ICT Diffusion and Trade in Sub-Saharan Africa, The Role of Financial Development

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Abstract

This study examines the relationship between ICT diffusion, financial development, and trade in sub-Saharan Africa. Using the two-step system GMM estimation technique, the findings provide compelling evidence that ICT diffusion plays a pivotal role in enhancing trade within the region. The results show that higher levels of ICT diffusion significantly drive trade openness, underscoring the transformative power of digital technologies in facilitating cross-border trade. Furthermore, the analysis reveals that while financial development complements ICT diffusion, its mediating role is less impactful than expected, suggesting the need for more robust financial systems to amplify the trade-enhancing benefits of ICT adoption. Furthermore, the study demonstrates that the trade-enhancing effects of ICT diffusion vary across countries, with nations having higher levels of ICT diffusion benefiting significantly more than their counterparts with lower diffusion levels. Governments in sub-Saharan Africa should prioritize investments in ICT infrastructure, particularly in rural and underserved areas, to enhance internet penetration and mobile connectivity. The Pan-African Payment and Settlement System (PAPSS) is confronted with various obstacles, including restricted access and adoption, especially in areas with low digital penetration and poor infrastructure. It is imperative that these bottlenecks are addressed to leverage technology and financial development to drive trade.

Keywords: ICT diffusion; Trade; Financial development.

1.0 Introduction

Since the last two decades, there has been a general rise in information and communication technologies (ICT) penetration in sub-Saharan Africa (Ewing, 2014). Indeed, its impact on economic growth and on key sectors of the economy has gained empirical traction across various jurisdictions, probably because of its key implications for sustainability (Kayisire and Wei, 2016 Adeleye and Eboagu, 2019, Asongu and Le Roux, 2017). In this study, we examine the impact of ICT diffusion on the trade sector in sub-Saharan Africa. Furthermore, we explore the role that financial development plays in shaping the ICT diffusion–trade nexus.

Since the late 1990s, several sub-Saharan African countries have liberalized their ICT sectors and relaxed several limitations. This has led to an upward trend in ICT infrastructure development across countries (Asongu and Le Roux, 2017). Investors from across the globe view Africa as a financial hotspot and investment destination because of the continent's market demand, expanding economic potential and the better rate of return on investment it offers than other developing economies (Ejemeyovwi, Osabuohien & Bowale, 2021). Consequently, the mobile penetration rate in the SSA region has more than doubled since the year 2000. For instance, countries like South Africa, Nigeria, the Democratic Republic of Congo, Uganda, and Cote d'Ivoire have more mobile phone lines than fixed lines, and this trend is expected to continue (Ejemeyovwi, Osabuohien & Bowale, 2021). According to the GSMA research (2024), the mobile sector contributed $140 billion, or 7%, of the region's GDP in 2023, with that amount predicted to rise to $170 billion by 2030. There have also been considerable transformations in the financial

technology landscape attributable to the rapid development of ICT. Indeed, data from the world bank shows that between 2000 to 2023, various measures of ICT expansion, such as fixed broadband subscriptions, fixed telephone subscriptions, ICT goods imports, internet users, have been on a relative upward trajectory. Indeed, ICT is a specific type of technology that promotes innovation across various sectors and generally propels economic performance. ICT diffusion opens new business prospects, increasing an industry's competitiveness and stimulating investment in various sectors of the economy. Quah (2003) states that ICT overcomes time and location constraints, speeds up information delivery, and eliminates information asymmetry. Furthermore, ICT helps to improve health outcomes, labour proficiency, market transparency, financial transactions, and resource allocation efficiency.

The trade sector is one of the key sectors in thriving economies. The importance of the trade sector transcends its prominence as a vital source of foreign exchange to being very critical in providing raw and intermediate goods keenly required by indigenous industries, and as well attain economic diversification. Given the important role that trade plays in the economy, access to the global market, payment and settlement system and global economic integration cannot be efficiently achieved without ICT. ICT plays a transformative role in trade development by enhancing efficiency, accessibility, and connectivity as has been established by some literature. For example, there are positive effects of ICT on trade, through the reduction in transaction costs linked to uncertainty (Abramovsky and Griffith, 2006) and increases in efficiency of logistical process (World Bank, 2016) resulting in higher trade volumes (Juhász and Steinwender, 2018; Rodríguez-Crespo and Martínez-Zarzoso, 2019; Ozcan, 2018). However, observation of the literature shows that it is narrowly skewed towards developed countries with little evidence on developing countries and sub-Saharan African countries.

However, sub–Saharan Africa is a region that has witnessed rapid adoption and deployment of the fourth industrial revolution technologies. According to GSMA report (2024), 4G penetration is increasing throughout the region and is predicted to account for half of all connections by 2030. 5G adoption is also increasing, and it is expected to add $10 billion to the region's economy by 2030, representing 6% of mobile's economic impact. Over time, the region has also recorded a steady rise in trade as shown in Figure 1.2. Indeed, while there are general improvements in ICT diffusion and trade in sub–Saharan Africa, there are also relative variations across the countries in the region. It will, hence, be appealing to explore and interrogate the interrelationships between ICT expansion and trade in the specific case of this region to proffer tailored recommendations that guide investments in ICT and the trade sector. This is more so justified by the paucity of research specifically in sub–Saharan Africa addressing this conundrum.

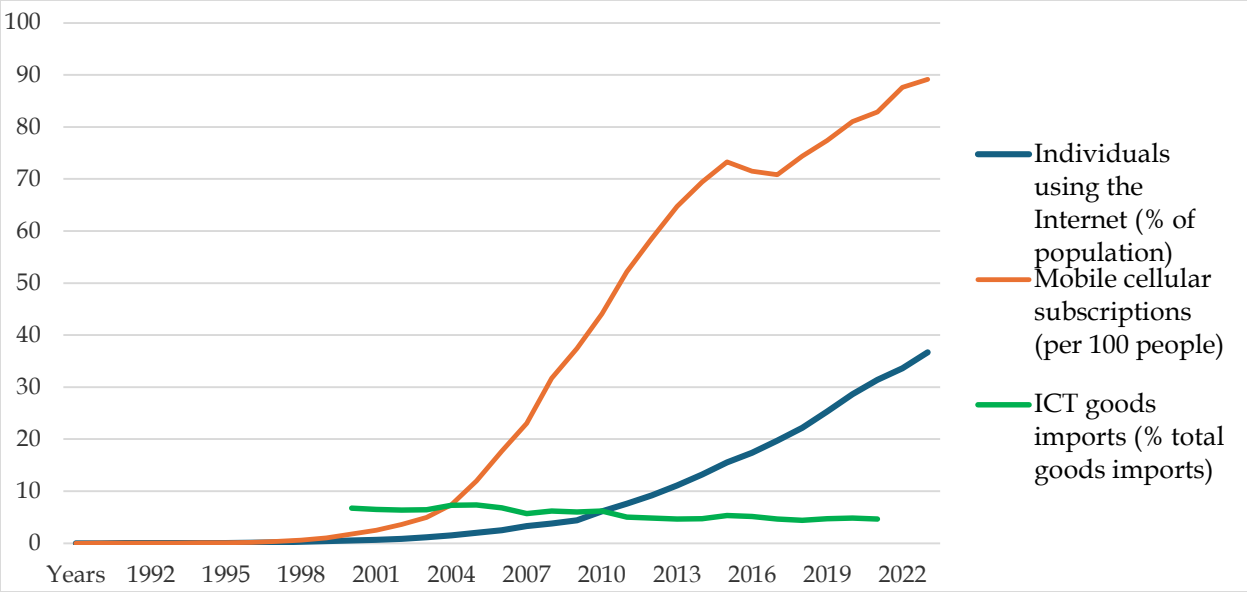


Figure 1.1: Various proxies for ICT diffusion in Sub-Saharan Africa
Source: World Bank - WDI

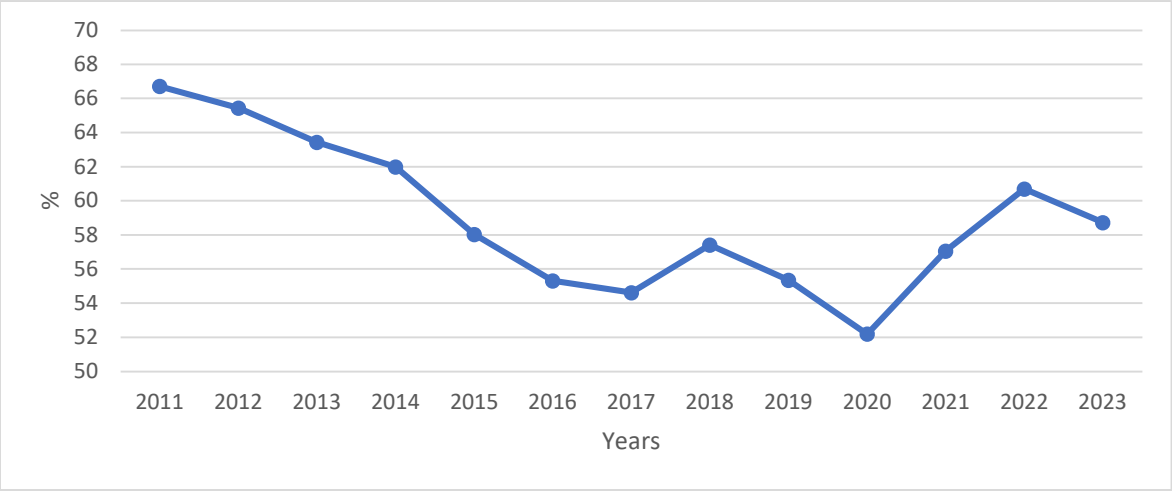


Figure 1.2: Trade % of GDP - Sub-Saharan Africa, 2011 – 2023
Source: World Bank - WDI

Financial development (FD) has also been recognized as a key driver of economic growth. The financial sector serves as a conduit between the debt and surplus units in the economy. Furthermore, the financial sector mobilizes capital, lowers transaction costs, encourages inter-industry transactions, and directs resources toward the most profitable investments. Schumpeter (1911) argues that the expansion of the financial sector improves the efficiency of resource allocation. According to Levine, financial development improves fund mobilization, usage, and monitoring. Given the general belief financial development improves material and human capital accumulation, increases allocative efficiency, and leads to better levels of economic development. According to Mlachila et al. (2016), in most sub-Saharan African countries, financial development has progressed over the past four decades. However, except for the region's middle-income countries, both financial markets and financial institutions are less

developed than in other developing regions. The banking system dominates the financial landscape in most countries. The banking sector accounts for the biggest share of assets in most countries, except for middle-income countries. Indeed, in Chigeto et. al. (2024), SSA countries benefit from increased trade because of the financial development of destination countries. Hence, financial development mediating the relationship between ICT diffusion and trade may show stronger positive results. Hence, the present study explores the effects of ICT diffusion and financial development on trade in the context of sub-Sahara Africa covering the period from 2015 to 2023.

The study has novel contributions to literature. It explains the impact of ICT diffusion on trade and the role of financial development in the nexus in sub–Saharan Africa cannot be overemphasized. Mainly this study contributes to literature in several ways. Firstly, this study aims to address the gap in research on the impact of ICT diffusion on trade within the specific context of sub-Saharan Africa. To achieve this, we examine multiple proxies for ICT diffusion to determine those that exert a stronger influence on trade. Commonly used indicators such as fixed telephone subscriptions (per 100 people), mobile cellular subscriptions (per 100 people), individuals using the internet (% of population), and ICT goods imports (% of total goods imports) are considered. Among these, individuals using the internet (% of population) is selected for the main regression analysis, while mobile cellular subscriptions (per 100 people) is used for robustness checks. The empirical literature on the combined effects of ICT diffusion and financial development on trade in developing countries remains limited. This study goes beyond assessing the direct impact of ICT diffusion on trade by also exploring the mediating role of financial development. Specifically, we examine whether financial development amplifies the effect of ICT diffusion on trade, thereby providing a more comprehensive understanding of this relationship. Additionally, we investigate whether the ICT diffusion–trade relationship holds consistently across countries with varying levels of ICT diffusion. It is hypothesized that nations with higher ICT diffusion will experience greater trade benefits compared to those with lower ICT adoption.

The other sections of this paper are presented as follows: In section 2 we discuss the theoretical framework and empirical literature review as well as the summary of hypotheses. In section 3, the materials and methods used to achieve the research objectives are presented. The results and discussion of findings are presented in section 4. In section 5, the conclusion and implications for policy are presented.

2.0 Literature review and hypothesis development

International trade as an engine for growth became relevant in the economic debate since the works of the classical Economists. These Economists argue in favour of trade openness. For instance, Smith (1776) proposed that international trade acts as a growth stimulus by increasing the size of the market and offering each country the possibility of taking advantage of increasing return to scale through division of labour and specialization. In this respect, each country gaining from international trade should focus on the production of goods, which has an absolute advantage. David Ricardo (1772-1823) on his part focused on the principle of comparative advantage. In this respect, differences in production technologies induce a country to specialize in the production of commodities in which it has a comparative advantage, and that the increasing returns to scale are not necessary but constant return to scale in every process may be

needed (Lam,2015). The classical economists thus agree on the benefits in international trade if each country specializes in its cheaper production commodity compared to other countries.

The new trade theory rationalizes the high levels of intra-industry trade and the large proportion of world trade that takes place between similar countries. It argues that the existence of increasing returns to scale and imperfect competition provides reasons for specialization and trade even when countries are Similar in factor endowment (Krugman,1979; Helpman &Krugman,1985). It relies on the fact that the diffusion of knowledge and technology in the relative flow of gains from trade to trading countries. The emergence of all these theoretical foundations has prompted authors to empirically verify the veracity of these thoughts.

The idea of financial dependence was also theoretically established by the Heckscher-Ohlin-Samuelson (H-O-S) trade model (see Samuelson, 1949; Heckscher et al., 1991) to illustrate how differences in financial development result in comparative advantages and benefits from specialization. Kletzer and Bardhan (1987) expanded on the H-O-S model, emphasizing that countries with a relatively well-developed financial system benefit from greater access to external finance and have a comparative advantage, causing them to specialize in industries and sectors that rely on external finance. Their model consists of two sectors, one providing an intermediate good and the other a final good. While the intermediate goods sector does not require investment, financial development is beneficial to the final goods industry. This leads to a situation where nations with more developed financial systems focus on finished goods, while those with less developed systems focus on intermediate products.

Various strands of empirical literature examine the impact of ICT on pertinent variables. It is common to find empirical work that examines the impact of ICT on a broader measure such as growth. For example, Pradhan, Arvin, Bahmani, et al. (2017) verified the causal connection between ICT and growth. They posit that the direction of causality is mainly dependent on the level of penetration of the IT indicators used. Likewise, the linkages between ICT and growth were studied by Cheng et al. (2021) for a panel of 72 countries from 2000 and 2015. It emanated from the study that ICT diffusion can boost growth in high-income economies, but its influence is unclear in medium- and low-income countries. Similarly, Pradhan et al. (2014) examined the relationship between ICT development and four other economic indicators for G-20 countries between 1991 and 2012 using a panel VAR model. Their findings suggest positive effects of ICT infrastructure expansion on economic growth. While these studies provide important findings for the economy, it is also instructive to examine the impact of ICT expansion on key sectors of the economy such as the trade sector to show the nuisances of the impacts of ICT diffusion on such sectors. For example, Liang and Tan (2024) investigated the effects of the digital economy on China's export technology upgrading. They employed the entropy weight TOPSIS as a measure of development level of provincial digital economy from 2012 to 2020. The revelation from the study indicates that the digital economy has significantly promoted the upgrading of China's export technical complexity. Furthermore, the study also shows that the digital economy can achieve export technology upgrading by promoting knowledge spillovers and accelerating the market processes. Export products are also upgraded through the upgrading of the industrial structure.

This study specifically seeks to examine the impact of ICT diffusion on trade. Concerning this relationship, it can be observed that only a few studies have been conducted specifically focusing on ICT expansion and trade, even so, even fewer studies exist in sub-Saharan Africa. This is the

gap this study intends to bridge. Rodriguez-Crespo and Martinez-Zarzoso (2019) is one notable study that interrogates the effect of ICT on trade. Nonetheless, the focus of the study was on establishing whether product complexity matters, considering bilateral exports of 120 countries over the period 2000 - 2014. In that regard, the study classified countries based on their degree of product complexity and employed the gravity model of trade to investigate the effect of internet use on aggregate trade flows for each classification. Overall, the results show that internet use increases trade. In addition, the classification by product complexity is more sensitive to internet use than classification by level of income of the sampled countries. According to Freund and Weinhold (2004), Abeliansky and Hilbert (2017) among others, ICT should have positive effects on trade. This positive effect may be attributed to the reduction in costs associated with trade which are enabled by ICT. However, the evidence in the specific case is sub–Saharan Africa is not available. However, given the traction ICT diffusion has gained over the last three decades in sub–Saharan Africa, we state hypothesis 1 and 2 as follows:

Hypothesis 1: ICT diffusion has a positive impact on trade in sub–Saharan Africa.

Hypothesis 2: the strength of the ICT diffusion -trade relationship differs across countries with varying levels of ICT diffusion.

Financial development plays a key role in national development and literature is replete with studies that examine its impact on the growth of various sectors and the economy (see Shen and Lee, 2006; Lee, 2013; Mishra and Narayan,2015; Narayanand Narayan, 2013; Chiu and Lee, 2019). Indeed Levine (1997) argues that the development of financial markets is one of the key factors in economic growth, because it helps make the economic system more efficient. Since 2000, there have been considerable transformations in the banking and financial sectors attributable to the rapid development of information and communication technologies (ICT). Statistics indicate consistent growth in financial development over the last two decades. The development of the financial sector also has implications for growth in other sectors, such as trade. This is mainly due to the extension of credit facilities to stakeholders in the trade sector. The trade sector also stands to benefit from improvements in the speed and availability of various payment channels used by importers and exporters, as well facilitating trade through the provision of a myriad of financial instruments. On the literature examining the relationship between financial development and trade, Tsaurai and Hlupo provide conflicting results of the impact of financial development on trade. Caporale et al. (2022) investigated the direct and indirect effects of financial development on international trade for six EU members from Central and Eastern Europe (CEEC). Their findings indicate that financial development affects trade flows and the structure of international trade. In sub–Saharan Africa, a study by Chigeto et. al. (2024) shows that financial development in origin and destination countries boosts intra-trade in SSA countries, and the developed financial sector of the destination countries contributes to both intra-bloc and international trade. Moreover, financial development of exporting countries also spurs intra-bloc trade in SSA countries and the global south. Other studies also provide contrary findings. For example, Sare et al. (2019) examined the connection between financial development and trade in a sample of 46 African nations. The potential impacts in both the short-term and long-term contexts were uniquely explored. The findings of the study indicate that the growth of the banking sector, which is a component of financial development, does not have a significant influence on international trade. Furthermore, Yakubu et al. (2018) investigated the impact of financial development on international trade in the African context, using data from 46 African countries. The study used

two variables as proxies for financial development; nevertheless, the results were inconsistent. Based on the foregoing literature, the third hypothesis is stated as follows.

Hypothesis 3: Financial development increases the effect of ICT diffusion on trade as a mediator.

3.0 Data and Methodology

3.1 Data

The study employs a panel dataset for 38 African economies covering the period 2015–2023. Data will be collected based on the availability of relevant data variables.

Description and Measurement of Variables

The choice of variables employed in the study is mainly informed by literature. Moreover, the choice of study period and number of countries depends exclusively on the availability of data. The variables trade openness, ICT diffusion, inflation, gross fixed capital formation, GDP per capita growth, and foreign direct investment were sourced from the World Bank's World Development Indicators (WDI). Financial development data was obtained from the International Monetary Fund (IMF) while data on institutions was derived from the World Governance Indicators.

Trade openness (TradeOpen) is the total of imports and exports of goods and services expressed as a percentage of gross domestic product.

ICT diffusion (ICTD) is measured using the individuals using the internet as a percentage of the population (IndInt). Internet users are individuals who have accessed the Internet from any location within the past three months. This access can be through devices such as mobile phones, computers, games machines, personal digital assistants, and digital televisions.

Financial development is proxied by the financial development index (FIN) which encompasses both financial markets (FMs) and financial institutions (FIs) in terms of their respective levels of access, depth, and efficiency. This proxy is more comprehensive compared to commonly used ones which are the ratio of private credit to GDP and the stock market capitalization to GDP. This is because the financial development index considers the complex multidimensional nature of financial development. A well-developed financial system positively impacts trade (Bilas et al., 2017).

Inflation (INF) is consumer price annual percentage. It reflects the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly. This is included to control for macroeconomic instability, which can significantly influence trade and investment decisions. Inflation has a negative correlation with trade (Atabay, 2016). High inflation typically increases uncertainty, discourages long-term investments, and raises transaction costs, potentially hampering trade. By including inflation, the model accounts for variations in macroeconomic stability across sub-Saharan Africa.

Gross Fixed Capital Formation (GFCF), expressed as a percentage of GDP, is a proxy for domestic investment. It represents the level of capital investment in physical assets such as machinery,

infrastructure, and technology. Higher GFCF typically signals enhanced productive capacity and competitiveness, which can positively impact trade.

Institutions (INT), measured as the mean of Kaufmann's governance indexes, capture the quality of governance and institutional frameworks in a country. There are six dimensions as follows, voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption. Oshota and Wahab (2022) found that institutional quality has a positive effect on trade flows. Moreover, strong institutions/governance facilitate trade by reducing transaction costs, enhancing transparency, and fostering investor confidence. Weak institutions, on the other hand, can hinder trade through inefficiency and corruption. This variable ensures the model considers the role of institutional quality in shaping trade dynamics.

The GDP per capita growth (GDPPC) calculated based on constant local currency, is GDP divided by mid-year population. GDP per capita growth reflects the economic development and income levels of a country. Higher income levels often translate into increased purchasing power, higher consumption, and stronger domestic demand for both imports and exports.

Foreign direct investment, net inflows (% of GDP) (FDI) represent cross-border investments and a critical driver of economic growth and trade. FDI often brings technological transfer (Dương, 2017), infrastructure development, and access to international markets, which can bolster trade performance. By controlling FDI, the model accounts for the role of external capital inflows in influencing trade outcomes, independent of the effects of ICT and financial development.

Aside from inflation, the expectation is that all other variables have a positive effect on trade.

Model Specification

The study begins with a baseline model to determine the impact of ICT diffusion on trade. Equation (1) is the general model specification for this study adapted from Ngouhouo et. al. (2021) with some augmentation:

$$Trade = f(ICTD, FD, INF, INS, GDPPC, FDI, GFCG) \ldots \qquad (1)$$

Equation (2) is obtained by fully expressing Equation (1) as a dynamic model as follows.

$$Trade_{jt} = \alpha_0 + \alpha_1 Trade_{jt-1} + \beta_1 ICTD_{jt} + \beta_2 FD_{jt} + \sum_{k=1}^{N} \beta_k X_{jt} + \gamma_j + \mu_t + \varepsilon_{jt} \qquad (2)$$

Where subscript j denotes cross-sectional dimension (country specifics), j = 1, …, M; t denotes the time series dimension (time), t = 1, …, T; $\alpha_{o\ and\ 1}$ is the constant term and the coefficient of the one year lag of the dependent variable proxied by trade openness respectively; $\beta_{1\ and\ 2}$ are the coefficients of ICT diffusion (ICTD) measured by the individuals using the internet (% of population)(IndInternet) and financial development (FD) proxied by the financial development index (FIN) respectively; $\beta_l : l = 1, \ldots, , \beta$ represent the regression coefficients of a vector of control variables; β_k: $_{k\ =\ 1, \ldots, N\ ,}$ are regression parameters for vector X (control variables) to be estimated; γ_j is the country fixed effect; and μ_t is the time fixed effect t; and $\mathcal{E}_{jt}$ is idiosyncratic error term, which controls for unit-specific residual in the model for the *j*th *country* at *period t*. The

control variables are inflation (INF), institutions (INS), gross domestic product per capita growth (GDPPC), foreign direct investment (FDI), gross fixed capital formation (GFCF).

Interaction effect of ICT diffusion and financial development

We specify a model that introduces the interactive effect of ICT diffusion and financial development on trade in sub-Saharan Africa as presented in Equation (3) below.

$$Trade_{jt} = \alpha_0 + \alpha_1 Trade_{jt-1} + \beta_1 ICTD_{jt} + \beta_2 FD_{jt} + \lambda_1 (ICTD_{jt} * FD_{jt}) \sum_{k=1}^{N} \beta_k X_{jt} + \gamma_j + \mu_t + \varepsilon_{jt}$$

Where λ_1 represents the coefficient of the interaction term; $\lambda_l : l = 1, \ldots$, and all other variables remain as previously described.

Estimation Technique

The study uses a two-step System Generalized Method of Moments (SGMM) estimator with robust standard errors, minimal sample size adjustments, and forward orthogonal deviations. The GMM estimator estimates the parameters of a model by minimizing the difference between the sample moments and the population moments. Potential endogeneity is addressed using the dynamic panel model with a two-step system Generalized Method of Moments (GMM). The strength of GMM is its ability to resolve the three sources of endogeneity comprising unobserved heterogeneity, simultaneity, and, most importantly, dynamic endogeneity (Ullaha et al., 2018; Li et al., 2021). The assumption underlying the selection of instruments is supported by several research works (see Batuman et al., 2022; Nguyen, 2022; Stewart & Chowdhury, 2021).

To discern the accuracy of the estimates, the serial correlation test and Hansen test are employed to test any potential serial correlation in the error terms and assess the exogeneity of the instruments plus ascertain whether there are any over-identifying restrictions respectively.

4. Results and Discussion

Descriptive Statistics and Correlation Matrix

Table 1 presents the summary statistics for the sample. Key variables include Trade Openness (TradeOpen), Individuals using the internet (IndInternet), Financial Development Index(FIN), and control variables such as Gross Fixed Capital Formation (GFCF), Inflation, Institutions, GDP per capita (GDPPC), and Foreign Direct Investment (FDI). Trade openness has a mean value of 73.37% and a standard deviation of 47.79%. The high standard deviation underscores the stark contrasts in trade openness among the countries in the sample, pointing to varying degrees of integration into the global economy. ICT diffusion has a mean of 30.85% with a standard deviation of 20.51%. The minimum value of 2% indicates extremely low internet penetration in some countries, suggesting challenges in access, infrastructure, or affordability. On the other hand, the maximum value of 92.58% reveals that some countries are approaching full internet adoption, likely driven by advancements in digital infrastructure and policies promoting ICT accessibility. The Financial Development Index has a mean value of 15.67% and a standard deviation of 11.65%. The minimum value of 3.93% reflects underdeveloped financial systems in certain countries, conversely, the maximum value of 59.25% indicates that a few countries have relatively robust financial systems capable of supporting economic activities, including ICT adoption and trade.

Table 1: Descriptive Statistics

Variable	Observation	Mean	Std. Dev	Min	Max
TradeOpen	360	73.365	47.786	2.208	342.702
IndInternet	360	30.848	20.513	2.000	92.583
FIN	360	15.672	11.650	3.930	59.250
Institutions	360	-0.642	0.578	-1.687	0.858
Inflation	351	8.139	23.633	-81.476	359.093
GDPPC	360	0.654	4.057	-22.383	10.628
FDI	359	3.748	5.543	-17.292	37.323
GFCF	347	22.352	8.568	2.017	78.001

Table 2: Correlation Matrix and Variance Inflation Factor

Variable	TradeOpen	IndInternet	FIN	Institutions	Inflation	GDPPC	FDI	GFCF	VIF	1/VIF
TradeOpen	1									
IndInternet	0.445***	1							1.736	0.576
FIN	0.199***	0.590***	1						2.571	0.389
Institutions	0.226***	0.583***	0.734***	1					2.793	0.358
Inflation	-0.169**	-0.022	-0.060	-0.161**	1				1.075	0.930
GDPPC	0.062	0.035	0.033	0.206***	-0.125*	1			1.095	0.913
FDI	0.229***	0.109*	0.002	0.070	-0.055	0.024	1		1.104	0.906
GFCF	0.149**	-0.107*	-0.112*	0.112*	-0.209***	0.158**	0.266***	1	1.256	0.796
Mean VIF									1.661	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2 presents the results of the correlation coefficient for the explanatory variables. In general, the results of the correlation matrix do not imply that multi-collinearity should be a concern in our sample (as confirmed by VIF below the threshold of 10).

Table 3: ICT Diffusion-Trade Nexus

Variables	1	2	3
L.TradeOpen	0.3815***	0.6650***	0.2568**
	(0.0936)	(0.0723)	(0.1239)
IndInternet	0.4412**		
	(0.2193)		
IndInternet*FIN			0.0125*
			(0.0073)
IndInternet<Mean		0.3519**	
		(0.1592)	
IndInternet≥Mean		0.3882***	
		(0.1477)	
FIN	1.9154**	-0.2084	
	(0.9641)	(0.2968)	
Inflation	-0.0275	-0.0607*	-0.0786**
	(0.0676)	(0.0317)	(0.0401)
Institutions	-28.7008*	-0.7235	-3.0183
	(15.6897)	(6.5778)	(11.4290)
GDPPC	1.1862***	0.4236	0.5219
	(0.2861)	(0.2702)	(0.5052)
FDI	0.2914*	0.3685*	0.9539*
	(0.1708)	(0.1960)	(0.5508)
GFCF	0.8817*	0.2037	0.5291
	(0.4835)	(0.4622)	(0.6260)
Constant	-41.1061	9.3991	23.1211
	(32.5547)	(15.6016)	(18.1701)
Observations	299	299	299
Number of Countries	38	38	38
Instruments	34	32	25
Hansen P-Value	0.265	0.174	0.236
AR(2)	0.522	0.966	0.0910
Chi-squared	541.5	1509	234.2
Chi-squared P-value	0	0	0

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The diagnostics from the two-step system GMM estimation validate the model's robustness. The Hansen test for overidentifying restrictions and the Arellano-Bond tests for autocorrelation confirm the validity of the instruments and the absence of autocorrelation in the residuals, ensuring reliable coefficient estimates. Furthermore, the number of instruments is well below the number of countries.

The first objective investigates the direct relationship between ICT diffusion and trade in sub-Saharan Africa. The regression results in Table 3 (column 1) indicate that ICT diffusion measured

by the individuals using the internet (IndInternet) exerts a positive and statistically significant impact on trade ($\alpha_1 = 0.4412$, $p < 0.05$). This means that a one-unit increase in the percentage of individuals using the internet is associated with a 0.4412 unit increase in trade, holding all other variables constant. This finding strongly supports Hypothesis 1, suggesting that increased ICT diffusion facilitates trade (Rodriguez-Crespo & Martinez-Zarzoso, 2019) by reducing information asymmetry, improving communication channels, and overcoming time and location constraints (Quah, 2003). This result underscores the transformative role of ICT in improving trade efficiency within the region. For example, the spread of internet access allows firms in sub-Saharan Africa to access real-time information on international prices, develop e-commerce platforms, and participate in global value chains.

Variables such as GDP per capita growth (GDPPC), gross fixed capital formation (GFCF), financial development, and foreign direct investment (FDI) all showed significant positive effects on trade. These findings suggest that economic growth, investment in physical capital, financial sector development, and foreign direct investment all play important roles in promoting trade. Specifically, the positive coefficient of GDP per capita (1.1862, $p< 0.01$) indicates that countries with higher levels of economic development tend to engage more in international trade. The significant positive effect of GFCF (0.8817, $p< 0.1$) suggests that investments in physical capital, such as infrastructure and machinery, can increase a country's trade competitiveness. The positive relationship between financial development (1.9154, $p< 0.05$) and trade indicates that a well-developed financial system can facilitate trade by providing access to credit and other financial services. Finally, the significant positive effect of FDI (0.2914, $p< 0.1$) suggests that foreign investment can contribute to trade growth by increasing the capacity for countries to produce and export goods and services. Institutions showed a significant and negative effect of (-28.7008, $p< 0.1$) which is contrary to expectation because the literature suggests a positive relationship between institutional quality and trade (Oshota and Wahab,2022).

The second objective is to ascertain whether the effect of ICT diffusion on trade differs across countries with varying levels of ICT diffusion. Hypothesis 2 is achieved by categorizing ICT diffusion values into two groups: countries with ICT diffusion values greater than or equal to the mean (30.848) are represented by 1 (IndInternet ≥ Mean = 1), while those below the mean are represented by 0 (IndInternet < Mean = 0). Subsequently, these dummy values are interacted with the ICT diffusion variable (IndInternet) to create a new independent variable that captures the differential effect of ICT diffusion on trade based on these two groups.
The results presented in Table 3 (column 2) indicate that for countries with ICT diffusion below the mean, the coefficient is positive and statistically significant (0.3519, $p< 0.05$). Similarly, for countries with ICT diffusion above or equal to the mean, the coefficient is also positive and statistically significant (0.3882, $p< 0.01$). Notably, the larger coefficient for countries with higher levels of ICT diffusion suggests that ICT diffusion has a greater impact on trade in these countries compared to their counterparts with lower levels of ICT diffusion. These findings highlight the importance of enhancing ICT diffusion to maximise its trade-enhancing benefits. Countries with lower ICT diffusion levels may not fully capitalise on the potential trade gains, emphasising the need for targeted investments in ICT infrastructure, capacity building, and policy interventions to bridge the digital divide. Additionally, FDI (0.3685, $p< 0.1$) showed significant and positive effects on trade and conversely, inflation showed a significant and negative effect (-0.0607, $p< 0.1$) on trade.

The third objective explores whether financial development enhances the relationship between ICT diffusion and trade, serving as a mediator that amplifies the trade-enhancing effects of ICT diffusion. To confirm hypothesis 3, an interaction term combining ICT diffusion and financial development (IndInternet × FIN) is incorporated into the model. The results in Table 3 (column 3) indicate a positive and statistically significant coefficient for the interaction term ($\lambda_1 = 0.0125$, $p < 0.1$). While this suggests that financial development complements ICT diffusion in fostering trade, the magnitude(coefficient) of the interaction term is smaller than the direct effects of ICT diffusion and financial development as shown in column 1. This finding implies that, although financial development plays a role in facilitating the ICT diffusion–trade nexus, it does not substantially amplify the direct impact of ICT diffusion on trade. The direct effect of ICT diffusion remains the dominant driver in this relationship, likely because ICT adoption directly reduces information and communication costs, enabling firms to connect with global markets more efficiently. In contrast, the role of financial development as a mediator may be constrained by structural factors such as limited access to credit and underdeveloped financial systems across sub-Saharan Africa (David et al., 2014). Nevertheless, the interaction term highlights the critical complementary role of financial development in enabling ICT-driven trade. Financial development provides crucial support mechanisms, including access to credit for ICT-related investments, robust digital payment systems that lower transaction costs, and financial innovations that improve the efficiency of cross-border trade. These elements create an enabling environment for ICT diffusion to achieve its full potential. Also, inflation (-0.0786, $p< 0.05$) shows a significant and negative effect on trade. Increasing inflation can negatively impact trade by reducing competitiveness, increasing uncertainty and volatility, and reducing investment. This can lead to decreased export demand, reduced import demand, and lower overall trade volumes.

Robustness Analysis

To ensure the robustness of the results, a sensitivity analysis is conducted. The proxy for ICT diffusion is replaced with Mobile Cellular Subscriptions per 100 people (MCS) used by Ghalayini et al. (2020). This substitution tests whether the coefficients and significance levels of the variables remain consistent. Table 4 (column 1) results indicate that MCS has a significant positive (0.2124, $p< 0.1$) effect on trade, supporting the premise that ICT diffusion enhances trade. Also, GDP per capita growth showed a significant and positive coefficient of 0.9168 ($p <0.01$).

Column 2 further explores the differential effects of ICT diffusion on trade by categorizing mobile cellular subscriptions (MCS) values into two groups based on the mean. Results reveal that MCS values greater than or equal to the mean have a significant and positive coefficient of 0.2146($p < 0.1$), suggesting that countries with higher levels of ICT diffusion experience greater trade-enhancing effects. Conversely, MCS values below the mean, although showing a positive coefficient, remain statistically insignificant, unlike the case of IndInternet<Mean in Table 1 (column 2) which showed a positive and statistically significant coefficient. GDP per capita growth (0.8591, $p< 0.01$) and gross fixed capital formation (0.4199, $p<0.05$) both maintain their positive and statistically significant coefficients, underscoring their continued importance as facilitators of trade.

For column 3, the interaction effect of ICT diffusion and financial development, represented by the variable MCS * FIN (Mobile Cellular Subscriptions × Financial Development), demonstrates a significant and positive impact on trade with a coefficient of 0.0122($p < 0.05$). This finding is consistent with that of interacting IndInternet and FIN, in that with MCS as the main independent variable in column 1, its coefficient is larger than that of (MCS x FIN). Additionally, inflation (-0.0987, $p< 0.05$) exhibits a significant and negative effect on trade, consistent with expectations that higher inflation erodes competitiveness and increases uncertainty. On the other hand, GDP per capita growth (0.8392, $p<0.1$) and gross fixed capital formation (0.9954, $p<0.1$) both show significant and positive effects, reflecting the role of economic growth and domestic investment in promoting trade activities.

Table 4: Robustness Analysis

Variables	1	2	3
L.TradeOpen	0.2697**	0.2097*	0.2044*
	(0.1135)	(0.1269)	(0.1194)
MCS	0.2124*		
	(0.1224)		
MCS*FIN			0.0122**
			(0.0056)
MCS<Mean		0.3558	
		(0.2436)	
MCS≥Mean		0.2146*	
		(0.1285)	
FIN	0.2992	0.2131	
	(1.4863)	(1.6877)	
Inflation	-0.1486	-0.1306	-0.0987**
	(0.0924)	(0.0960)	(0.0460)
Institutions	-5.0024	-1.2905	-31.3032*
	(26.8166)	(19.3110)	(17.5882)
GDPPC	0.9168***	0.8591***	0.8392*
	(0.1580)	(0.2994)	(0.4964)
FDI	0.0184	-0.0155	0.9605
	(0.1329)	(0.1869)	(0.6725)
GFCF	0.1360	0.4199**	0.9954*
	(0.3379)	(0.2113)	(0.5323)
Constant	20.0376	14.6172	-14.8414
	(39.7690)	(33.9285)	(25.7395)
Observations	299	299	299
Number of Countries	38	38	38
Instruments	33	36	34
Hansen P-Value	0.282	0.397	0.569
AR(2)	0.260	0.199	0.159
Chi-squared	327.2	300.3	317.1
Chi-squared P-value	0	0	0

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5. Conclusion and Recommendations

This study examines the relationship between ICT diffusion, financial development, and trade in sub-Saharan Africa. Using the two-step system GMM estimation technique, the findings provide compelling evidence that ICT diffusion plays a pivotal role in enhancing trade within the region. The results show that higher levels of ICT diffusion significantly drive trade openness, underscoring the transformative power of digital technologies in facilitating cross-border trade. Furthermore, the analysis reveals that while financial development complements ICT diffusion, its mediating role is less impactful than expected, suggesting the need for more robust financial

systems to amplify the trade-enhancing benefits of ICT adoption. Furthermore, the study demonstrates that the trade-enhancing effects of ICT diffusion vary across countries, with nations having higher levels of ICT diffusion benefiting significantly more than their counterparts with lower diffusion levels.

Based on the findings, the following recommendations are proposed. Governments in sub-Saharan Africa should prioritize investments in ICT infrastructure, particularly in rural and underserved areas, to enhance internet penetration and mobile connectivity. Such investments will enable businesses in both rural and urban areas in region to access global markets and drive trade growth. Secondly financial systems should be strengthened as a key enabler of trade. Policymakers should work to deepen financial markets and improve access to financial services that are also trade-facilitating. This includes creating an enabling environment for digital payment systems, credit and insurance products, and investment in ICT-related ventures to support trade activities. Strategic collaborations among key stakeholders will play a key role in harnessing the benefits of ICT diffusion for trade. Hence, regional bodies, such as the African Union (AU), the Economic Community of West African States (ECOWAS), the African Continental Free Trade Area (AfCFTA) among others should collaborate to harmonize ICT policies and regulations across borders, reducing barriers to trade and fostering more interconnected regional markets. In that regard, the Pan-African Payment and Settlement System (PAPSS) is a laudable initiative. However, the Pan-African Payment and Settlement System (PAPSS) is confronted with various obstacles, including restricted access and adoption, especially in areas with low digital penetration and poor infrastructure. It is imperative that these bottlenecks are addressed. Last but not least is to encourage Public-Private Partnerships in the improvement of ICT infrastructure, given the huge cost outlays in some of the ICT projects. Thus, governments should partner with private sector actors to accelerate the rollout of ICT infrastructure and promote digital literacy programs that empower individuals and businesses to effectively utilize ICT for trade purposes. By addressing these areas, sub-Saharan African countries can leverage ICT diffusion and financial development to drive trade, foster economic growth, and achieve sustainable development. These recommendations serve as a roadmap for policymakers, stakeholders, and development partners to unlock the region's full trade potential.

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