Timisoara Journal of Economics and Business TJE&B

# THRESHOLD ANALYSIS OF ICT INFRASTRUCTURE'S EFFECTIVENESS IN STIMULATING SECTORAL GROWTH IN SUB-SAHARAN AFRICA

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DOI: 10.2478/ tjeb-2025-0008

*Over the past two decades, Sub-Saharan Africa (SSA) has witnessed substantial investments in Information and Communication Technology (ICT) infrastructure. However, the anticipated uniform growth across economic sectors has not materialized, indicating the existence of threshold effects. Hence, this study explores the threshold effects of ICT infrastructure on sectoral growth across twenty-six (26) SSA countries from 1991 to 2022, using dynamic panel threshold regression methods. The findings reveal that in agriculture, ICT indicators such as mobile subscriptions (3.55%), fixed-line subscriptions (2.97%), and composite infrastructure levels (-0.897%) have insignificant impact below their respective thresholds but significantly enhance growth when these thresholds are surpassed, largely due to improved labour participation and foreign direct investment. In the industrial sector, meaningful growth effects emerge only after ICT usage (4.221%) and mobile subscriptions (41.68%) exceed identified thresholds, with labour input further enhancing productivity. For the services sector, mobile penetration (77.26%) supports growth below the threshold, but yields diminish above it—though partially offset by labour efficiency improvements. These results demonstrate the need for targeted ICT investments that reflect sector-specific conditions. The study highlights the importance of reaching critical ICT thresholds to unlock growth, recommending that ICT infrastructure planning in SSA should be aligned with sectoral characteristics and broader economic strategies to maximize development outcomes.*

**Keywords:** **Economic sectors, economic growth, ICT infrastructure, and dynamic threshold regression, Sub-Saharan African (SSA).**

**JEL Classification:** **C82, O4, O33**

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# 1. Introduction

Policy debates on economic growth these days mostly centre information and communication technology (ICT) infrastructure, particularly within Sub-Saharan Africa (SSA), where digital innovation is seen as a route to socioeconomic advancement. While ICT infrastructure investment has increased significantly; from $1.6 billion in 2000 to over $10 billion annually by 2022 (ITU, 2023); the associated economic gains have not been fairly distributed across sectors and regions. This disparity raises important questions about the conditions under which ICT infrastructure effectively supports sectoral development. As of 2023, mobile phone usage in SSA reached 82%, while internet penetration averaged 36%, ranging from below 10% in South Sudan to over 60% in Kenya and South Africa (GSMA, 2023). Similarly, the digital economy's contribution to GDP ranges from less than 2% to over 15% depending on the country (World Bank, 2022).

ICT infrastructure shows great capacity to increase world economic development. With mobile phone subscriptions and internet use favourably linked with equitable development across income levels, ICT and innovation are major drivers of productivity and global integration in OECD nations (Kurniawati, 2020). Incorporating ICT into industry and education improves learning, lowers running expenses, and increases the impact of globalisation (Onuogu et al., 2024). Furthermore, boosting ICT investments are growing per capita earnings (Awad & Albaity, 2024). In SSA, where structural transformation is still a key obstacle, knowledge of the sector-specific consequences of ICT infrastructure is especially crucial. Evidence points to broadband adoption, internet access, and mobile phone use as more likely drivers of economic development than fixed phone infrastructure (Abdullahi & Sieng, 2023).

However, the benefits of ICT infrastructure are not uniform across sectors. While ICT enhances productivity in trade and education sectors, its isolated contribution to GDP growth can be limited without complementary factors like stable governance and skilled labour (Abdullahi & Sieng, 2023). The interaction between ICT and trade liberalization has been shown to foster inclusive growth through initiatives like the African Continental Free Trade Area (Bello et al., 2024). Further, several theoretical frameworks explain these threshold effects. Network externalities suggest that the benefits of ICT adoption rise exponentially as usage increases (Katz & Shapiro, 1986). Complementarity theory emphasizes that ICT investments yield optimal returns only when accompanied by factors such as human capital, institutional quality, and reliable electricity (Basu & Fernald, 2007). Technological leapfrogging further suggests that developing nations can bypass certain stages of development once critical adoption levels are reached (Lee & Lim, 2001). Yet, sector-specific threshold studies in SSA remain limited. Recent evidence from Matsvai and Hosu (2024) shows that mobile phone and internet use positively affected agricultural output and productivity in South Africa, while fixed telephone subscriptions had negative long-term impacts. Given that agriculture employs about 60% of SSA's workforce and contributes 23%

to GDP (FAO, 2023), sectoral differences in ICT thresholds, compared to manufacturing (11% of GDP) and services (53% of GDP) (AfDB, 2023), are likely significant.

Given these shortcomings, this study aims to investigate, in sub-Saharan Africa, the threshold effects of ICT infrastructure on sectoral growth. Specifically, it answers three questions: what are the minimum ICT infrastructure thresholds necessary for accelerated growth in agriculture, manufacturing, and services; how do these thresholds differ across sectors; and what complementary factors affect these thresholds? This paper answers these questions using the dynamic threshold technique (DTT) since of its capacity. First of all, it considers cross-sectional dependency (Seo and Shin, 2016) and enables endogenous threshold variables; both of which are very important in the SSA where nations show different development pathways yet confront similar regional difficulties. Unlike static threshold models, the dynamic method allows the persistence of ICT effects across time, thereby addressing the observation made by Chakraborty and Nandi (2011) that technology adoption advantages typically materialise with considerable lags. Thirdly, DTT manages the non-linear connection between ICT infrastructure and economic production (Wang et al., 2023) rather well. It also guarantees accurate estimations in spite of the typical data quality problems in poor countries (Kremer et al., 2013). Following Pradhan et al. (2018), who used threshold approaches to investigate ICT-growth relationships across economic corridors, our DTT implementation enables multiple thresholds and regime-specific coefficients, so capturing the transitional dynamics of digital infrastructure development across many economic sectors.

This study contributes to the body of knowledge in three ways. First, it identifies the specific penetration rates of ICT infrastructure needed to trigger growth in key sectors. In agriculture, relatively low thresholds for mobile subscriptions (3.55%), fixed subscriptions (2.97%), and ICT infrastructure (-0.897%) mark critical transition points where technology adoption begins generating significant positive growth effects, primarily through enhanced labour participation and increased FDI inflows. The industrial sector demonstrates higher threshold requirements, with ICT usage (4.221%) and mobile subscriptions (41.68%) needing to reach more substantial penetration levels before triggering productivity gains, with labour involvement serving as a key amplifying factor. Contrastingly, the services sector exhibits a unique pattern where mobile penetration drives growth most effectively below a higher threshold (77.26%), after which diminishing returns emerge but are counterbalanced by efficiency gains in labour productivity. Second, it explores the joint effects of ICT infrastructure and complementary factors such as foreign direct investment, economic growth, and human capital—relationships largely overlooked in prior studies. Third, it offers practical policy insights for sequencing and targeting ICT investments to maximize returns, helping policymakers allocate limited resources more efficiently by matching ICT strategies to sectoral and national development stages. This evidence-based approach is crucial for SSA where misaligned digital investments have often failed to deliver anticipated development outcomes.

The rest of this paper is organized as follows. The review of relevant literature is carried out in Section 2, while Section 3 presents and discusses the theoretical framework and methodology. Discussion of the results and their implications was presented in Section 4, while Section 5 concludes the paper with information on policy recommendations.

# 2. Literature Review

## 2.1 Theoretical Framework

The premise of this work is the technology diffusion theory (TDT). Rooted in the writings of Rogers (1962) and later developments by Mansfield (1961), TDT asserts that the adoption and use of technology across economic agents follow a methodical process affected by certain thresholds and enabling conditions. This theory emphasises the need of adoption rates, network externalities, and innovation dissemination, so helping one to comprehend how ICT infrastructure supports sectors growth. Given the required thresholds for acceptance are reached, the dispersion of ICT technologies including mobile and fixed-line telecommunication services, internet access, and digital platforms of Sub-Saharan Africa (SSA) is hypothesised to promote production and efficiency. This approach underscores a non-linear relationship in which ICT infrastructure generates transformative effects only after critical levels of use or penetration are achieved. Hence, increasing access to information, markets, and financial services, ICT will improve results for smallholder farmers in agriculture therefore supporting the adoption of technology. Likewise, mobile cellular subscriptions (MCS) and fixed telephone subscriptions (FTS) may allow rapid spread agricultural knowledge, and weather forecasts, so helping to lower inefficiencies and improve market integration. Still, these advantages are contingent on reaching particular degrees of ICT access in keeping with the threshold paradigm. Under such levels, network effects are modest and the wider economic influence stays confined. It is hypothesized that by improving complimentary elements like labour force participation and foreign direct investment (FDI), which once thresholds are reached have more beneficial effects, ICT also acts as a catalyst. This creates an enabling environment where innovation diffusion drives sectoral development. In the industrial sector, the spread of ICT, through advanced data systems and communication tools, improves manufacturing efficiency, supply chain coordination, and innovation. According to Technology Diffusion Theory, ICT infrastructure, particularly as captured by the ICT Usage Index (IUI), fosters productivity by facilitating firm-level cooperation and knowledge spillovers. Yet, the full benefits of these dynamics depend on achieving sufficient infrastructure penetration; otherwise, the result is fragmented networks and underutilized technologies.

## 2.2 Empirical Literature

The impact of information and communication technology (ICT) on the economic growth and social development of the countries has been investigated over the past three decades by many authors who have used different methodologies, data sources, and different time periods either at the country level, or at the level of a panel of countries. However, a plethora number of the empirical studies have demonstrated that ICT enhance GDP growth, productivity, as well as creating employment opportunities. The review of extant literature however shows diverse arguments regarding the subject without reaching an agreement and ignored its impact on sectorial growth. For instance, Toader, Firtescu, Roman, and Anton (2018) employed panel-data estimation technique to evaluate the effect of using ICT infrastructure on economic growth in European Union (EU) countries for a period of 18 years (2000–2017). The study demonstrated a positive and strongly effect of using ICT infrastructure on economic growth in the EU member states, but the magnitude of the effect differs depending on the type of technology examined. The findings further indicated that inflation rate, unemployment rate, the degree of trade openness, government expenditures, and foreign direct investments significantly affect GDP per capita at EU level. Using panel cointegration and vector error correction models (VECM) techniques, Pradhan, Mallik and Bagchi (2018) examined the long-run relationships nexus among per capita real GDP, information and communication technology (ICT) infrastructure, consumer price index, labour force participation rate, and gross fixed capital formation manifest in G-20 countries spanning from the 2001–2012. The study finding showed that the variables are cointegrated and do not drift apart in the long run. Also, the findings of the vector error correction models (VECM) confirms that embellishment of ICT infrastructure.

Besides, Kumari and Singh (2023) employed the ordinary least square (OLS) regression, the fixed effect regression (FER), and the generalized method of moments (GMM) method to estimate the joint impact of information communications technology (ICT) infrastructure, financial development (FD), and trade openness (TO) on the economic growth (EG) of 85 countries (including 27 low- and 58 high-income countries) for the period 2000–2019. The findings of the study revealed that the individual effects of ICT (Internet, secure Internet, broadband, and telephone) on EG are positive, excluding only telephone in LIC and excluding broadband in the high-income countries (HICs); in case of individual effects, the majority of ICT proxies have a positive and significant relationship with EG in low income countries (LICs) and HICs; while the joint effect of ICT infrastructure and FD in both LICs and HICs indicates that FD complements the positive impact of EG. Remeikiene, Gaspareniene, Fedajev, and Vebraite (2021) examined the role of ICT development in enhancing the economic growth in 11 EU transition economies over the 2000- 2019 period, using the linear regression analysis. The study findings indicated that ICT development has a positive impact on the economic growth in the considered countries, and only the link between the number of internet users and economic growth is statistically significant for the 11 EU transition economies. While Huang, Li, Guo, and Hall (2022) also demonstrated that ICTs positively promoted firm performance, including financial profitability, marketing performance and innovation performance in selected China city's over the 2001-2016 period.

Besides, Bahrini and Qaffas (2019) evaluated the impact of information and communication technology (ICT) on the economic growth of selected developing countries in the Middle East and North Africa (MENA) region and the Sub-Saharan Africa (SSA) region by using a panel Generalized Method of Moment (GMM) model spanning from 2007 to 2016. The results of the Generalized Method of Moment (GMM) model showed that except fixed telephone, other information and communication technologies such as mobile phone, Internet usage, and broadband adoption are the main drivers of economic growth in MENA and SSA developing countries. Also, Owolabi, Adedeji, Aderounmu, Oku, and Ogunbiyi (2023) confirmed that the Information and Communications Technology significantly reduced economic diversification, while internet and mobile users were, respectively, insignificant for boosting economic diversification, and fixed broadband and secure internet servers were insignificant in adversely affecting economic diversification in the 37 sub-Saharan Africa countries over the period of 2000 to 2019. Recently, Saba, Ngepah, and Odhiambo (2024) analyzed the nexus between ICT diffusion-economic growth-development for 73 countries from sub-Saharan Africa (SSA), the Middle East and North Africa (MENA), and Latin America and the Caribbean (LAAC) over the period 2000–2018. The study employed the newly developed panel vector autoregression (PVAR) in the generalized method of moments (GMM) estimation approach and suggested a long-run equilibrium relationship between the three variables. The findings differ from the causality results for the overall panel and each of the regions differs. The inconsistency in the causality results across the regions suggests that the level of ICT diffusion is still underdeveloped. Whereas, the PVAR-GMM results reveal that ICT diffusion is a significant and positive predictor of growth across the regions, with a greater effect reported in MENA; (ii) ICT diffusion is a significant and positive predictor of development across the regions with a lesser effect noticed in MENA.

Unlike the experience of SSA, data from developed countries exposes different dynamics. From 1996 to 2017, Kurniawati (2020) looks at the interplay of ICT, innovation, globalisation, and economic development in OECD nations. Using robust econometric methods, the study reveals that global integration, ICT and innovation are favourably tied with economic performance; feedback effects of ICT use, innovation, and global integration are therefore observed. This implies that in order to maintain momentum of expansion even developed nations have to keep spending in technological infrastructure and innovation. Wang et al. (2023) underline even more the general relevance of ICT in society by examining its correlation with inclusive development in top African countries. They find, using an expanded GMM framework, that ICT spread promotes inclusive development, especially in view of trade openness, foreign direct investment (FDI), and financial inclusion. But inflation is found to be a constraint, which emphasises the need of macroeconomic stability in optimising the development returns of ICT. The foregoing indicates that ICT infrastructure plays a role in promoting sectoral growth across various contexts. While the existing literature extensively examines the relationship between ICT infrastructure and economic growth across various regions, there is a notable research gap regarding the specific threshold levels of ICT infrastructure required to stimulate sectoral growth in Sub-Saharan Africa.

# 3. Methodology

## 3.1 Data Description

This study utilizes panel data from 26 Sub-Saharan African countries over the period 1991 to 2022. The decision to select a sampling period from 1991 to 2022 is partly driven by the availability of reliable data, but also corresponds to a critical period in the region's technological evolution. This timeframe captures several significant ICT development phases in SSA: the initial introduction of mobile telecommunications in the early 1990s, the subsequent rapid expansion of cellular networks in the early 2000s, the emergence of mobile internet in the mid-2000s, and the ongoing broadband revolution since 2010. The 32-year panel structure enables robust examination of long-term relationships while providing sufficient observations for detecting threshold effects, which typically require extensive temporal variations (see, Batuo (2015). Following Tchamyou et al. (2019), we excluded countries with significant data gaps exceeding five consecutive years to maintain estimation integrity. The selection also ensures representation across the region's economic communities and diverse economic structures, allowing for robust analysis of how sectoral composition influences ICT infrastructure thresholds.

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 sectors toward GDP respectively. This is in line with Tahiret al., (2019). Trade Openness was measured as the sum of import and export to GDP ratio. The current research looked at how increased trade integration has contributed to sectoral economic growth through various mechanisms. ICT infrastructure has a significant impact on sectoral economic growth. The development and deployment of ICT infrastructure can be supported by ICT policies, which allow nations to allocate resources for optimal resource utilization and stimulate economic growth. In the study, ICT infrastructure index, mobile users, individual internet users, and fixed telephone users were considered as proxies of ICT infrastructure. This study relies on the principal component analysis (PCA) to develop the ICT infrastructure index and to marginally reduce the endogeneity of regressors. It began by relying on one randomly selected ICT infrastructure measure selected from each broad composition for sample recruitment in the PCA analysis. The PCA helps summarise the three indicators taking cognizance of the possible endogeneity of the regressor and obtaining orthogonal variations in the institutional variables (Andrés et al., 2015). The results of the principal components of the ICT infrastructure index, derived from the three variables included in the model, are presented in Table 1.

**Table 1.** Principal Component Analysis for ICT Infrastructure

| Principal Components | ICT Infrastructure Index | | | | | |
|---|---|---|---|---|---|---|
| | Component Matrix | | | Proportion | Cumulative Proportion | Eigen value |
| | 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 Compilation using data from World Development Indicator (WDI)*

Other main factors of sectoral output growth in this study are capital stock, foreign direct investment, and economic growth. Capital investment, which is proxied by gross fixed capital formation, is employed to capture the accumulation of physical capital and infrastructure development across sectors. Following Solow's growth model and its empirical applications by Mankiw et al. (1992), we include this variable to account for the traditional factor inputs that drive productivity improvements and capacity expansion. Capital formation is particularly crucial in the SSA where infrastructure gaps remain substantial, with the African Development Bank (2023) estimating annual infrastructure investment needs of $130-170 billion. Foreign direct investment (FDI) serves as another critical control variable, measuring the inflow of external capital, technology transfer, and managerial expertise that can accelerate sectoral transformation. FDI contributes to productivity spillovers and market access opportunities across SSA economies (Gui-Diby, 2014), though with varying sectoral impacts. The inclusion of this variable allows us to isolate the effects of ICT infrastructure from those of general investment trends and international linkages. Economic growth, measured as real GDP growth rate, controls for overall macroeconomic conditions and business cycle effects that influence sectoral performance through demand channels and resource allocation mechanisms. This strategy fits Rodrik's (2016) focus on the need of including economy-wide dynamics into analysis of sectoral changes in emerging countries. These parameters taken together constitute a set of controls that consider both demand-side growth determinants and supply-side capacity augmentation, therefore perhaps confusing the link between ICT infrastructure and sectoral performance. Table 2 summarises the many sources and observations.

**Table 2.** Data Description, Measurement, and Sources

| Variables | Description | Sources |
|---|---|---|
| Sectoral output growth (y) | Agriculture, manufacturing, and services sectors | WDI (2024) |
| ICT infrastructure (ict) | ICT infrastructure index | Author compilation |
| Mobile users (mcs) | Mobile cellular subscriptions (per 100 people) | WDI, ITU (2024) |
| Fixed telephone users (fts) | Fixed telephone subscriptions per 100 people | WDI, ITU (2024) |
| Individual internet (iui) | % of the population using the Internet | WDI, ITU (2024) |
| Trade openness (to) | Ratio of total trade to GDP | WDI (2024) |
| Human capital investment (k) | Gross fixed capital formation to GDP | WDI (2024) |

| Variables | Description | Sources |
|---|---|---|
| Labour participation (lb) | Labour force ratio to working-age population | WDI (2024) |
| Foreign direct investment (fdi) | Foreign direct investment to GDP (% of GDP), | WDI (2024) |
| Income (inc) | Gross domestic product per capita | WDI (2024) |
| Inflation (inf) | Inflation, Consumer price index | WDI (2024) |

*Source: Author's Compilations (2025)*

## 3.2 Model and Theoretical Framework

Inspired by the pioneering works of Solow (1956) and Swan (1956), our approach takes a stance anchored in the neoclassical development model. The model shows how three main economic forces, labour, capital, and technology, interact to produce a steady pace of economic growth: This idea offers a basic framework for the baseline model of examination of impact of trade openness and ICT infrastructure on sectoral growth in SSA. To answer the main question of the study, the study includes two more variables (TO) and (ICT) into equa. (1), which is specified as:

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

The study argues that $A$ in equa. (1) represents technology, resource endowments, and policy framework which differ across countries. Thus, to capture the different initial levels of technology efficiency across countries, a measure of ICT infrastructure is added to the equ. (1):

$$Y_t = A.K_t{}^{\propto}L_t{}^{1-\propto}TO_t^{\theta}ICT_t^{\gamma} \tag{2}$$

The natural logarithm of both sides is taken to linearize the equation (2):

$$lnY_t = lnA + \alpha lnK_t + (1{-}\propto)lnL_t + \theta lnTO_t + \gamma lnICT_t \tag{3}$$

The model presented in equation (3) 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−α 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. Accordingly, drawing upon the theoretical literature outlined above, we formulate the association between sectoral growth and its determinants within the framework of a multi-sector economic growth model. As a result, this study specifies the following model:

$$lnY_{it} = a_0 + a_1 lnTO_{it} + a_2 lnICT_{it} + a_3 lnL_{it} + a_4 lnK_{it} + a_5 lnZ_{it} + \mu_i + \varepsilon_{it} \quad (4)$$

## 3.3 Empirical strategy

Towards a data-driven, evidence-based policy formulation, our threshold analysis of ICT infrastructure's effectiveness in stimulating sectoral growth in SSA, requires rigorous data-cleaning procedures that are essential to ensure the reliability and validity of our empirical findings. In this regard, our study employs advanced econometric techniques, including second-generation panel unit root tests and second-generation cointegration analysis, to preprocess the data and address potential issues of stationarity and cointegration. Subsequently, we leverage the dynamic panel threshold and endogeneity regression model piloted by Seo and Shin (2016) and Seo et al. (2019) for estimating the parameter estimates of our model. The summary of each step and the contribution to the robustness of our analysis is provided to show a clear line of thought. Before proceeding with the analysis, it is imperative to assess the stationarity of variables to avoid spurious regression results (Tsay & Chung, 2000). Advanced second-generation panel unit root tests, like Pesaran's (2007) cross-sectional augmented IPS (CIPS) and cross-section augmented Dickey-F (CADF) unit root test, are preferred because of the high precision with cross-sectional dependence in panel unit roots. Pesaran (2007) enhances Augmented Dickey-Fuller (ADF) regressions by incorporating cross-section averages of lagged levels and first differences of individual series. This approach proxies the common factor using the cross-section mean of $y_{it}$ and its lagged values, employing cross-sectional ADF statistics (CADF). Pesaran's CIPS test, based on modified IPS statistics (Im et al., 2003), averages individual CADF to provide further insights. We hypothesis that by accounting for cross-sectional dependence and heterogeneity, the paper provides more accurate assessments of stationarity, ensuring that our subsequent analysis is based on non-spurious relationships, unlike the first generations such as the Levin et al. (2002) test, which typically treat individual units as independent, which might not be the case in many real-world scenarios where there could be cross-sectional dependence or heterogeneity among the units.

Further, cointegration analysis is crucial for investigating long-run relationships among variables, particularly in panel data settings where unit roots and cointegration may exist simultaneously. Second-generation cointegrating analysis, which incorporates the presence of cross-sectional dependence and heterogeneity, allows us to identify cointegrating relationships more accurately. We considered the Pedroni and Kao tests, particularly in their ability to handle cross-sectional dependence, accommodate heterogeneous cointegration relationships, and provide robust inference in panel data analysis. Following the cleaning of data, we considered the dynamic threshold regression (DTR) approach as the preferred method for estimating the parameter estimates of our model. The DTR methodology offers several advantages over alternative approaches, making it highly relevant and superior over other traditional methodologies. The DTR model (5), which is specified as:

$$Y_{i,t} = \vartheta_i + \theta' Z_{i,t} + \beta_1 d_{i,t} I(d_{i,t} \leq \gamma) + \beta_2 d_{i,t} I(d_{i,t} > \gamma) + \varepsilon_t \quad (5)$$

where I(.) represents the indicator function. Equation (5) can also be written as:

$$Y_{i,t} = \vartheta_i + \theta' Z_{i,t} + \beta' d_{i,t}(\gamma) + \varepsilon_t \quad (6)$$

$$\beta = (\beta_1, \beta_2) + \varepsilon_t \quad (7)$$

The observations are divided into two regimes depending on whether the threshold variable $d_{i,t}$is smaller or greater than the threshold value ($\gamma$). The regimes are distinguished by different regression slopes, $\beta_1$ *and* $\beta_2$

# 4. Results and Discussion

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

Table 3 present 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.

DOI: 10.2478/tjeb-2025-0008



**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 in Table 4. Table 4 reveals several significant relationships: agriculture and services 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 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

| | 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 | |
| INF | -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 |
| LnINF | 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 (Mao & Shen, 2019; Eberhardt & Teal, 2010). 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 (2006) 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 Swammy & 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 | 1st Difference | Integration order | Level | 1st 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 Threshold Estimates and Sectoral Analysis

The paper answered the question in this study by using the dynamic panel threshold and the endogeneity regression model piloted by Seo and Shin (2016) and Seo et al. (2019). It estimates a robust dynamic panel threshold of the ICT infrastructure beyond which trade openness is significantly stimulated to spur the growth of 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 threshold variables: Internet users (IUI), mobile cellular subscriptions (MCS), fixed telephone subscriptions (FTS), and an overall ICT infrastructure index (ICTINF).

### 4.3.1. Result of Panel threshold of Agricultural Sector with ICT Infrastructure

Table 9 showcases the outcomes of panel threshold analysis, elucidating the influence of different ICT infrastructure variables on the agricultural sector. The examination encompassed four key ICT infrastructure variables: ICT Use Index (IUI), Mobile Cellular Subscriptions (MCS), Fixed Telephone Subscriptions (FTS), and the overall ICT Infrastructure index (ICTINF). Remarkably, threshold effects were discerned for all ICT variables excluding IUI, suggesting distinct impacts on agriculture above and below specific thresholds of ICT accessibility. Notably, the threshold coefficient for MCS stands at 0.0355, signifying significance at a 10% level. This indicates a pivotal threshold level of mobile cellular subscriptions, where the dynamics of its impact on agriculture undergo a significant change at a remarkably low level of just 3.55%.

Moreover, the FTS threshold coefficient registers at 2.966, as reported in Table 9, displaying significance at a 5% level. This observation hints at a structural transformation in the impact of fixed telephone subscriptions once they approximate 3 subscriptions per 100 individuals. Equally intriguing is the ICTINF threshold coefficient, quantified at -0.897, and significant at a 5% level. The negative value implies effects on agriculture even at minimal levels of ICT infrastructure. Interestingly, below the determined thresholds, most ICT variables failed to exert a significant impact on agriculture, indicating that restricted ICT access offers limited assistance to the agricultural sector. Conversely, in the upper regime surpassing the thresholds, elevated levels of mobile and overall ICT manifest positive effects on agriculture, underscoring the advantages of surpassing critical ICT thresholds. It is noteworthy that capital investment exhibited a negative impact on agriculture beyond the ICTINF threshold, while Foreign Direct Investment (FDI) yielded a positive influence. Additionally, labour participation emerged as a pivotal factor, showcasing substantial positive effects on agriculture in the upper regime for all ICT variables, indicative of ICT's capacity to amplify labour leverage within the agricultural domain.

**Table 9.** Result of Panel threshold of Agricultural Sector with ICT Infrastructure

| Dependent variable: Agricultural Sector | ICT INFRASTRUCTURE VARIABLES | | | |
|---|---|---|---|---|
| | IUI | MCS | FTS | ICTINF |
| Threshold value of ICT | 8.437* (0.089) | 0.0355*(0.099) | 2.966*(0.021) | -0.897** (0.044) |
| Constant | -230.9*** (0.003) | 14.07* (0.074) | -6.928*(0.07) | 14.07*(0.074) |
| **Lower regime** | | | | |
| Lagged of Agriculture | -0.106 (0.986) | 0.1283 (0.679) | 0.258(0.368) | 0.128 (0.679) |
| Trade openness (to) | 0.408 (0.97) | -0.0165(0.971) | -0.088(0.841) | -0.016 (0.971) |
| Labour participation (lfb) | 2.104 (0.878) | -0.6216(0.829) | 1.315 (0.354) | -0.621 (0.829) |
| Capital investment (k) | 0.152 (0.986) | 0.7448(0.122) | -0.283(0.739) | 0.744 (0.122) |
| Foreign direct invest. (FDI) | -0.013 (0.99) | -0.0488 (0.167) | -0.049(0.847) | -0.048 (0.167) |
| GDP per capita (INC) | 0.277 (0.948) | 0.5405(0.168) | -0.076(0.869) | 0.540 (0.168) |
| **Upper regime** | | | | |
| Lagged of Agriculture | 6.045 (0.28) | -0.404(0.201) | 0.255 (0.617) | -0.404 (0.201) |
| Trade openness (to) | 19.46* (0.073) | -0.140(0.768) | -0.334 (0.8) | -0.140 (0.768) |
| Labour participation (lfb) | 35.73*** (0.001) | -0.822(0.642) | 1.242 (0.621) | -0.822 (0.642) |
| Capital investment (k) | 2.958 (0.733) | -1.353*** (0.00) | -0.628 (0.61) | -1.353***(0.00) |
| Foreign direct invest. (FDI) | -1.117 (0.486) | 0.100* (0.099) | 0.262 (0.357) | 0.100* (0.099) |
| GDP per capita (INC) | -0.5291 (0.922) | -0.869** (0.029) | 0.506 (0.631) | -0.869**(0.029) |

*Note: ***, ** and * represent 1%, 5%, and 10% levels of significance respectively. Probability values are reported in parentheses.*

### 4.3.2. Result of Panel threshold of Industrial Sector with ICT Infrastructure

Table 10 illustrates the outcomes of a panel threshold analysis aimed at exploring the influence of ICT infrastructure variables on the industrial sector. Four ICT variables, namely IUI, MCS, FTS, and ICTINF, were scrutinized to discern any threshold effects. Notably, threshold effects were observed for IUI and MCS, suggesting varying impacts on the industry depending on the levels of these variables. The identified thresholds were 4.221 for IUI and 41.68 for MCS, both statistically significant at the 5% level. In regimes below the identified thresholds, particularly for MCS, a noteworthy positive and significant effect on the industry was discerned. However, the impact of other ICT variables remained statistically insignificant in these lower regimes. Conversely, in the upper regime above the thresholds, a distinct pattern emerged, where higher levels of IUI and labour participation demonstrated positive and significant effects on the industrial sector. This underscores the role of ICT in facilitating labour utilization and productivity enhancement, particularly in more advanced stages of ICT infrastructure development. The implications of these findings are twofold. Firstly, the observed threshold for IUI at 4.221 indicates a critical point at which the level of ICT use significantly impacts the industry. Similarly, the threshold for MCS at 41.68 suggests that mobile subscription rates above this level trigger different effects of ICT on industrial

DOI: 10.2478/tjeb-2025-0008



performance. These results collectively indicate that while limited ICT access may not substantially benefit the industry, surpassing certain thresholds in ICT use and mobile subscriptions can notably boost industrial productivity and growth, emphasizing the importance of continued investment and development in ICT infrastructure for economic advancement.

**Table 10.** Result of Panel threshold of Industrial Sector with ICT Infrastructure

| Dependent variable: Industrial Sector | ICT INFRASTRUCTURE VARIABLES | | | |
|---|---|---|---|---|
| | ***IUI*** | ***MCS*** | ***FTS*** | ***ICTINF*** |
| Threshold value of ICT | 4.221** (0.036) | 41.68**(0.030) | 1.341 (0.841) | -0.008 (0.993) |
| Constant | -13.14** (0.011) | -3.076**(0.02) | 2.964**(0.042) | -3.076 (0.222) |
| ***Lower regime*** | | | | |
| Lagged of Industrial Sector | 0.785 (0.242) | 0.495**(0.039) | 0.069 (0.814) | 0.495**(0.039) |
| Trade openness (*to*) | -0.035 (0.942) | 0.059 (0.777) | 0.411 (0.308) | 0.059 (0.777) |
| Labour participation (*lfb*) | 2.174 (0.437) | 1.019 (0.234) | 0.808** (0.030) | 1.019 (0.234) |
| Capital investment (*k*) | -0.190 (0.740) | -0.122 (0.563) | -0.015 (0.948) | -0.122 (0.563) |
| Foreign direct investment *(FDI)* | 0.014 (0.763) | -0.005 (0.674) | -0.022 (0.448) | -0.005 (0.674) |
| GDP per capita *(INC)* | 0.261 (0.447) | 0.053 (0.652) | 0.156 (0.291) | 0.053 (0.652) |
| ***Upper regime*** | | | | |
| Lagged of Industrial Sector | -0.476 (0.671) | -0.025 (0.948) | 0.383 (0.247) | -0.025 (0.948) |
| Trade openness (*to*) | -0.192 (0.837) | 0.123 (0.565) | -0.636 (0.109) | 0.123 (0.565) |
| Labour participation (*lfb*) | 4.182*** (0.003) | 0.249 (0.610) | 0.272 (0.681) | 0.249 (0.610) |
| Capital investment (*k*) | -0.808 (0.274) | 0.300 (0.258) | -0.433* (0.095) | 0.300 (0.258) |
| Foreign direct investment *(FDI)* | -0.001 (0.994) | 0.015 (0.794) | -0.028 (0.618) | 0.015 (0.794) |
| GDP per capita *(INC)* | 0.388 (0.403) | 0.133 (0.500) | -0.214 (0.474) | 0.133 (0.500) |

*Note: ***, ** and * represent 1%, 5%, and 10% levels of significance respectively. Probability values are reported in parentheses.*

### 4.3.3. Result of Panel threshold of Service Sector with ICT Infrastructure

Table 11 shed light on the relationship between ICT infrastructure variables and the service sector. Among the four ICT variables examined; namely, IUI, MCS, FTS, and ICTINF; only MCS exhibited a notable threshold effect, with a coefficient of 77.26, significant at the 5% level. This finding suggests that there exists a critical threshold of mobile phone saturation, beyond which the effects of ICT on the service sector undergo a significant change. Below this threshold, higher MCS values were associated with a positive and statistically significant impact on the service sector, indicating that increased mobile phone penetration fosters growth in service-related activities. However, the analysis revealed no significant effects for the other ICT variables below their respective thresholds, highlighting the unique role of mobile phone saturation in driving changes within the service sector. Moreover, the examination of the upper regime, above the MCS threshold, unveiled additional insights into the dynamics between ICT penetration and service sector performance. Specifically, the findings revealed a negative coefficient of -0.581 for lagged service, significant at the 5% level, suggesting that high levels of mobile penetration may lead to diminishing returns in service-related activities. Conversely, labour participation exhibited a positive coefficient of 2.224 above the threshold, also significant at 5%, indicating that increased mobile access facilitates more efficient utilization of labour within the service sector. This dual effect underscores the importance of considering not only the level of ICT penetration but also its interaction with other variables, such as labour participation, in shaping the performance of the service sector.

**Table 11.** Result of Panel threshold of Service Sector with ICT Infrastructure

| ***Dependent variable: Service Sector*** | ***ICT INFRASTRUCTURE VARIABLES*** | | | |
|---|---|---|---|---|
| | ***IUI*** | ***MCS*** | ***FTS*** | ***ICTINF*** |
| Threshold value of ICT | 0.680(0.985) | 77.26**(0.015) | 1.011(0.880) | 0.752 (0.268) |
| Constant | 2.954* (0.072) | -12.73* (0.091) | 2.905** (0.041) | -12.73* (0.091) |
| ***Lower regime*** | | | | |
| Lagged of Service Sector | 0.772 (0.238) | 0.511* (0.099) | 0.137 (0.820) | 0.511*(0.099) |
| Trade openness *(to)* | -0.010 (0.917) | -0.329***(0.006) | 0.031 (0.889) | -0.329***(0.006) |
| Labour participation *(lfb)* | 0.160 (0.745) | -1.418 (0.104) | -0.673 (0.103) | -1.418 (0.104) |
| Capital investment *(k)* | 0.019 (0.912) | 0.265 (0.136) | -0.007 (0.973) | 0.265 (0.136) |
| Foreign direct investment *(FDI)* | 0.044***(0.001) | -0.016 (0.570) | 0.011 (0.757) | -0.016 (0.570) |
| GDP per capita *(INC)* | -0.038 (0.546) | -0.066* (0.088) | -0.022 (0.705) | -0.066* (0.088) |
| ***Upper regime*** | | | | |
| Lagged of Service Sector | -0.581**(0.046) | 0.660 (0.499) | -0.866* (0.052) | 0.660 (0.499) |
| Trade openness *(to)* | 0.057 (0.527) | -0.054 (0.845) | -0.332 (0.258) | -0.054 (0.845) |
| Labour participation *(lfb)* | -0.251 (0.332) | 2.224** (0.044) | 0.430 (0.368) | 2.224** (0.044) |
| Capital investment *(k)* | 0.061 (0.759) | -0.556 (0.238) | 0.278 (0.323) | -0.556 (0.238) |
| Foreign direct investment *(FDI)* | -0.001 (0.965) | -0.073 (0.509) | -0.049 (0.114) | -0.073 (0.509) |
| GDP per capita *(INC)* | -0.027 (0.706) | 0.521 (0.102) | -0.088 (0.526) | 0.521 (0.102) |

*Note: ***, ** and * represent 1%, 5%, and 10% levels of significance respectively. Probability values are reported in parentheses.*

DOI: 10.2478/tjeb-2025-0008



## 4.4. Discussion of the findings

In view of the objective of the study focusing on the investigation of the threshold of the ICT infrastructure beyond which trade openness is significantly stimulated to spur the growth of agriculture, industrial, and service sectors in SSA. The panel threshold analyses reveal that the threshold level of ICT infrastructure had a positive but insignificant threshold effect on the service sector ($a_3 = 0.752, \delta = 0.678$), while exhibiting a negative and insignificant threshold level on the agriculture ($a_1 = -0.897, \delta = 0.614$) and industrial {$a_2 = -0.008, \delta = 0.859$) sectors. These findings suggest evidence of differentiated and statistically insignificant threshold effects of ICT infrastructure across the agriculture, industry, and service sectors. Specifically, ICT infrastructure demonstrates a positive but insignificant threshold effect on the service sector, while exerting negative and insignificant effects on both the agricultural and industrial sectors. These findings suggest that while the service sector shows potential to benefit from increasing ICT penetration, current infrastructure levels or associated enablers are insufficient to yield statistically robust productivity gains. The negative coefficients for agriculture and industry indicate potential mismatches between ICT deployment and sectoral absorptive capacities, possibly due to inadequate support systems such as digital skills, sectoral digitization strategies, or integration with existing production frameworks. These results are consistent with emerging literature emphasizing that ICT infrastructure alone is not sufficient to catalyze sectoral productivity (see, for example, Pradhan, Mallik & Bagchi, 2018; Nkandu & Phiri, 2022; Gao & Lyu, 2023; Imbulagodage Don, 2025; Paul & Ghosh, 2025). For instance, Imbulagodage Don (2025) reports that ICT tools such as mobile technology and internet access significantly contribute to agricultural growth in the BIMSTEC region, but only when combined with infrastructural development and human capital investment. Similarly, Paul and Ghosh (2025) show that ICT infrastructure's long-term effects may be detrimental without clean energy and policy alignment, underscoring the conditional nature of ICT impact. Though the lack of significance indicates the presence of continuing bottlenecks such as low digital readiness or institutional inertia, the marginal positive result in the service sector fits the global trend of digital transformation in finance, logistics, and communication-intensive industries.

Moreover, our results align with the evidence stressing the need of digital ecosystems and sector-specific enablers (see, for instance, Rajkhowa and Baumüller, 2024; Pradhan, et al., 2018; Gao & Lyu, 2023; Zheng et al., 2025). Zheng et al. (2025), for instance, show how blockchain and associated digital innovations might improve agricultural output; , but only when shared with operational technologies and safe digital platforms. Therefore, the insignificant threshold effects in our study may reflect a more general structural issue: that ICT infrastructure, while necessary, is not a sufficient condition for sectoral transformation in the absence of complementary factors such as regulatory support, workforce upskill, and investment in sector-tailored digital applications. Particularly in industry and agriculture, ICT infrastructure must create significant economic returns for which legislators must develop a comprehensive plan coordinating infrastructure development with ecosystem-building activities improving sectoral absorption and technological integration.

## 5. Conclusion and Policy Implications

This paper examined the threshold effects of ICT infrastructure on sectoral development across 26 sub-Saharan African nations over the period 1991 to 2022. Using the dynamic panel threshold model, the paper show that the influence of ICT infrastructure differs greatly in the service, industrial, and agricultural sectors. The findings on the threshold level of ICT infrastructure indicated that it had a positive but insignificant threshold effect on the service sector, while exhibiting a negative and insignificant threshold level on the agriculture, and industrial sectors. These sectoral variations suggest the need for sector-specific ICT policies rather than a one-size-fits-all approach to digital infrastructure development. The agricultural sector exhibited significant threshold effects for mobile subscriptions (3.55%), fixed telephone subscriptions (2.97%), and overall ICT infrastructure (-0.897%), with positive impacts manifesting primarily above these thresholds. In the industrial sector, the identified thresholds for internet users (4.221%) and mobile subscriptions (41.68%) underscore the importance of more advanced ICT infrastructure for industrial development. The service sector's unique threshold effect for mobile subscriptions (77.26%) highlights the sector's dependence on advanced mobile connectivity. However, the observed diminishing returns above this threshold, coupled with enhanced labour efficiency, indicate the need for policies that optimize rather than merely maximize ICT infrastructure.

Nevertheless, the findings indicate that a one-size-fits-all approach to ICT policy is insufficient taking into account the varying threshold effects of ICT across industries. More specifically emphasising on the agricultural and industrial sectors where ICT infrastructure now shows either negative or neutral effects, SSA officials are urged to create and apply sector-tailored digital plans. While industry should concentrate on digital supply chains, automation, and industrial IoT integration, for agriculture this may include supporting ICT-enabled extension services, precision farming, and mobile-based market information systems. Second, the little threshold effects imply that without supporting systems, ICT infrastructure by itself is not enough to create productivity increases. Reliable energy, internet connection in rural and industrial zones, digital literacy programs, and sector-specific technical training are among the complementing enablers governments of all the SSA nations should invest in. These steps are essential to improve the absorptive capacity of ICT technologies and close the difference between the actual economic results and the infrastructure development. Furthermore, SSSA governments should try to support inclusive ICT policies to guarantee the advantages of ICT reach underprivileged sectors—especially agriculture and rural economy. This covers subsidising access to digital tools for smallholder farmers and SMEs, offering localized digital material in native languages, and helping the creation of low-cost ICT innovations fit for rural needs. Unlocking the full potential of ICT in all economic sectors will depend on closing the digital gap. Fourthly, the results show that the success of ICT in increasing productivity depends on ecosystem-level coordination which implies that public-private partnerships (PPPs) combining governments, telecom operators, agritech and fintech startups, and research institutions should be promoted overall by all shareholders and legislators. These partnerships help to speed the spread of creative ICT solutions catered to particular industry problems. Encouragement of private sector investment by means of tax breaks, innovation grants, and regulatory support also helps to foster native digital creativity. At last, initiatives should be directed towards the application of strong monitoring and evaluation (M&E) systems to routinely evaluate how ICT infrastructure affects sectoral production. Creating data systems tracking ICT uptake, usage patterns, and financial results is part of this task. Real-time bottleneck and feedback loop identification helps M&E systems to guarantee that ICT policies remain evidence-based, flexible, and responsive.

The study's shortcomings include the difficulty of catching fast technical changes within the examined period and possible data availability restrictions among SSA nations. The study might potentially not adequately explain informal sector activities and their interaction with ICT infrastructure, therefore affecting the observed threshold effects. However, the future research could explore the interaction between ICT infrastructure thresholds and other critical factors such as institutional quality and innovation capacity. Future studies could also investigate the role of emerging technologies (5G, AI, IoT) in shifting these thresholds and examine how different policy interventions affect threshold achievement rates across sectors. Additionally, research comparing SSA's ICT infrastructure thresholds with other developing regions could provide valuable policy insights.

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