growth in SSA. Agriculture growth (AGRV) shows a mean of 21.3%, indicating resource reallocation toward industry and services sectors. The services sector leads with the highest average growth rate of 45.9%, compared to agriculture (21.3%) and industry (26.1%), highlighting its role in economic expansion. Services demonstrate the lowest volatility with a standard deviation of 9.2, versus agriculture (12.4) and industry (11.3), indicating a more stable growth trajectory. Services growth (45.9%) correlates positively with ICT variables including internet usage (IUI), mobile subscriptions (MCS), and ICT infrastructure index (ICTINF), emphasizing technology's role in sector expansion. Agriculture's high standard deviation of 12.4 relative to its 21.3% mean indicates significant volatility. This sectoral shift signals a modernizing economy, though the high agricultural volatility suggests continued food security and rural income risks. The services sector's stability and growth indicate increasing urbanization and potential for formal employment, while also highlighting opportunities for economic diversification. Further, Table 3 presents the sector's right-skewed distribution (skewness: 0.22), suggesting periodic booms and contractions. Services growth maintains symmetrical distribution (skewness: 0.22), while industry's right-skewed pattern (skewness: 1.4) aligns with historical industrialization phases. ICT infrastructure index shows near-normal distribution (skewness: 0.83, kurtosis: 2.5), suggesting consistent technological development patterns across countries.

Table 3: Summary statistics

	Mean	Max.	Min.	Std. Dev.	Skewness	Kurtosis
Agric. sector value added (agrv)	21.3032	61.4162	-2.5136	12.364	0.2227	2.3678
Ind. sector value added (indv)	26.0880	73.3508	0.0000	11.283	1.3967	5.3879
Serv. sector value added (serv)	45.8963	77.0200	20.992	9.2109	0.2217	2.8386
Trade openness (to)	64.4358	175.798	20.722	26.278	0.9612	3.7486
Labour parti. (lfp)	46.1520	79.6380	16.653	15.516	0.2649	2.2647
Human capital investment (k)	21.1025	93.5474	2.0004	8.1968	1.4361	10.775
Individual internet (iui)	9.51736	80.8740	0.0000	15.638	2.1114	7.0198
Mobile cellular sub. (mcs)	42.0644	174.025	0.0000	46.805	0.8345	2.5031

ICT infra. index (ictinf)	1.20E-10	2.81937	-0.8987	1.0000	0.8345	2.5031
Fixed telephone sub. (fts)	2.64335	36.8847	0.0000	5.2975	4.1507	21.803
Foreign direct investment (fdi)	2.58747	46.2752	-11.191	4.0120	4.0010	34.929
Inflation (inf)	21.063	4145.1	-11686	182.24	18.340	374.06

Note: Std. dev. is standard deviation; Min: minimum; Max: Maximum; Obs.: observation; sub: subscriptions; infra: infrastructure.
Source: Authors computation, 2025.

Correlation analysis is reported with Table 4. Table 4 reveals several significant relationships: agriculture and services value-added show negative correlation (-0.47), indicating resource shift from agriculture to services. Industrial value added positively correlates with trade openness (0.51), highlighting trade-oriented growth. Services value added correlates positively with internet usage (0.36) and mobile subscriptions (0.32), demonstrating ICT's impact. The strong correlation between services growth and ICT variables demonstrates technology's role in economic development. The positive relationships with internet usage, mobile subscriptions, and ICT infrastructure (correlations of 0.36, 0.32, and positive respectively) suggest digital technology is enabling service sector expansion. This digital transformation has critical inferences for workforce development, educational priorities, and infrastructure investment needs across SSA countries. The normal distribution of the ICT infrastructure index (skewness 0.83, kurtosis 2.5) indicates relatively predictable technology adoption patterns, though varying significantly across countries. A significant negative correlation (-0.47) between agriculture and services value-added as reported in Table 4 reflects ongoing structural transformation. This transition, while potentially improving overall economic productivity, raises concerns about rural development and income inequality as labour shifts from agriculture to services. The positive correlation (0.51) between industrial value-added and trade openness suggests that manufacturing growth is closely tied to international trade engagement, emphasizing the importance of export-oriented industrialization strategies.

However, the correlation coefficients reported in Table 4 are generally low to moderate in magnitude, suggesting limited linear associations among the variables. Most coefficients fall within the range of -0.5 to 0.5, indicating weak to moderate relationships. Notably, the strongest correlation is observed between IUI and MCS/ICTINF (0.792), which may raise concerns about multicollinearity if these variables are included together in a regression model. Several coefficients are statistically significant at the 1% and 5% levels; however, statistical significance does not necessarily imply a strong relationship. The foregoing suggests that multicollinearity is unlikely to pose a serious problem for most of the variables, though further verification using variance inflation factors (VIFs) is provided in Table 5. The findings of the VIF shows values ranging from 1.09 to 2.89, well below the critical threshold of 10. The minimum tolerance value of 0.346 exceeds the 0.10 requirement, confirming absence of multicollinearity among variables. These results validate the model's specification for analyzing relationships between trade openness, ICT infrastructure, and sectoral value added. The findings suggest that while services-led growth presents immediate opportunities, policymakers must carefully manage the transition to minimize disruption to agricultural communities while promoting industrial development and digital infrastructure.

Table 4: Correlation Matrix

Correlation	AGRV	INDV	SERV	TO	LFP	K	IUI	MCS	ICTINF	FTS	FDI	INF
AGRV	1.000											
INDV	-0.597*	1.000										
SERV	-0.472*	-0.288*	1.000									
TO	-0.527*	0.515*	0.031	1.000								
LFP	0.384*	-0.231*	-0.213*	-0.395*	1.000							
K	-0.118*	0.359*	-0.263*	0.219*	-0.062	1.000						
IUI	-0.374*	0.074**	0.361*	0.087**	-0.351*	0.023	1.000					
MCS	-0.381*	0.074**	0.319*	0.122*	-0.385*	0.091*	0.792*	1.000				
ICTINF	-0.381*	0.075**	0.319*	0.123*	-0.385*	0.091*	0.792*	1.000	1.000			
FTS	-0.488*	0.022	0.497*	0.441*	-0.187*	-0.024	0.30*	0.265*	0.265*	1.000		
FDI	-0.037	0.113*	-0.084**	0.214*	-0.072**	0.309*	0.035	0.104*	0.104*	-0.012	1.000	
INC	-0.088**	0.255*	-0.136*	0.101*	0.059	0.120*	-0.043	-0.067	-0.067	-0.035	0.061	1.000

Note: ***P < 0.01, **P < 0.05

Source: Authors computation, 2025

Table 5: Variance Inflation Factor (VIF)

Variable	VIF	Tolerance (1/VIF)
IUI	2.89	0.346
MCS	2.86	0.349
LnTO	2.19	0.455
FTS	1.88	0.531
LnINDV	1.81	0.551
LnSERV	1.79	0.558
LnLFP	1.46	0.684
LnK	1.32	0.759
LnFDI	1.17	0.853
LnINC	1.09	0.915
Mean VIF	2.06	

Source: Authors computation, 2025.

4.2. Results of Panel Unit Root, Cross-sectional dependence, and Cointegration Analysis

Cross-sectional dependence emerges as a critical consideration in panel data analysis of macroeconomic studies, particularly due to common shocks affecting different countries and regions. Table 6 presents the results of the Pesaran CD test. The results reject the null hypothesis of no cross-sectional dependence at the 1% significance level, confirming substantial dependency among variables across SSA nations. This finding aligns with Dong et al. (2018) and Grossman and Krueger (1995), who warn that ignoring cross-sectional dependence leads to inconsistent estimates and potentially misguided policy decisions. Pesaran (2006) further emphasizes the risk of biases and size distortions when cross-sectional dependence is overlooked, necessitating the use of estimators that account for both cross-sectional dependence and heterogeneity.

Table 6: Results of cross-sectional dependence

Pesaran (2004) Cross-sectional dependence test		
Variables	CD-Test	abs (Corr.).
LnAGRV	32.78 ***	0.489
LnINDV	-0.75	0.363
LnSERV	7.63 ***	0.434
LnTO	5.85 ***	0.328
LnLFP	61.24 ***	0.676
LnK	1.64 ***	0.332
IUI	91.93 ***	0.901
MCS	96.52 ***	0.946
FTS	36.68 ***	0.483
ICTINF	91.93 ***	0.901
LnFDI	12.97 ***	0.254
LnINF	31.19 ***	0.376

Source: Author's computation (2025)

The presence of cross-sectional dependence necessitates second-generation unit root tests, specifically Pesaran's (2007) CIPS and CADF tests, as supported by research from Swamy & Dharni (2020) and Hussain et al. (2021). The CIPS test, as reported in Table 7, with critical values of -2.04, -2.11, and -2.23 at 10%, 5%, and 1% significance levels respectively, reveals varying stationarity patterns. Agriculture value added (AGRV), services value added (SERV), foreign direct investment (FDI), and inflation (INF) exhibit I(0) stationarity at levels, while industry (INDV), trade openness (TO), and ICT infrastructure (ICTINF) demonstrate I(1) stationarity after first differencing, indicating the need for different treatment of variables in subsequent analyses.

Table 7: Results of panel unit root test

Variables	CIPS			CADF		
	Level	1 st Difference	Integration order	Level	1 st Difference	Integration order
lnAGRV	-2.326 ***	-5.742 ***	I_0	-2.201 **	-4.322 ***	I_0
lnINDV	-1.942	-5.322 ***	I_1	-1.610	-3.851 ***	I_1
lnSERV	-2.130 **	-5.186 ***	I_0	-2.120 **	-4.013 ***	I_0
lnTO	-1.957	-5.196 ***	I_1	-1.809	-4.078 ***	I_1
lnLFP	-1.354	-2.704 ***	I_1	-2.079	-2.403 ***	I_1
lnK	-1.752	-5.286 ***	I_1	-1.844	-4.194 ***	I_1
IUI	-0.401	-3.239 ***	I_1	-1.199	-2.757 ***	I_1
MCS	-1.860	-4.278 ***	I_1	-1.961	-3.279 ***	I_1
FTS	-1.511	-4.619 ***	I_1	-1.806	-3.787 ***	I_1
lnICTINF	-0.401	-3.239 ***	I_1	-1.199	-2.757 ***	I_1
lnFDI	-3.104 ***	-5.773 ***	I_0	-2.373 ***	-4.434 ***	I_0
lnINF	-3.641 ***	-5.686 ***	I_0	-3.803 ***	-4.695 ***	I_0

p < 0.05; *p < 0.01; critical values: -2.04, -2.11, -2.23 for 10%, 5%, and 1% significance level respectively.

Source: Author's computation (2025)

Further, the cointegration analysis employs both Pedroni (1999, 2004) and Kao (1999) techniques to examine the long-run relationship among trade openness, ICT infrastructure, and sectoral growth in SSA. These tests, according to Table 8, specifically designed to address cross-sectional dependence, heterogeneous effects, and non-stationarity, reveal significant cointegrating relationships at the 5% level. The rejection of the null hypothesis of no cointegration, supported by coefficients and variance ratio probability values significant at 1%, confirms the existence of a long-run equilibrium binding the non-stationary series. This finding has important implications for understanding the sustainable relationships between trade, technology, and sectoral development in SSA economies.

Table 8: Results of panel co-integration test

Pedroni (1999, 2004)			Kao (1999)	
Tests	Within dimension	Between dimension	Tests	Statistics
v-statistic	-2.405 ***	--	Modified DF t	-3.0545 ***
rho-statistic	-2.814	3.288 ***	DF t	-2.9278 ***
PP-statistic	-3.620 ***	-3.751 ***	Augmented DF t	-2.1656 ***
ADF-statistic	-4.099 ***	-4.7972 ***	Unadjusted modified DF t	-4.9257 ***
--	--	--	Unadjusted DF t	-3.7572 ***

Note: v: variance; PP: Phillips-Perron; ADF: Augmented Dickie Fuller; DF: Dickie Fuller; *p < 0.1; **p < 0.05; ***p < 0.01

Source: Author's computation (2025)

4.3 Regression Results

The paper answered the question in this study by using panel Autoregressive Distributive Lag Approach (ARDL) with second-generation estimators (i.e., PMG/ARDL). The PMG/ARDL model allows for capturing both short-run and long-run dynamics, accounting for potential endogeneity, and accommodating heterogeneous country-specific effects. It estimates the interactive effect of ICT infrastructure on trade openness with agriculture, industrial, and service sector in SSA are presented in Table 9, 10, and 11, respectively. Specifically, four ICT infrastructure indicators are evaluated individually as interactive variables: Internet users (IUI), mobile cellular subscriptions (MCS), fixed telephone subscriptions (FTS), and an overall ICT infrastructure index (ICTINF).

4.3.1. Interactive Effect of Trade Openness and ICT Infrastructure on Agricultural Sector Growth in SSA

Table 4.10 presents the long-run and short-run results for the interaction between trade openness (LNTO) and ICT infrastructure in explaining agricultural sector growth in SSA. In the long run, LNTO consistently shows a negative and statistically significant coefficient across all model specifications, with a 1% increase in LNTO associated with a 0.13–0.18% decline in agricultural sector growth. This finding suggests that greater trade openness, in the absence of complementary structural reforms, can exert downward pressure on agricultural performance. Such a trend aligns with

arguments that trade liberalisation can expose domestic producers to external competition without necessarily improving productivity in resource-constrained economies (see Hossain and Mitra, 2013). Among the ICT variables, fixed telephone subscriptions (FTS) alone exert a negative and significant effect on agricultural growth in one model, while its interaction with trade openness (TO_FTS) is positive and significant at the 5% level. This indicates that when integrated with trade, even basic ICT infrastructure can facilitate agricultural growth, possibly by improving market access and coordination. This outcome is consistent with Ngwenyama et al. (2006), who highlight the role of basic telecommunications in supporting agricultural productivity in developing economies. However, the insignificance coefficient for interactions involving mobile subscriptions (MCS) and internet use (IUI) contradicts Hossain and Mitra (2013), suggesting that the benefits of advanced ICT adoption may not automatically materialise in SSA without parallel investments in enabling infrastructure. Aker and Fafchamps (2015) similarly note that rural electrification deficits limit effective ICT utilisation in SSA, reinforcing the importance of foundational infrastructure.

Table 9: Result of the Interactive Effect of Trade Openness with ICT Infrastructure on Agricultural Sector Growth in SSA.

Variable/Column	1	2	3	4
Long Run				
LNT0	-0.1807*** {0.0361}	-0.0921** {0.0364}	-0.1325*** {0.0400}	-0.1278*** {0.0401}
IUI	-0.0086 {0.0091}			
MCS		0.002184 {0.0023}		
FTS			-0.1113*** {0.0333}	
ICT_INF				0.102197 {0.1103}
TO_IUI	0.0017 {0.0021}			
TO_MCS		-0.0008 {0.0005}		
TO_FTS			0.0182** {0.0073}	
TO ICTINF				-0.0397 {0.0254}
LNLFP	-0.1146 {0.0738}	-0.1485* {0.0795}	-0.0598 {0.0741}	-0.1485* {0.0795}
LNK	0.1133*** {0.0213}	0.1129*** {0.0205}	0.1500*** {0.0263}	0.1129*** {0.0205}
LNFDI	-0.026983 {0.0076}	-0.0291*** {0.0073}	-0.0337*** {0.0085}	-0.0291*** {0.0073}
LNINC	-0.2741*** {0.0214}	-0.1880*** {0.0286}	-0.2930*** {0.0226}	-0.1880*** {0.0286}
Short Run				
COINTEQ01	-0.5283*** {0.0531}	-0.5525*** {0.0513}	-0.5260*** {0.0502}	-0.5525*** {0.0513}
LNT0	0.0940 {0.0781}	0.1066 {0.1128}	0.0768 {0.1445}	0.1232* {0.0701}
IUI	0.0042 {0.0263}			
MCS		-0.0031 {0.0098}		
FTS			-0.6424 {0.7777}	
ICT_INF				-0.1458 {0.4623}
TO_IUI	-0.0009 {0.0070}			
TO_MCS		0.0003 {0.0022}		
TO_FTS			0.1835 {0.1974}	
TO ICTINF				0.0184 {0.1048}
LNLFP	-0.6466 {0.8220}	-0.5647 {0.7818}	-0.4163 {0.6728}	-0.5647 {0.7818}
LNK	-0.0616 {0.0600}	-0.0450 {0.0554}	-0.0312 {0.0639}	-0.0450 {0.0554}
LNFDI	0.0191***	0.0208***	0.0237***	0.0208***

LNINC	{0.0072} 0.0716	{0.0071} 0.0601	{0.0068} 0.0741***	{0.0071} 0.0601
Constant	{0.0454} 2.9520*** {0.3084}	{0.0473} 2.6584*** {0.2646}	{0.0393} 2.7724*** {0.2734}	{0.0473} 2.7091**** {0.2690}
Diagnostics				
CD Stat.	0.2650	0.5189	0.1817	0.0700
CD Prob.	(0.791)	(0.603)	(0.855)	(0.944)
Residual	I (0)	I (0)	I (0)	I (0)
RMSE	0.994	0.992	0.994	0.991
Adjusted R2	0.967	0.989	0.985	0.990
No. of Obser.	832	832	832	832

Note: *p < 0.10; **p < 0.05; *p < 0.01. Standard errors in parentheses {}**

Source: Author's compilation (2025)

Other control variables reveal that labour force participation (LNLFP) and GDP per capita (LNINC) have significant negative long-run effects, possibly reflecting the sector's vulnerability to labour shifts and structural transformation pressures. Conversely, capital investment (LNK) and foreign direct investment (LNFDI) display significant positive effects, underscoring their role in enhancing agricultural capacity. The error correction term (−0.5283 to −0.5525) is negative and significant in all models, confirming a stable long-run relationship. In the short run, trade openness, ICT variables, and their interactions are largely insignificant, suggesting limited immediate responsiveness of agricultural growth to changes in these factors. However, LNFDI is consistently positive and significant, indicating that foreign capital inflows provide short-term support for agricultural output. This pattern implies that while trade–ICT synergies may shape agricultural trajectories over the long term, FDI remains a key short-run driver.

4.3.2 Interactive Effect of Trade Openness and ICT Infrastructure on Industrial Sector Growth in SSA

Table 4.12 shows a consistent and statistically significant negative long-run effect of trade openness (LNTO) on industrial sector growth in SSA, with coefficients ranging from −0.09% to −0.29% for every 1% increase in LNTO. This finding suggests that liberalisation, in the absence of robust industrial competitiveness, may expose domestic firms to external pressures that hinder growth. Such a pattern aligns with structuralist perspectives on premature deindustrialisation in developing economies. ICT infrastructure (ICT_INF) emerges as a positive and significant driver in model 4, with a 1% improvement linked to a 0.26% increase in industrial growth. This supports Mbarika and Byrd (2009), who emphasise ICT as a catalyst for Africa's industrial development. However, the interaction terms between trade openness and ICT variables (TO_IUI, TO_MCS, TO_FTS, TO_ICTINF) are negative and significant in the long run. This indicates that the growth-enhancing effects of ICT are dampened in more open trade environments, possibly due to technology spillovers favouring external rather than domestic producers. This outcome contrasts with Hur et al. (2011), who suggest that trade openness can amplify technology adoption benefits, but aligns with Atsu et al. (2018), who stress the need for complementary human capital and infrastructure investments to fully leverage ICT in industrialisation.

Table 10: Result of the Interactive Effect of Trade Openness with ICT Infrastructure on Industrial Sector Growth in SSA.

Variable/Column	1	2	3	4
Long Run				
LNTO	-0.2914*** {0.0626}	-0.0396* {0.0222}	-0.1151*** {0.0280}	-0.0978*** {0.0194}
IUI	0.0645*** {0.0145}			
MCS		0.0055*** {0.0013}		
FTS			-0.0061 {0.0086}	
ICT_INF				0.2594*** {0.0617}
TO_IUI	-0.0154*** {0.0033}			
TO_MCS		-0.0013*** {0.0003}		
TO_FTS			0.0026 {0.0019}	
TO_ICTINF				-0.0648***

LNLFP	-0.2942** {0.1436}	-0.0172 {0.0466}	-0.0067 {0.0328}	{0.0145} -0.0172 {0.0466}
LNFDI	0.0339*** {0.0093}	0.0030 {0.0023}	0.0058* {0.0031}	0.0030 {0.0023}
LNINC	0.1053*** {0.0319}	0.0456*** {0.0062}	0.0607*** {0.0097}	0.0456*** {0.0062}
COINTEQ01	-0.1667*** {0.0335}	-0.2562*** {0.0432}	-0.2310*** {0.0295}	-0.2562*** {0.0432}
D(LNTO)	-0.0362 {0.0428}	-0.0379 {0.0522}	0.0085 {0.0597}	-0.0634 {0.0419}
D(IUI)	-0.0105 {0.0153}			
D(MCS)		0.0031 {0.0032}		
D(FTS)			0.1759 {0.3218}	
D(ICT_INF)				0.1481 {0.1501}
D(TO_IUI)	0.0031 {0.0035}			
D(TO_MCS)		-0.0006 {0.0008}		
D(TO_FTS)			-0.0295 {0.0772}	
D(TO_ICTINF)				-0.0283 {0.0386}
D(LNLFP)	-0.6644 {0.5375}	-0.4353 {0.3318}	-0.8164** {0.3728}	-0.4352 {0.3318}
D(LNFDI)	0.0015 {0.0026}	0.0032 {0.0029}	0.0017 {0.0025}	0.0032 {0.0029}
D(LNINC)	-0.0339 {0.0392}	-0.0249 {0.0382}	-0.0206 {0.0422}	-0.0249 {0.0382}
Constant	0.8821*** {0.1756}	0.9524*** {0.1628}	0.8924*** {0.1171}	1.0121*** {0.1729}
Diagnostics				
CD Stat.	0.2340	0.1131	0.0028	0.1078
CD Prob.	(0.814)	(0.909)	(0.997)	(0.914)
Residual	I (0)	I (0)	I (0)	I (0)
RMSE	0.997	0.993	0.997	0.992
Adjusted R2	0.979	0.984	0.982	0.985
No. of Obser.	832	832	832	832

Note: *p < 0.10; **p < 0.05; ***p < 0.01. Standard errors in parentheses Source: Author's compilation (2024)

Control variables show mixed effects: labour force participation (LNLFP) has a significant negative coefficient in one model, pointing to workforce-related challenges, while FDI (LNFDI) and income per capita (LNINC) generally support industrial growth. The error correction term (−0.1667 to −0.2562) is consistently negative and significant, confirming long-run cointegration between industrial growth and its determinants. In the short run, the majority of trade openness and ICT variables are insignificant. A notable exception is the change in labour force participation (D(LNLFP)) in model 3, which has a large and negative effect (−0.8164), suggesting that sudden declines in labour availability can quickly constrain industrial output. The generally insignificant short-run interaction effects indicate that ICT–trade linkages operate more slowly in industry, requiring sustained investment and policy coordination to yield measurable results.

4.3.3 Interactive Effect of Trade Openness and ICT Infrastructure on Service Sector Growth in SSA

Table 4.13 presents the findings of the interactive effect of trade openness and ICT infrastructure on the service sector. The long-run effect of trade openness is mixed: positive and significant in model 1 (0.2427) but negative and significant in models 2–4 (−0.10% to −0.12%). This variation suggests that the impact of openness depends on underlying structural conditions, market integration, and competitive capacity in the service sector. The ambiguity mirrors findings in trade–services literature that highlight both market expansion opportunities and displacement risks. ICT infrastructure (ICT_INF) again plays a positive and significant role in model 4, with a coefficient of 0.2594,

indicating that a 1% improvement in ICT can raise service sector growth by around 0.26%. This aligns with Gosavi (2018), who emphasises ICT's potential to enable service innovations and efficiency gains. However, the negative and significant interaction terms between trade openness and ICT variables (TO_IUI, TO_MCS, TO_FTS, TO_ICTINF) suggest that greater openness reduces the net benefits of ICT for services. Specifically, each 1% increase in openness lowers ICT's contribution to service growth by 0.03%–0.06%. This finding contrasts with Andrianaivo and Kpodar (2011), who argue that ICT and openness can be mutually reinforcing, and echoes Foster and Azmeh (2019), who warn that without domestic capability strengthening, openness may primarily benefit foreign service providers.

Table 11: Result of the Interactive Effect of Trade Openness with ICT Infrastructure on Service Sector Growth in SSA

Variable/Column	1	2	3	4
LNT0	0.2427* {0.1301}	-0.0396* {0.0222}	-0.1151*** {0.0280}	-0.0978*** {0.0194}
IUI	0.1436*** {0.0300}			
MCS		0.0055*** {0.0013}		
FTS			-0.0061 {0.0086}	
ICTINF				0.2594*** {0.0617}
TO_IUI	-0.0328*** {0.0068}			
TO_MCS		-0.0013*** {0.0003}		
TO_FTS			0.0026 {0.0019}	
TO_ICTINF				-0.0648*** {0.0145}
LNLFP	0.5183** {0.2503}	-0.0172 {0.0466}	-0.0067 {0.0328}	-0.0172 {0.0466}
LNFDI	0.0148 {0.0157}	0.0030 {0.0023}	0.0058* {0.0031}	0.0030 {0.0023}
LNINC	0.2102*** {0.0292}	0.0456*** {0.0062}	0.0607*** {0.0097}	0.0456*** {0.0062}
Short Run				
COINTEQ01	-0.1196*** {0.0425}	-0.2562*** {0.0432}	-0.2310*** {0.0295}	-0.2562*** {0.0432}
TO	-0.0814* {0.0448}	-0.0379 {0.0522}	0.0085 {0.0597}	-0.0634 {0.0419}
IUI	-0.0199 {0.0157}			
MCS		0.0031 {0.0032}		
FTS			0.1759 {0.3218}	
ICT_INF				0.1481 {0.1501}
TO_IUI	0.0052 {0.0036}			
TO_MCS		-0.0006 {0.0008}		
TO_FTS			-0.0295 {0.0772}	
TO_ICTINF				-0.0283 {0.0386}
LNLFP	-1.8572** {0.7555}	-0.4353 {0.3318}	-0.8164** {0.3728}	-0.4352 {0.3318}
LNFDI	0.0025 {0.0025}	0.0032 {0.0029}	0.0017 {0.0025}	0.0032 {0.0029}
LNINC	-0.0362	-0.0249	-0.0206	-0.0249

	{0.0432}	{0.0382}	{0.0422}	{0.0382}
Constant	-0.1120**	0.9524***	0.8924***	1.0121***
	{0.0439}	{0.1628}	{0.1171}	{0.1729}
Diagnostics				
CD Stat.	0.0995	0.2687	0.2161	0.2170
CD Prob.	(0.920)	(0.788)	(0.828)	(0.828)
Residual	I (0)	I (0)	I (0)	I (0)
RMSE	0.991	0.993	0.995	0.994
Adjusted R2	0.955	0.959	0.981	0.988
No. of Obser.	832	832	832	832

Note: *p < 0.10; **p < 0.05; ***p < 0.01. Standard errors in parentheses

Source: *Author's compilation (2025)*

Labour force participation (LNLFP) has a positive and significant effect in model 1 (0.5183) but is generally insignificant in other models. In the short run, LNLFP shows large negative effects in models 1 and 3, indicating adjustment frictions in labour deployment. FDI remains mostly insignificant, while income per capita (LNINC) consistently supports service growth. Short-run effects of ICT and trade openness on services are limited, supporting Sassi and Goaiad's (2013) conclusion that ICT benefits in services take time to materialise. Maswera et al. (2008) emphasise that bridging the digital divide in services requires not only access but also skills development, a point reinforced here by the stronger long-run compared to short-run impacts of ICT.

5. Conclusion, Policy Implications, and Future Research

This study examined the moderating role of ICT infrastructure in the relationship between trade openness and sectoral growth across 26 SSA countries from 1992 to 2023. The results indicate that ICT infrastructure generally supports industrial and service sector growth in the long run, while its benefits for agriculture are more closely linked to basic connectivity such as fixed-line access. However, the negative long-run interaction effects between trade openness and ICT suggest that in the absence of sufficient absorptive capacity, trade liberalisation can weaken the growth-enhancing potential of ICT adoption. These effects vary across sectors, underlining the need for differentiated policy approaches.

From a policy standpoint, trade liberalisation in SSA should be carefully synchronised with the expansion and upgrading of ICT infrastructure. Simply opening markets without ensuring that domestic producers and service providers have the technological capacity to compete risks eroding local industries and limiting the developmental gains from openness. Governments should prioritise investments in affordable, high-quality digital infrastructure, with particular emphasis on broadband connectivity, last-mile access, and

integration of ICT into production and distribution systems. At the same time, policies must address human capital constraints by promoting digital skills training, vocational education, and innovation support programmes. These measures would strengthen firms' capacity to adopt ICT productively, enabling them to respond effectively to competitive pressures in liberalised markets and to exploit export opportunities more fully.

In addition, sector-specific strategies are needed to reflect the heterogeneous ICT–trade dynamics revealed by the study. In agriculture, expanding rural connectivity and embedding ICT tools into extension services, market information systems, and supply chain management can enhance productivity and market access for smallholder farmers. For industry, targeted support should encourage the adoption of advanced manufacturing technologies and participation in higher-value segments of global value chains, coupled with incentives for research, development, and industrial innovation. In the services sector, where digital platforms and data networks are core enablers, policies should foster competitive domestic service providers, ensure fair market conditions, and safeguard data security. Regional cooperation—through cross-border ICT infrastructure projects, harmonised regulations, and joint capacity-building initiatives—would further lower costs, improve interoperability, and strengthen SSA's collective ability to capture value in global trade.

The study has certain limitations. The ICT infrastructure index includes fixed-line subscriptions, which, although historically relevant, may overstate their current economic importance in the digital era. The trade openness measure aggregates goods and services trade, limiting the ability to distinguish between their potentially different impacts. Although the PMG/ARDL method accounts for cross-sectional dependence and heterogeneity, the results remain correlational and cannot establish definitive causality. Furthermore, the use of country-level data may mask significant subnational differences in ICT access and sectoral performance. Future research could address

these limitations by disaggregating trade into merchandise and services components, constructing ICT indices that place greater emphasis on mobile broadband and emerging digital platforms, and using instrumental variable or quasi-experimental methods to strengthen causal inference. Incorporating firm- or household-level microdata would capture heterogeneity in ICT adoption and sectoral responses more accurately.

References

- Aker, J.C. & Fafchamps, M. (2015). Mobile phone coverage and producer markets: evidence from West Africa. *The World Bank Economic Review*, 29(2), 262-292.
- Andrianaivo, M. & Kpodar, K. (2011). ICT, Financial Inclusion, and Growth Evidence from African Countries. IMF Working Paper No. 11/73.
- Asada, H. (2022). Effects of Foreign Direct Investment, Trade Openness, and Human Capital Development on the Economic Growth of Thailand. *International Journal of Asian Business and Information Management (IJABIM)*, 13(1), 1-14. <https://doi.org/10.4018/IJABIM.309989>
- Babatunde, A. (2011). *Trade Openness, Infrastructure, FDI and Growth in Sub-Saharan African Countries*. http://www.na-businesspress.com/JMPP/BabatundeA_Web12_7_.pdf
- Bahrini, R., & Qaffas, A. A. (2019). Impact of Information and Communication Technology on Economic Growth: Evidence from Developing Countries. *Economies*, 7(1), 21. <https://doi.org/10.3390/economies7010021>
- Çakar, N. D., Gedikli, A., Erdoğan, S., & Yıldırım, D. Ç. (2021). A comparative analysis of the relationship between innovation and transport sector carbon emissions in developed and developing Mediterranean countries. *Environmental Science and Pollution Research International*, 28(33), 45693. <https://doi.org/10.1007/s11356-021-13390-y>
- Cinar, M., & Nulambe, N. A. h. (2018). Foreign Direct Investment, Trade Openness and Economic Growth: A Panel Data Analysis for Sub-Saharan Africa. *Business and Economics Research Journal*, 9(4), 749–760. <https://doi.org/10.20409/BERJ.2018.136>
- Danish (2019). Effects of information and communication technology and real income on CO2 emissions: The experience of countries along Belt and Road. *Telematics and Informatics*, 45, 101300. <https://doi.org/10.1016/j.tele.2019.101300>
- Dong, H., Geng, Y., Sarkis, J., & Fujita, T. (2018). Recycling and its effects on economic and environmental sustainability in industrial systems: A circular economy perspective. *Journal of Cleaner Production*, 185, 933–942.
- Dumor, K., Zhao, S., Dumor, H. K., Ampaw, E. M., Amouzou, E. K., Okae-Adjei, S., & Boadi, E. K. (2023). Evaluating the effect of ICT on trade and economic growth from the perspective of Eastern African belt and road countries. *Information Technology for Development*. <https://doi.org/10.1080/02681102.2023.2237461>
- Foster, C. & Azmeh, S. (2019). *The TPP and the digital trade agenda: Digital industrial policy and Silicon Valley's influence on new trade agreements*. London: International Institute for Environment and Development.
- Gosavi, A. (2018). Can mobile money help firms mitigate the problem of access to finance in Eastern sub-Saharan Africa. *Journal of African Business*, 19(3), 343-360.
- Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics*, 110(2), 353–377. <https://doi.org/10.2307/2118443>
- Hossain, M.A. & Mitra, D. (2013). The productive impact of using mobile telephone technology: Evidence from the informal sector in Bangladesh. *The Journal of Development Studies*, 49(10), 1380-1394.
- Huang, Y., Usman, M., Haseeb, M. et al. (2024). The Asymmetric Impact of Financial Expansion, ICT Development, and Trade Openness on China's Economic Growth. *J Knowl Econ*. <https://doi.org/10.1007/s13132-024-01903-2>
- Huang, Y., Usman, M., Haseeb, M. et al. (2024). The Asymmetric Impact of Financial Expansion, ICT Development, and Trade Openness on China's Economic Growth. *J Knowl Econ* 15, 20851–20882. <https://doi.org/10.1007/s13132-024-01903-2>
- Hussain, A., Batool, I., Akbar, M., & Nazir, M. (2021). Is ICT an enduring driver of economic growth? Evidence from South Asian economies. *Telecommunications Policy*, 45(8), 102202.
- Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. *Journal of Econometrics*, 90, 1–44.
- Kapingura, F. M., & Sanusi, K. A. (2024). Infrastructural development and trade performance in Sub-Saharan African

- countries. *International Journal of Applied Economics, Finance and Accounting*.
<https://doi.org/10.33094/ijaefa.v18i1.1352>
- Kurniawati, M.A. (2020). The role of ICT infrastructure, innovation and globalization on economic growth in OECD countries, 1996-2017. *Journal of Science and Technology Policy Management*, 11(2), 193–215. <https://doi.org/10.1108/jstpm-06-2019-0065>.
- Maswera, T., Dawson, R. & Edwards, J. (2008). E-commerce adoption of travel and tourism organisations in South Africa, Kenya, Zimbabwe and Uganda. *Telematics and Informatics*, 25(3), 187-200.
- Matsvai, S., & Hosu, Y. S. (2024). ICT and Agricultural Development in South Africa: An Auto-Regressive Distributed Lag Approach. *Agriculture*, 14(8), 1253.
<https://doi.org/10.3390/agriculture14081253>
- Monyela, M.N. & Saba, C.S. (2024). Trade openness, economic growth and economic development nexus in South Africa: a pre- and post-BRICS analysis. *Humanit Soc Sci Commun* 11, 1108.
<https://doi.org/10.1057/s41599-024-03604-2>
- Ngwenyama, O., Andoh-Baidoo, F. K., Bollou, F., & Morawczynski, O. (2006). Is there a relationship between ICT, health, education and development? An empirical analysis of five West African countries from 1997-2003. *The Electronic Journal of Information Systems in Developing Countries*, 23(1), 1-11.
- Osuma, G. O., & Nzimande, N. P. (2024). Exploring the Dynamic Link Between Trade Openness, External Debt, and Economic Growth in Sub-Saharan Africa: Challenges and Considerations. *Economies*, 12(11), 283.
<https://doi.org/10.3390/economies12110283>
- Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics*, 61(S1), 653–670.
- Pedroni, P. (2004). Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric Theory*, 20(3), 597–625.
- Pesaran, M. H. (2006). Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica*, 74(4), 967–1012.
<https://doi.org/10.1111/j.1468-0262.2006.00692.x>
- Sassi, S., & Goaid, M. (2013). Financial development, ICT diffusion and economic growth: Lessons from MENA region. *Telecommunications Policy*, 37(4-5), 252-261.
<https://doi.org/10.1016/j.telpol.2012.12.004>
- Semenya, D., & Ogujiuba, K. (2024). Evaluating the Effectiveness of Investment in Boosting South Africa's Economic Growth: A Comparative Analysis across Different Administrations. *Administrative Sciences*, 14(8), 173.
<https://doi.org/10.3390/admsci14080173>
- Shahbaz, M., Bhattacharya, M., & Mahalik, M.K. (2018). Financial development, industrialization, the role of institutions and government: A comparative analysis between India and China. *Applied Economics*, 50, 1952 - 1977.
<https://doi.org/10.1080/00036846.2017.1383595>
- Solow, R. M. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics*, 70(1), 65-94.
- Swan, T. W. (1956). Economic growth and capital accumulation. *Economic Record*, 32(2), 334-361.
<https://doi.org/10.1111/j.1475-4932.1956.tb00434.x>
- Swammy, A., & Dharni, K. (2020). Sustainable financial practices and corporate social responsibility in developing economies. *Journal of Financial Performance*, 35(4), 312–328.
- Tahir, M., Mazhar, T., & Afridi, M. A. (2019). Trade openness and sectoral growth in developing countries: some new insights. *Journal of Chinese Economic and Foreign Trade Studies*, 12(2), 90-103.
<https://doi.org/10.1108/JCEFTS-01-2019-0001>
- Varriale, R., Bartoletto, S., & Sabiu, S. (2024). Coal and Mines in the Era of Fascist Ventennio in Italy. *Histories*, 4(4), 508-524.
<https://doi.org/10.3390/histories4040026>
- Wang, W., Ning, Z., Shu, Y., Riti, M. J., & Riti, J. S. (2023). ICT interaction with trade, FDI and financial inclusion on inclusive growth in top African nations ranked by ICT development. *Telecommunications Policy*, 47(4), 102490.
<https://doi.org/10.1016/j.telpol.2023.102490>
- Xiao, A. et al. (2024). Bridging the digital divide: the impact of technological innovation on income inequality and human interactions. *Humanities and Social Sciences Communications*, 11(1).
<https://doi.org/10.1057/s41599-024-03307-8>.