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**Telephone communication, ICT use and digitalisation in healthcare performance**

## Telephone communication, ICT use and digitalisation in healthcare performance

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## **Abstract**

This study explores the impact of telephone communication, ICT use, and digitalization on healthcare performance in Sub-Saharan Africa (SSA), a region facing challenges such as limited infrastructure and resources, geographical barriers, and a high disease burden. It uses panel vector autoregressive (PVAR) GMM-style estimation, variance decomposition, and Granger causality methods, and analysing data from 1998 to 2022. Advancements in telephone communication, measured by fixed telephone subscriptions, significantly enhance economic growth, government expenditure, and population growth, supporting the hypothesis that improved ICT infrastructure contributes to broader socio-economic and healthcare benefits. Increased ICT metrics, including ICT goods' exports and imports, correlate with reduced malaria incidence, aligning with the hypothesis that ICT engagement positively affects health outcomes, though the effect on tuberculosis is less pronounced. Digitalisation, represented by fixed broadband subscriptions, significantly reduces both malaria and tuberculosis incidences, confirming the hypothesis that digital infrastructure plays a critical role in improving health performance.

Keywords: Telephone communication; ICT use; digitalisation; healthcare performance; Sub-Saharan Africa

## 1. Introduction

Globally, nearly four billion individuals lack adequate access to healthcare, leading to severe financial strain for many households. Annually, over 250 million people are pushed near or below the World Bank's extreme poverty line due to healthcare-related expenses (WHO, 2017). SSA faces numerous challenges in delivering healthcare to its vast and diverse population (Adeola, 2018; Odipo et al., 2024). From limited infrastructure and resources to geographical barriers and a high burden of disease, the region grapples with multifaceted obstacles that impede access to quality healthcare services. However, amidst these challenges, a beacon of hope emerges in the form of technological innovation. Use of Information and Communication Technology (ICT), and digitalization are increasingly recognized as potent tools in transforming healthcare delivery across SSA (Odipo et al., 2024; WHO, 2017).

Against this backdrop, the paper is motivated by three main factors: Firstly, SSA faces significant challenges in accessing quality healthcare, particularly in rural and underserved areas. ICT use-digitalization offer avenues to bridge these gaps by enabling remote consultations, health information dissemination, and improved access to medical resources. Through studying the role of these technologies, the research aims to uncover strategies to reduce healthcare inequities and ensure universal access to essential healthcare services (DeRenzi et al., 2012; Honka et al., 2011). Secondly, traditional healthcare systems in SSA struggle with inefficiencies in service delivery, resource allocation, and patient management. Introducing ICT solutions, and digitalization can streamline processes, enhance communication between healthcare providers and patients, and optimize resource utilization. By investigating the impact of these technologies on healthcare performance metrics, the study seeks to identify strategies for improving the efficiency and effectiveness of healthcare delivery in the region (Labrique et al., 2013; Osei-Frimpong et al., 2018). Last, SSA is vulnerable to infectious disease outbreaks, such as malaria and tuberculosis. ICT use, and digitalization have proven to be invaluable tools in epidemic preparedness, response, and surveillance. Through examining the role of these technologies, the research aims to identify best practices and policy recommendations for leveraging technology to strengthen healthcare systems' resilience to epidemics and mitigate the impact of future health crises (Källander et al., 2013).

In recent years, SSA has witnessed a remarkable surge in mobile phone penetration, surpassing all expectations and creating unprecedented opportunities for healthcare interventions. With over 80% of the population having access to mobile phones (GSMA, 2020), these devices have become ubiquitous and powerful instruments for disseminating health information, facilitating remote consultations, and monitoring patient adherence to treatment

regimens. Moreover, the integration of ICT into healthcare systems has revolutionized the way medical professionals deliver care and manage health data. Electronic health records, telemedicine platforms, and mobile health applications have streamlined processes, improved diagnostic accuracy, and expanded access to specialized care, particularly in remote and underserved areas (Asongu & Odhiambo, 2022; GSMA, 2020; Källander et al., 2013).

Additionally, digitalization has permeated every aspect of healthcare, from administrative tasks to clinical decision-making. Through the adoption of digital health solutions such as predictive analytics, artificial intelligence, and Internet of Things (IoT) devices, healthcare providers can optimize resource allocation, personalize patient care, and preemptively identify health trends and outbreaks (Abdulqadir & Asongu, 2022; AlGhamdi & Moussa, 2012; Pedrero-Pérez et al., 2018). Despite notable progress in ICT use, and digitalization efforts, a significant proportion of the population in SSA lacks access to affordable internet services and faces high mobile costs, hindering their ability to access information, education, and health services. This contributes to misinformation and a lack of proper information on health risks (Lam et al., 2012; Peabody et al., 2005; Smith et al., 2014). Furthermore, the region faces persistent challenges in healthcare delivery, including inadequate infrastructure, healthcare workforce shortages, and limited access to essential medicines and medical technologies (WHO, 2017).

Furthermore, digitalization and telephone connectivity offer unprecedented opportunities to bridge gaps in healthcare access, delivery, and information dissemination. Mobile phones, in particular, have become ubiquitous tools for communication, commerce, and healthcare delivery, enabling innovative solutions such as mobile health (mHealth) applications, telemedicine services, and health information platforms (Aker & Mbiti, 2010; Constantine et al., 2024; Repacholi, 2001). Additionally, the proliferation of telephone access points and social media platforms has facilitated the dissemination of health information, patient education, and community engagement on health-related issues (Korda & Itani, 2013; Petersen, 2024).

While existing studies have explored the impact of technology on economic growth and healthcare separately (Chipunza & Nhamo, 2023), this study uniquely integrates ICT metrics, and digitalization to provide a holistic view of their combined effects on healthcare performance in SSA (Rani et al., 2023). This comprehensive approach fills a gap in understanding how different facets of technological advancement interact to influence health outcomes in SSA. Additionally, while many studies focus on cross-sectional data or shorter time periods (Moyo et al., 2020), this study's use of data spanning from 1998 to 2022 offers a long-term perspective, providing insights into temporal trends and long-term effects

(Chukwu & Essue, 2024). Furthermore, existing literature often treats healthcare indicators in a generalized manner (Teshome, 2023). This study addresses this by differentiating between the impacts of technological advancements on malaria and tuberculosis, enhancing understanding of how technology affects different health conditions (Jumbri et al., 2019). By employing advanced methodologies such as PVAR GMM-Style, IRF, variance decomposition, and Granger causality, this study contributes a more rigorous analysis to the literature, which has been less common in SSA-focused research. Finally, while many studies offer theoretical insights (Adedoyin et al., 2023), this study provides actionable policy recommendations based on empirical evidence, addressing the gap in translating research findings into practical guidelines for enhancing technological and healthcare development in SSA. These contributions advance the understanding of leveraging technological infrastructure to improve health outcomes and provide a basis for future research and policy development in the region.

## 2. Theoretical and empirical literature review

The Health Belief Model (HBM), proposed by Rosenstock (1974), provides insights into individuals' perceptions of health threats and the likelihood of adopting preventive health behaviours. Applying the HBM can help elucidate factors influencing the adoption of digital health technologies, such as perceived susceptibility to diseases and perceived benefits of technology-enabled healthcare interventions. The HBM model is consistent with this study because users employ telephone communication, ICT, and digitalization frameworks in view of the perceived benefits in health services. Similarly, the Technology Acceptance Model (TAM), developed by Davis (1989), offers a theoretical framework for understanding users' acceptance and adoption of new technologies. By examining factors such as perceived usefulness and ease of use, the TAM can inform strategies to promote the uptake of ICT use, and digitalization among healthcare providers and patients. Hence, prior to accepting a given ICT platform, users are aware of anticipated rewards in terms of health performance. Furthermore, the Diffusion of Innovations theory, proposed by Rogers (1983), explores how new ideas, technologies, and practices spread within a society. Applying this theory can shed light on the factors influencing the diffusion of digital health innovations, including communication channels, social networks, and cultural norms. The Diffusion of Innovations theory applies within the context of this study because users are continuously looking for benefits of ICT, especially in terms of how the diffusion of ICT engenders positive externalities like better health services.

The literature surrounding ICT use, and digitalization in healthcare performance provides valuable insights into the implementation, impact, and challenges of these technologies in improving healthcare delivery. Studies by Labrique et al. (2013) and Osei-Frimpong et al. (2018) have demonstrated the effectiveness of ICT interventions in enhancing maternal and child health outcomes, as well as improving medication adherence among HIV-positive patients. These findings underscore the potential of ICT use as a tool for expanding healthcare access and improving patient outcomes in resource-constrained settings. Additionally, research by Honka et al. (2011) and UNICEF (2018) has highlighted the role of ICT in healthcare management, showcasing its potential to strengthen health systems and improve service delivery.

Furthermore, studies by Agarwal et al. (2015) and GSMA (2020) have explored the impact of digitalization on healthcare delivery, shedding light on the effectiveness of digital health solutions in addressing healthcare challenges in rural and underserved areas. However, despite the promising findings, studies by Odipo et al. (2024) and Petersen (2024) have identified barriers to technology adoption, including infrastructure limitations, regulatory constraints, and socio-economic disparities. These findings underscore the importance of addressing these barriers to realize the full potential of ICT use, and digitalization in improving

healthcare performance in Sub-Saharan Africa. Moreover, studies by Angell et al. (2022) and Källander et al. (2013) have emphasized the role of policy and regulatory frameworks in promoting the use of technology in healthcare delivery, highlighting the need for supportive policy environments to facilitate innovation and investment in digital health solutions.

In SSA, characterized by a myriad of healthcare challenges, including inadequate infrastructure and limited access to quality services, ICT use, and digitalization have emerged as transformative tools in healthcare delivery (DeRenzi, Borriello, & Jackson, 2012). These technologies offer promising solutions to bridge geographical barriers and improve healthcare access for remote and underserved populations. Through remote consultations, health information dissemination, and enhanced access to medical resources, ICT use, and digitalization facilitate the delivery of essential healthcare services, particularly in regions with limited physical infrastructure (Labrique et al., 2013).

However, while the potential benefits of these technologies are evident, their widespread adoption in Sub-Saharan Africa's healthcare systems faces challenges. Inadequate infrastructure, limited resources, and socio-economic disparities can impede the effective implementation of ICT use, and digitalization initiatives, particularly in rural areas where access to technology and internet connectivity is limited (Adeola, 2018; Angell et al., 2022). Furthermore, cultural and linguistic diversity across SSA necessitates tailored approaches to ensure the relevance and effectiveness of digital health interventions (Agarwal et al., 2015). To address these challenges and maximize the potential impact of ICT use, and digitalization in Sub-Saharan Africa's healthcare systems, it is crucial to understand the current landscape and identify areas for improvement.

Empirical evidence and case studies highlighting successful implementations of these technologies can provide valuable insights into their effectiveness and scalability in the region (Labrique et al., 2013). Additionally, studies examining the socio-economic and cultural factors influencing the adoption and utilization of digital health solutions can inform the development of targeted interventions (Chukwu & Essue, 2024; Constantine et al., 2024). By leveraging existing research and empirical evidence, policymakers, healthcare practitioners, and stakeholders can design and implement strategies to overcome barriers to adoption and promote the effective integration of ICT use, and digitalization in Sub-Saharan Africa's healthcare systems. This includes investments in infrastructure development, capacity building initiatives, and community engagement efforts to ensure that these technologies reach the populations most in need (Labrique et al., 2013; Agarwal et al., 2015).

In the study of telemedicine and telehealth applications, as evident in Scott and Mars (2020), solutions to healthcare challenges in remote areas take center stage. The research emphasizes the pivotal role of perceived usefulness in shaping healthcare professionals'

attitudes toward these innovations. Consequently, this perspective uncovers the intricate relationship between technology acceptance and its practical impact on healthcare delivery in SSA, providing valuable insights into the dynamics of healthcare accessibility. Furthermore, Mulogo et al. (2023) study reveals a significant shift in information-seeking behavior, with SSA residents increasingly relying on online platforms for maternal health information. However, the literature acknowledges the need to address factors influencing internet use, such as digital literacy and contextual relevance. This recognition adds depth to our understanding of the challenges and potential of utilizing the internet for health information, acknowledging the evolving nature of information-seeking behaviours.

Gichoya (2005) emphasizes culturally sensitive approaches and also draws attention to the diverse cultural contexts within SSA. Tailoring strategies to align with the cultural values and preferences of the population emerges as a crucial factor for the effectiveness and acceptance of digital health initiatives. This cultural lens enriches our comprehension of the dynamics in technology adoption, recognizing the significance of cultural context in shaping healthcare practices. In the study of government-led initiatives and policies by Nguyen et al. (2020) and Zhang et al. (2022), the pivotal role of policies and initiatives in shaping the technology landscape in SSA comes into focus. The impact of regulatory frameworks on the promotion of e-health initiatives underscores the interconnectedness between governmental support and successful technology implementation. Consequently, this section underscores the importance of a conducive policy environment for sustainable technology adoption, recognizing the need for supportive regulatory frameworks.

Moreover, Amoakoh-Coleman et al. (2016) examine the potential for community-based technology applications through the involvement of Community Health Workers (CHWs). This decentralized approach aligns with the need to empower local communities to actively participate in healthcare delivery. Consequently, the role of CHWs adds a community-centric dimension to our understanding of technology's role in healthcare, highlighting the importance of community engagement and local empowerment in healthcare initiatives. Despite the transformative potential, Ali et al. (2022), Amoako-Gyampah and Salam (2004), Hartley et al. (2019) and Zhang et al. (2022) identify barriers to technology adoption in SSA. Ranging from infrastructure limitations to cultural resistance, understanding and addressing these multifaceted challenges is deemed essential for the successful implementation of technology in the unique context of SSA. This recognition underscores the importance of a comprehensive and context-specific approach to overcoming barriers and ensuring the effective adoption of healthcare technologies.

In summary, ICT use, and digitalization have the potential to revolutionize healthcare delivery in SSA. However, their successful implementation requires an understanding of the

region's healthcare landscape and targeted interventions to address the unique challenges faced by its diverse populations. By drawing on empirical evidence and leveraging existing research, stakeholders can work towards harnessing the full potential of these technologies to improve healthcare access, delivery, and outcomes in SSA.

## **2.2 Testable hypotheses**

The preceding discussion has brought forth three empirical inquiries concerning the relationship among ICT use, and digitalization in healthcare performance in SSA. Firstly, does the utilization of fixed telephone subscriptions in healthcare services impact access to healthcare resources and information dissemination among underserved populations in SSA? Secondly, does the increasing use of ICT in healthcare services influence access to healthcare resources and information dissemination among underserved populations in SSA? Lastly, what are the effects of enhancing digitalization, particularly through fixed broadband subscriptions, on access to healthcare resources and information dissemination among underserved populations in SSA? The responses to these inquiries hold significant implications for policymakers. Should the answer to the first question be affirmative, it suggests that effective use of ICT need not necessarily impede health progress; instead, it could spur technological innovation, thereby enhancing information dissemination and fostering health development. Moreover, an affirmative response to the second question implies the imperative for policymakers to embrace technological innovation as a driver for achieving information dissemination among underserved populations. Finally, if the answer to the third question is affirmative, it underscores the unforeseen benefits of strong digitalization efforts in healthcare, including fixed broadband subscriptions, in stimulating technological innovation and improving sustainable healthcare practices, ultimately benefiting underserved populations in SSA.

Based on these three related questions, we test the following hypotheses in the context of SSA:

**Hypothesis 1:** *Using fixed telephone subscriptions for communications in healthcare services improves access to healthcare resources and information dissemination among underserved populations in Sub-Saharan Africa.*

**Hypothesis 2:** *Increasing the use of ICT in healthcare services enhances access to healthcare resources and information dissemination among underserved populations in Sub-Saharan Africa.*

**Hypothesis 3:** *Enhancing digitalization, particularly through fixed broadband subscriptions, in healthcare services positively correlates with improved access to healthcare resources and information dissemination among underserved populations in Sub-Saharan Africa.*

### 3. Data and methodology

#### 3.1 Model estimation

Based on the underlying hypotheses in Section 2, the formulation in Equation (1) captures the relationship between ICT use, digitalisation and health performance.

$$HP = f(TC, ICT, D) \quad (1)$$

where health performance (HP) is represented by the incidence of malaria and the incidence of tuberculosis. Telephone communication (*TC*) is represented by fixed telephone subscriptions (per 100 people) and fixed telephone subscriptions. ICT use is measured by ICT goods exports (% of total goods exports) (ICTGE) and ICT goods imports (% of total goods imports) (ICTGI). Digitalisations denote Fixed broadband subscriptions (per 100 people) and Fixed broadband subscriptions. We control for economic growth, government final expenditure, and population.

Intuitively, in Equation (2), we incorporate the natural logarithm of the variables for health performance:

$$\ln(HP) = \alpha + \beta_1 \ln(TC) + \beta_2 \ln(ICT) + \beta_3 \ln(D) + \beta_4 \ln(CV) + \varepsilon \quad (2)$$

The light of the above, Equation (2) aims to understand how various factors (Telephone communication, ICT use, digitalization, and control variables) influence health performance, measured by the incidence of malaria and tuberculosis (Ali et al., 2022; Danmaraya et al., 2022; Kirikkaleli & Adebayo, 2021). By taking the natural logarithm of the variables, we can interpret the coefficients as elasticities, indicating the percentage change in health performance resulting from a one percent change in each independent variable. This transformation helps to linearize relationships and handle heteroskedasticity issues in the data.

Based on Equation 1, we construct a panel dataset from 30 SSA countries. Table 1 outlines the key variables used in the study to assess the relationship between telephone communication, ICT use, digitalization, and healthcare performance. Specifically, healthcare performance is measured by the incidence of malaria (*MAL*) and tuberculosis (*TUB*), which are critical indicators of the effectiveness of healthcare systems in managing and reducing disease prevalence (WHO, 2020). The choice of choosing these variables lies in the significant health challenges posed by malaria and tuberculosis in SSA. Malaria remains a leading cause of morbidity and mortality in the region, making its incidence a vital measure of the success of healthcare interventions (WHO, 2019). Similarly, tuberculosis, often exacerbated by the high prevalence of HIV/AIDS, is a major public health concern (UNAIDS, 2019). Tracking its incidence provides insights into the healthcare system's capacity to manage infectious diseases. These variables reflect the broader impact of healthcare policies, infrastructure, and technological advancements on public health outcomes, aiming to

show how improvements in telephone communication, ICT use, and digitalization can enhance health management and disease prevention strategies in the region (GSMA, 2020).

Telephone communication is proxied by fixed telephone subscriptions per 100 people (FTSI) and the total number of fixed telephone subscriptions (FTS), reflecting the level of telecommunication infrastructure essential for health information dissemination and coordination of health services (GSMA, 2020). ICT use is gauged by the percentage of ICT goods exports (ICTGE) and ICT goods imports (ICTGI), indicating the role of ICT in the economy and its potential to support health systems through technological innovations. Digitalization is measured by fixed broadband subscriptions per 100 people (FBS1) and the total number of fixed broadband subscriptions (FBS), highlighting internet accessibility which enables various digital health solutions such as telemedicine and electronic health records (GSMA, 2020).

The control variables include economic growth, measured by GDP per capita (constant 2015 US\$), government final expenditure, indicated by the general government final consumption expenditure as a percentage of GDP, and population, represented by the total population. These control variables are essential for understanding the broader economic and demographic context within which health and technological indicators operate in SSA (WHO, 2020). They help isolate the impact of specific factors on health outcomes and technological advancements, ensuring that the analysis accounts for variations in economic performance, government spending, and population size (WHO, 2019).

Table 1. Variable description

<b>Variables</b>		
Healthcare performance	Incidence of malaria	WDI
	Incidence of Tuberculosis	WDI
Telephone communication	Fixed telephone subscriptions (per 100 people)	WDI
	Fixed telephone subscriptions	WDI
ICT use	ICT goods exports (% of total goods exports) (ICTGE)	WDI
	ICT goods imports (% total goods imports) (ICTGI)	WDI
Digitalisation	Fixed broadband subscriptions (per 100 people)	WDI
	Fixed broadband subscriptions	WDI
Economic growth	GDP per capita (constant 2015 US\$)	WDI
Government final expenditure	General government final consumption expenditure (% of GDP)	WDI
Population	Population, Total	WDI

**Note:** WDI represents World Development Indicators of the World Bank.

The correlation matrix plot in Figures 1a-b provides valuable insights into the relationships between various economic, technological, and health-related indicators in SSA. The negative correlations between malaria incidence and fixed telephone subscriptions per 100 people (FTS1, -0.24), ICT goods imports (ICTGI, -0.50), and GDP per capita (-0.37) suggest that higher economic and technological development is associated with lower malaria cases. Similarly, the negative correlations between tuberculosis incidence (Tub) and fixed telephone subscriptions (FTS, -0.42), ICT goods imports (ICTGI, -0.39), and GDP per capita (-0.36) indicate that advancements in telephone communication, ICT use, and economic growth can significantly improve health outcomes by reducing the prevalence of both malaria and tuberculosis.

The correlation between fixed telephone subscriptions and health outcomes supports the literature indicating that telecommunication infrastructure is crucial for health information dissemination and coordination of health services, particularly in rural and underserved areas (Labrique et al., 2013; DeRenzi et al., 2012). The significant negative correlation between ICT goods imports and malaria incidence is consistent with studies highlighting the role of ICT in strengthening health systems and enhancing access to health technologies (GSMA, 2020; Agarwal et al., 2015). The correlation with GDP per capita aligns with findings that economic development is essential for improving health infrastructure and access to quality healthcare services (Asongu & Le Roux, 2017). These correlations underscore the importance of integrating economic and technological advancements to address healthcare challenges in SSA and highlight the potential of telephone communication and ICT use to enhance health outcomes in the region.

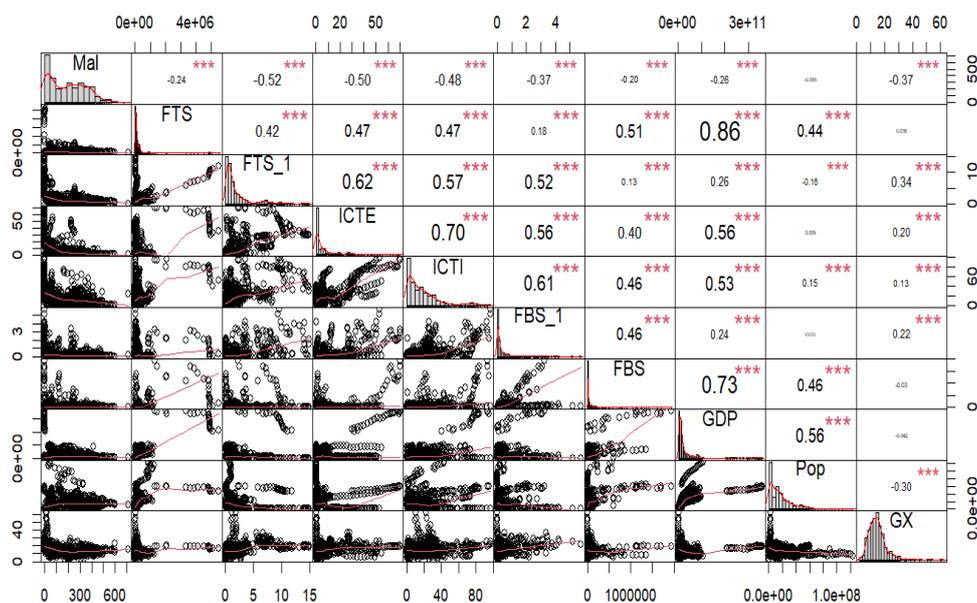
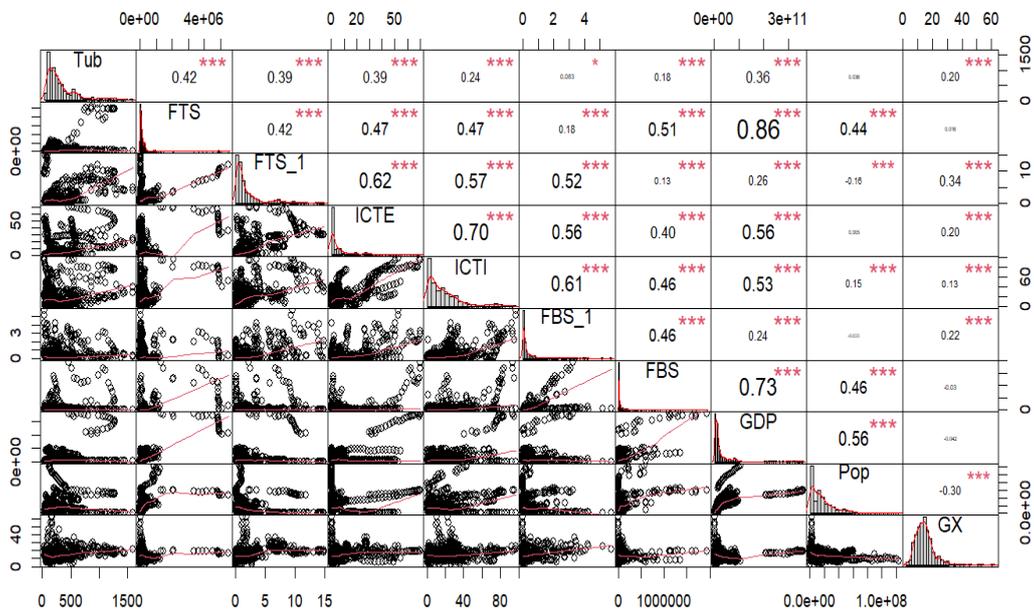


Figure 1a. Correlation matrix (Malaria)

Strong positive correlations between GDP per capita and ICT goods exports (ICTGE, 0.56) highlight that economic growth is closely linked with higher investments in technology, further enhancing development and health infrastructure. Additionally, the positive correlations among fixed telephone subscriptions, ICT investments, and government expenditure (% of GDP) suggest integrated growth in these sectors. This indicates that increased government spending on technology and communication services supports overall economic growth. The negative correlations between population and the incidences of malaria (-0.30) and tuberculosis (-0.30) might imply that more populous regions have better resources and infrastructure for disease control, leading to lower incidence rates. These findings underscore the importance of coordinated policy efforts in SSA to foster economic growth, technological advancements, and health improvements.



**Figure 1b. Correlation matrix (Tuberculosis)**

In summary, leveraging the interlinked dynamics between economic growth, technological advancements, and healthcare improvements is crucial for achieving sustainable development goals. Investments in telephone communication and ICT use can enhance health outcomes by reducing disease prevalence. Simultaneously, economic growth driven by ICT investments and government expenditure can create a robust infrastructure that supports health and development. Coordinated policy efforts that integrate these elements can significantly reduce the disease burden and improve the quality of life for the population in SSA.

## 3.2 Econometric approach

### 3.2.1 Panel Vector Autoregression (PVAR)

We incorporate the panel vector autoregression (PVAR) into Equation (1) to extend the model and capture the dynamic interactions among the variables over time. The PVAR framework allows us to analyze the simultaneous relationships between telephone communication, ICT use, digitalization, and health performance. The PVAR specification for Equation (1) is as follows in Equation (3):

$$Hp_{it} = \alpha_i + \beta_{1i}TC_{it} + \beta_{2i}ICT_{it} + \beta_{3i}D_{it} + \varepsilon_{it} \quad (3)$$

where  $Hp_{it}$  represents the health performance for country  $i$  at time  $t$ .  $TC_{it}$ ,  $ICT_{it}$ , and  $D_{it}$  denote the Telephone communication, ICT use, and digitalization for country  $i$  at time  $t$ , respectively.  $\alpha_i$  is the country-specific intercept, capturing the baseline level of health performance for each country.  $\beta_{1i}$ ,  $\beta_{2i}$ , and  $\beta_{3i}$  are the country-specific coefficients associated with the respective explanatory variables, representing the marginal effects of telephone communication, ICT use, and digitalization on health performance.  $\varepsilon_{it}$  is the error term, capturing unobserved factors affecting health performance for country  $i$  at time  $t$ .

We extend the framework for estimating the dynamic responses of health performance to shocks in telephone communication, ICT use, and digitalisation using a panel vector autoregression (PVAR) model and analyzing the impulse response functions as articulated in Equation (4).

$$Y_t = \alpha + \sum_{i=1}^p A_i Y_{t-i} + \sum_{j=1}^m B_j X_{t-j} + \varepsilon_t \quad (4)$$

$Y_t$  is the vector of endogenous variables (including health performance).  $X_t$  is the vector of exogenous variables (including telephone communication, ICT use, and digitalisation).  $A_i$  and  $B_j$  are coefficient matrices.  $p$  and  $m$  denote the number of lags for endogenous and exogenous variables, respectively.  $\varepsilon_t$  is the error term (Abrigo & Love, 2016; Canova & Ciccarelli, 2013).

### 3.2.2 Impulse Response Function (IRF)

The impulse response function (IRF) equation is as in Equation (5):

$$\Delta Y_t = \sum_{j=0}^h C_j \Delta X_{t-j} + \eta_t \quad (5)$$

where  $\Delta Y_t$  represents the change in the vector of endogenous variables (health performance),  $\Delta X_{t-j}$  denotes the change in the vector of exogenous variables (telephone communication, ICT use, and digitalization),  $C_j$  is the impulse response coefficient matrix that captures the dynamic response of  $Y_t$  to shocks in  $X_t$ ,  $h$  is the number of periods over which the response is traced, and  $\eta_t$  is the error term (Lütkepohl, 2010; Sims, 1980). This function allows for the assessment of how health performance responds to various shocks over time, providing insights

into the impact of technological and communication advancements on health outcomes (Stock & Watson, 2001).

### 3.2.3 Variance decomposition

The variance decomposition analysis allows us to understand the relative importance of different shocks in explaining the variability of health performance within the context of a panel vector autoregression (PVAR) model. The variance decomposition formulation can be presented as follows in Equation (6):

$$\Sigma = \sum_{i=1}^p A_i \Sigma A_i' + \sum_{j=1}^m B_j \Omega B_j' + \Psi \quad (6)$$

where  $\Sigma$  is the covariance matrix of the residuals ( $\varepsilon_t$ ),  $\Omega$  is the covariance matrix of the shocks to the exogenous variables, and  $\Psi$  is the covariance matrix of the initial errors. The variance decomposition analysis calculates the proportion of the variance of health performance explained by each shock, including shocks to the endogenous variables (autoregressive shocks) and shocks to the exogenous variables (innovation or structural shocks). By decomposing the variance, we can assess the relative importance of different factors, such as telephone communication, ICT use, and digitalization, in explaining the fluctuations in health performance over time. This analysis provides valuable insights into the drivers of variability in health performance and helps policymakers prioritize interventions to address the most influential factors (Canova & Ciccarelli, 2013; Holtz-Eakin et al., 1988; Lütkepohl, 2010).

### 3.2.4 Granger causality

In a panel vector autoregression (PVAR) model, Granger causality can be tested between variables to determine if one variable can predict another (Granger, 1988). Equation (7) below provides the general equation for testing Granger causality between two variables, say, variable  $X$  and variable  $Y$ , in a PVAR model is:

$$NR_{it} = \alpha_i + \sum_{j=1}^p \beta_j MM_{i,t-j} + \varepsilon_{it} \quad (7)$$

$NR_{it}$  represents health performance at time  $t$  for unit  $i$ .  $\alpha_i$  is the unit-specific intercept or constant term.  $\sum_{j=1}^p \beta_j MM_{i,t-j}$  is the sum of lagged values of telephone communication as predictors of health performance, where  $p$  represents the number of lagged terms included in the model, and  $\beta_j$  are the coefficients associated with each lag.  $\varepsilon_{it}$  is the error term or residual, representing the difference between the observed value of health performance and the value predicted by the model. This equation tests whether past values of telephone communication can predict current values of health performance. If the coefficients  $\beta_j$  are statistically significant, it suggests that past values of telephone communication Granger cause health performance, indicating a predictive relationship between telephone communication and health performance.

## 4. Empirical results

### 4.1. Telephone communication -health performance in SSA

To support hypothesis 1, Table 2 shows insightful findings between telephone communication, economic indicators, social indicators, and healthcare indicators (the incidence of malaria and tuberculosis) in SSA using the PVAR GMM-Style. To start, when examining healthcare indicators in SSA, the incidence of malaria and tuberculosis have distinct effects. A 1% increase in malaria incidence results in a notable decrease in both economic growth and government final expenditure, specifically by approximately 0.087% and 0.086%, respectively. This suggests that higher malaria rates have a broad negative impact on economic and fiscal performance, underscoring the need for enhanced healthcare and malaria control initiatives (Sachs & Malaney, 2002). In contrast, the incidence of tuberculosis shows a more complex dynamic; a 1% increase in tuberculosis incidence leads to a 1.081% increase in future tuberculosis rates and a 0.026% decrease in economic growth. This indicates that tuberculosis not only exacerbates its own prevalence but also slightly hinders economic growth, highlighting the critical need for focused tuberculosis interventions (Bloom et al., 2004).

Conversely, telephone communication, as represented by fixed telephone subscriptions (both per 100 people and in total), plays a crucial role in fostering economic growth, government expenditure, and population increases. A 1% rise in fixed telephone subscriptions per 100 people leads to a 5.325% boost in economic growth, a 2.436% increase in government expenditure, and a 0.388% rise in population. Similarly, an increase in total fixed telephone subscriptions results in a 2.469% rise in economic growth, a 2.390% boost in government spending, and a 0.390% increase in population. These findings underscore the significant positive impact of telecommunications infrastructure on economic and social development, demonstrating the importance of integrating telephone communication advancements with efforts to address healthcare challenges (Aker & Mbiti, 2010).

Lastly, the relationship between economic growth and government expenditure reveals a significant relationship. Economic growth positively influences fixed telephone subscriptions and itself, with a 1% increase resulting in a 0.221% rise in fixed telephone subscriptions per 100 people and a 0.214% increase in fixed telephone subscriptions. Moreover, economic growth shows a robust positive effect on itself, suggesting a reinforcing cycle of economic expansion. Government final expenditure also demonstrates significant positive effects on both economic growth and population, with a 1% increase in expenditure leading to a 2.390% rise in economic growth and a 0.595% increase in population. These interactions highlight the importance of targeted government spending and economic growth strategies

to drive broader infrastructure development and demographic growth (Asongu & Le Roux, 2017).

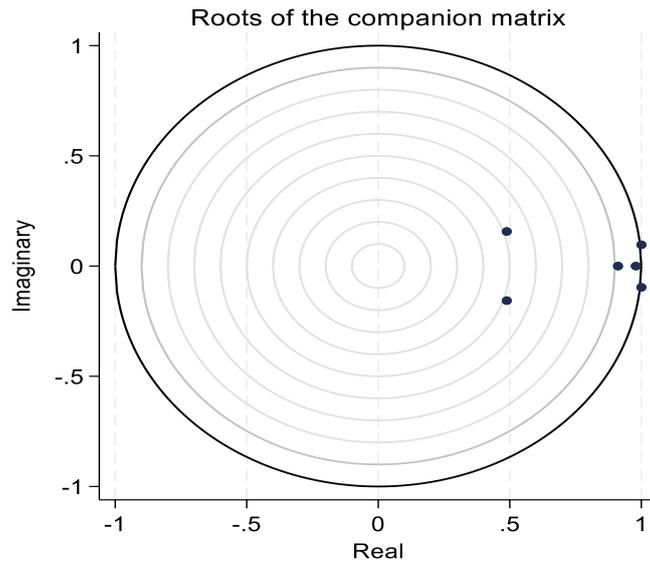
In summary, telephone communication plays a crucial role in boosting economic growth, government expenditure, and population growth in SSA. Improvements in telecommunications infrastructure positively impact economic and social indicators, emphasizing the importance of investing in telephone communication technologies. The findings suggest that advancing telephone communication infrastructure can complement efforts to address healthcare challenges, such as malaria and tuberculosis. Therefore, policymakers should prioritize investments in telecommunications to foster economic and social development while simultaneously enhancing healthcare systems to improve overall public health. Integrating telephone communication advancements with targeted healthcare initiatives can drive comprehensive progress in the region (Labrique et al., 2013; DeRenzi et al., 2012).

**Table 2. PVAR GMM-Style results**

Variables	1	2	3	4	5	6	7	8	9	10	11	12
Incidence of malaria/tuberculosis	0.167 (0.338)	- 0.087** (0.032)	- 0.086** (0.031)	0.019 (0.014)	-0.001 (0.001)	-0.018 (0.031)	1.081*** (0.026)	-0.037 (0.057)	-0.037 (0.057)	-0.026** (0.016)	0.000 (0.001)	0.003 (0.051)
Fixed telephone subscriptions (per 100 people)	70.447 (62.201)	1.364 (3.772)	0.060 (3.653)	-3.409 (2.533)	0.235** (0.114)	0.577 (3.213)	-0.481 (1.143)	5.325** (3.003)	4.015 (2.993)	-2.436** (1.078)	-0.388*** (0.093)	-0.810 (2.187)
Fixed telephone subscriptions	-70.415 (62.231)	-0.340 (3.768)	0.966 (3.649)	3.435 (2.533)	0.236** (0.114)	-0.630 (3.217)	0.474 (1.145)	-4.322 (3.000)	-3.010 (2.989)	2.469** (1.080)	0.390*** (0.094)	0.758 (2.192)
Economic growth	0.722 (0.937)	0.221** (0.113)	0.214** (0.113)	0.961*** (0.043)	0.009*** (0.003)	0.024 (0.111)	-0.026 (0.038)	0.039 (0.101)	0.049 (0.101)	0.931*** (0.036)	0.008*** (0.002)	-0.017 (0.105)
Government final expenditure	68.532 (61.408)	0.269 (3.677)	-0.049 (3.559)	-3.363 (2.507)	0.745*** (0.110)	0.497 (3.131)	-0.397 (1.123)	3.944 (2.948)	3.613 (2.936)	-2.390** (1.064)	0.595*** (0.092)	-0.794 (2.129)
Population	0.506 (0.370)	0.025 (0.045)	0.026 (0.044)	0.046** (0.020)	0.003** (0.001)	0.667*** (0.060)	-0.044 (0.028)	0.103** (0.050)	0.104** (0.051)	-0.031** (0.018)	-0.002*** (0.001)	0.683*** (0.068)

Notes: Models 1-6 represent incidences with malaria as the dependent variable while Models 7-12 show incidences with tuberculosis as the dependent variable.

- Significance Levels: \*\*p < 0.05, \*\*\*p < 0.01
- Standard Errors are in parentheses



**Stability graph for Incidence of malaria**

In SSA, a stability graph for the incidence of malaria- telephone communication can provide valuable insights into the effectiveness of both healthcare interventions and telecommunications infrastructure. By analysing trends in malaria incidence alongside changes in telephone communication capabilities, such as fixed telephone subscriptions, policymakers can evaluate how improvements in telecommunications might influence healthcare outcomes. A declining trend in malaria rates coupled with enhanced telephone communication infrastructure could signal successful public health interventions and improved access to healthcare information. Conversely, if malaria rates remain unstable or increase despite advancements in telephone communication, it would highlight the need for more targeted healthcare strategies. Thus, such combined analyses are crucial for optimizing resource allocation and improving health outcomes in the region.

#### **4.2. ICT use-health performance in SSA**

To support Hypothesis 2, Table 3 reports the impact of ICT metrics and economic-healthcare indicators, showing significant differences between malaria and tuberculosis. For malaria, a 1% increase in incidence is associated with a 0.855% decrease in economic growth and a 0.358% reduction in government final expenditure, indicating that higher malaria rates negatively affect economic and fiscal performance. This is supported by literature indicating that malaria exerts substantial economic burden due to lost productivity and increased healthcare costs (WHO, 2020; Adeola, 2018). Conversely, tuberculosis shows a distinct pattern; a 1% rise in incidence results in a 1.073% increase in future tuberculosis rates and a 0.037% decrease in economic growth, suggesting that while tuberculosis exacerbates its own

prevalence, its impact on economic growth is relatively smaller. This aligns with studies highlighting tuberculosis' direct and indirect effects on economic stability and workforce productivity (Odipo et al., 2024; UNAIDS, 2019).

In terms of ICT metrics, a 1% increase in ICT goods exports correlates with a 0.638% decrease in malaria incidence, suggesting that higher ICT exports may improve health outcomes through enhanced access to health technologies. Similarly, a 1% increase in ICT goods imports is linked to a 0.110% decrease in malaria incidence, further indicating the positive role of technology in health improvement. These findings are consistent with research showing the beneficial impact of ICT on healthcare delivery, such as improving data management, enhancing communication, and providing better access to health services (GSMA, 2020; Asongu & Odhiambo, 2022). For tuberculosis, a 1% increase in ICT goods exports correlates with a 0.031% increase in tuberculosis incidence, while ICT goods imports show a minor 0.010% decrease in tuberculosis rates. This mixed result suggests variability in how ICT investments impact different health conditions (Odipo et al., 2024).

Economic growth positively influences ICT metrics, with a 1% increase leading to a 1.023% rise in ICT goods exports and a 1.006% increase in ICT goods imports. This relationship is supported by studies that indicate economic growth drives technological advancement and increases the capacity for ICT adoption (GSMA, 2020; Asongu & Odhiambo, 2022). Government expenditure, on the other hand, shows mixed effects; a 1% increase in spending corresponds with a 0.972% rise in government final expenditure and a 0.476% decrease in tuberculosis incidence. This supports the notion that targeted government spending can improve health outcomes by funding healthcare services and disease control programs (WHO, 2017; Odipo et al., 2024). Population growth is associated with a 0.589% increase in population metrics and a 0.109% decrease in tuberculosis incidence, reflecting the demographic factors influencing health outcomes (Adeola, 2018).

Overall, these findings highlight the complex interplay between healthcare, economic, and ICT indicators, underscoring the importance of integrating technological advancements with healthcare investments to address both malaria and tuberculosis effectively while supporting economic and social development. The extant literature supports the positive impact of ICT on health outcomes and economic growth, emphasizing the need for policies that promote technological integration in healthcare (GSMA, 2020; Odipo et al., 2024).

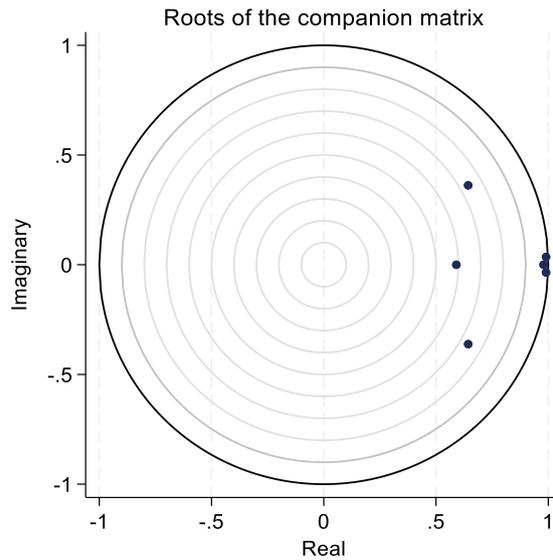
**Table 3. PVAR GMM-Style results**

Variables	1	2	3	4	5	6	7	8	9	10	11	12
	<b>0.855***</b>	0.122	0.275**	0.018**	-0.001	-0.043	<b>1.073***</b>	0.169**	0.044	0.011	-0.002	-0.004
Incidence of malaria	<b>(0.124)</b>	(0.077)	(0.096)	(0.010)	(0.001)	(0.028)	<b>(0.026)</b>	(0.082)	(0.133)	(0.018)	(0.002)	(0.045)
ICT goods exports (% of total goods exports) (ICTGE)	<b>-0.638***</b>	0.679***	-0.333**	-0.041**	0.006***	-0.095**	<b>0.031**</b>	0.901***	0.268**	-0.011	0.007***	0.066
	<b>(0.138)</b>	(0.101)	(0.107)	(0.013)	(0.001)	(0.033)	<b>(0.023)</b>	(0.076)	(0.144)	(0.015)	(0.002)	(0.044)
ICT goods imports (% of total goods imports) (ICTGI)	<b>-0.110**</b>	-0.158**	0.589***	-0.020**	0.000	0.013	<b>-0.010*</b>	-0.083**	0.640***	-0.017**	-0.002**	0.011
	<b>(0.065)</b>	(0.046)	(0.076)	(0.006)	(0.001)	(0.014)	<b>(0.011)</b>	(0.036)	(0.087)	(0.008)	(0.001)	(0.018)
Economic growth												-
	-0.273**	<b>1.023***</b>	<b>1.006***</b>	1.152***	0.018***	0.351**	<b>-0.037**</b>	0.593**	0.716**	1.040***	0.014***	0.182**
	(0.356)	<b>(0.268)</b>	<b>(0.343)</b>	(0.047)	(0.003)	(0.123)	<b>(0.053)</b>	(0.207)	(0.302)	(0.042)	(0.003)	(0.104)
Government final expenditure	<b>-0.358**</b>	-0.770**	-0.702	-0.145**	<b>0.972***</b>	0.319**	-0.031	<b>0.476**</b>	-0.662	-0.013	0.985***	0.110
	<b>(0.421)</b>	(0.316)	(0.430)	(0.072)	<b>(0.004)</b>	(0.181)	(0.064)	<b>(0.261)</b>	(0.437)	(0.062)	(0.004)	(0.146)
Population												
	-0.089**	0.026	-0.294**	0.000	0.000	<b>0.589***</b>	<b>0.109***</b>	-0.188**	0.698***	-0.055**	-0.003**	0.622**
	(0.126)	(0.100)	(0.131)	(0.019)	(0.001)	<b>(0.055)</b>	<b>(0.032)</b>	(0.086)	(0.183)	(0.023)	(0.002)	(0.080)

Notes: Models 1-6 represent incidences with malaria as the dependent variable while Models 7-12 show incidences with tuberculosis as the dependent variable.

- Significance Levels: \*\*p < 0.05, \*\*\*p < 0.01
- Standard Errors are in parentheses





**Stability graph for Incidence of malaria**

The stability graph for malaria incidence in relation to ICT use in SSA demonstrates the complex interplay between health and technology. Plotting ICT goods exports and imports against malaria incidence reveals a generally negative relationship, suggesting that higher ICT exports and imports are associated with reduced malaria cases. This graphical representation helps illustrate that while ICT use may contribute to better health outcomes by improving access to health technologies, the impact of these advancements on malaria incidence can vary, underscoring the need for integrated approaches in health and technology policy.

#### **4.3. Digitalisation-health performance in SSA**

To support Hypothesis 3, Table 4 reports the effects of digitalization on health performance (malaria and tuberculosis incidence) in SSA, revealing notable differences and similarities, reflecting how digital infrastructure impacts these diseases uniquely. For malaria, a 1% increase in its incidence results in a subsequent increase of approximately 0.601% to 0.415% in malaria rates, demonstrating a persistent and robust effect. In contrast, a 1% increase in fixed broadband subscriptions per 100 people leads to a substantial decrease in malaria incidence ranging from 0.370% to 1.546%. This suggests that better broadband access correlates with improved malaria control, potentially through enhanced health communication and services. Fixed broadband subscriptions also show a significant reduction in malaria incidence when considering total numbers, ranging from 0.319% to 2.268%. Economic growth impacts malaria incidence in a less consistent manner, with a slight increase of 0.004% to 1.008% per 1% growth, whereas higher government expenditure generally results in a decrease in malaria incidence between 0.642% and 2.273%, indicating that increased health spending can positively influence malaria control. Population growth is associated with a

slight increase in malaria incidence, suggesting that larger populations may face greater malaria challenges.

These findings align with previous studies highlighting the role of digital infrastructure in improving healthcare delivery and outcomes. For instance, Asongu and Odhiambo (2022) emphasize the transformative impact of ICT in enhancing health systems, particularly in remote and underserved areas. The reduction in malaria incidence with better broadband access supports the notion that digital communication can facilitate timely health information dissemination and more effective disease management (Adeola, 2018; GSMA, 2020).

Conversely, tuberculosis incidence displays a strong positive feedback loop, where a 1% increase in current tuberculosis incidence results in a future rise of 1.061% to 1.191%. Fixed broadband subscriptions also play a crucial role in reducing tuberculosis rates, with a 1% increase in subscriptions per 100 people decreasing tuberculosis incidence between 0.075% and 0.209%, and a total increase in subscriptions resulting in a decrease of 0.066% to 0.970%. This reinforces the beneficial impact of digital infrastructure on tuberculosis control. Economic growth shows varying impacts on tuberculosis, with a modest increase in incidence ranging from 0.070% to 0.978% per 1% economic growth, reflecting a complex relationship. Government expenditure also positively affects tuberculosis rates, with a 1% increase in spending reducing incidence by up to 0.986%, suggesting that effective health spending can contribute to tuberculosis reduction. Similar to malaria, an increase in population size is associated with a significant rise in tuberculosis incidence by 0.662%, highlighting the difficulties in managing tuberculosis in more densely populated areas.

These observations are in line with research by Odipo et al. (2024), which underscores the importance of technological integration in healthcare for improving disease outcomes. The reduction in tuberculosis incidence with increased broadband access corroborates the findings of Källander et al. (2013), who demonstrated the effectiveness of digital health solutions in managing infectious diseases. The mixed effects of economic growth on both diseases reflect the intricate balance between economic development and health outcomes, as discussed by Adeola (2018).

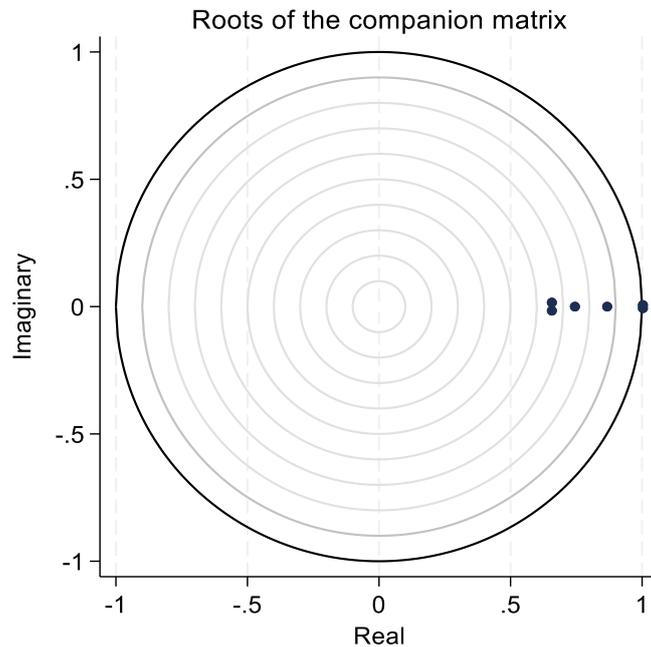
In summary, digitalization has a profound impact on health performance in SSA, with significant effects observed for both malaria and tuberculosis. Increased fixed broadband subscriptions are associated with substantial reductions in malaria incidence, suggesting that enhanced digital infrastructure can improve malaria control through better health communication and services. Similarly, while the reduction in tuberculosis incidence due to digital infrastructure is less pronounced, improved broadband access still plays a critical role in decreasing tuberculosis rates. Economic growth and government expenditure show mixed effects on both diseases, but higher health spending generally leads to better outcomes. Given these findings, policy recommendations include expanding digital infrastructure to enhance health services and communication and increasing government health expenditure to support disease control efforts, particularly in densely populated areas where both malaria and tuberculosis are more challenging to manage.

**Table 4. PVAR GMM-Style results**

Variables	1	2	3	4	5	6	7	8	9	10	11	12
Incidence of malaria/tuberculosis	0.601** (0.252)	0.371** (0.191)	0.415** (0.217)	-0.006 (0.015)	-0.003** (0.001)	0.018 (0.029)	1.061*** (0.028)	1.171**8 (0.316)	1.191*** (0.323)	-0.012 (0.016)	0.004** (0.001)	0.007 (0.052)
Fixed broadband subscriptions (per 100 people)	-	-	-	-	-	-	-	-	-	-	-	-
Fixed broadband subscriptions	0.370** (0.134)	-0.653** (0.361)	1.546*** (0.429)	-0.031** (0.014)	-0.003** (0.001)	-0.087** (0.044)	-0.075** (0.026)	-0.707** (0.211)	-0.209** (0.248)	0.057*** (0.015)	-0.004*** (0.001)	0.125*** (0.033)
Economic growth	0.319** (0.124)	1.377*** (0.355)	2.268*** (0.422)	-0.033** (0.013)	-0.003** (0.001)	0.080** (0.042)	-0.066** (0.025)	-0.056 (0.207)	0.970*** (0.245)	0.058*** (0.015)	-0.003*** (0.001)	0.120*** (0.031)
Government final expenditure	0.004 (0.398)	-0.789 (0.587)	-0.846 (0.623)	1.008*** (0.039)	0.013*** (0.003)	-0.093 (0.116)	0.070** (0.040)	0.178 (0.421)	0.214 (0.435)	0.978*** (0.034)	0.010*** (0.002)	-0.133 (0.098)
Population	-0.642 (0.794)	-2.030** (1.047)	-2.273** (1.135)	0.000 (0.072)	0.972*** (0.005)	0.122 (0.197)	-0.067 (0.063)	-0.736 (0.758)	-0.737 (0.796)	-0.054** (0.059)	-0.986*** (0.004)	0.119 (0.173)
	0.503** (0.271)	-0.186 (0.245)	-0.180 (0.257)	0.000 (0.015)	0.000 (0.001)	0.737*** (0.065)	-0.013 (0.019)	-0.155 (0.199)	-0.144 (0.205)	-0.018 (0.016)	0.000 (0.001)	0.662*** (0.066)

Notes: Models 1-6 represent incidences with malaria as the dependent variable while Models 7-12 show incidence with tuberculosis as the dependent variable.

- Significance Levels: \*\*p < 0.05, \*\*\*p < 0.01
- Standard Errors are in parentheses



**Stability graph for Incidence of malaria**

A stability graph depicting the incidence of malaria in relation to digitalization in SSA reveals that increased broadband subscriptions are associated with a significant reduction in malaria rates. As digitalization, represented by fixed broadband subscriptions per 100 people, rises, the incidence of malaria tends to decrease, illustrating a positive impact of enhanced digital infrastructure on health outcomes. This trend is consistent across various models, suggesting that better access to broadband facilitates improved health communication and services, leading to better malaria control. The stability graph effectively demonstrates the beneficial role of digitalization in mitigating malaria incidence, reinforcing the need for increased investment in digital health infrastructure as a policy recommendation.

#### **4.4 IRF**

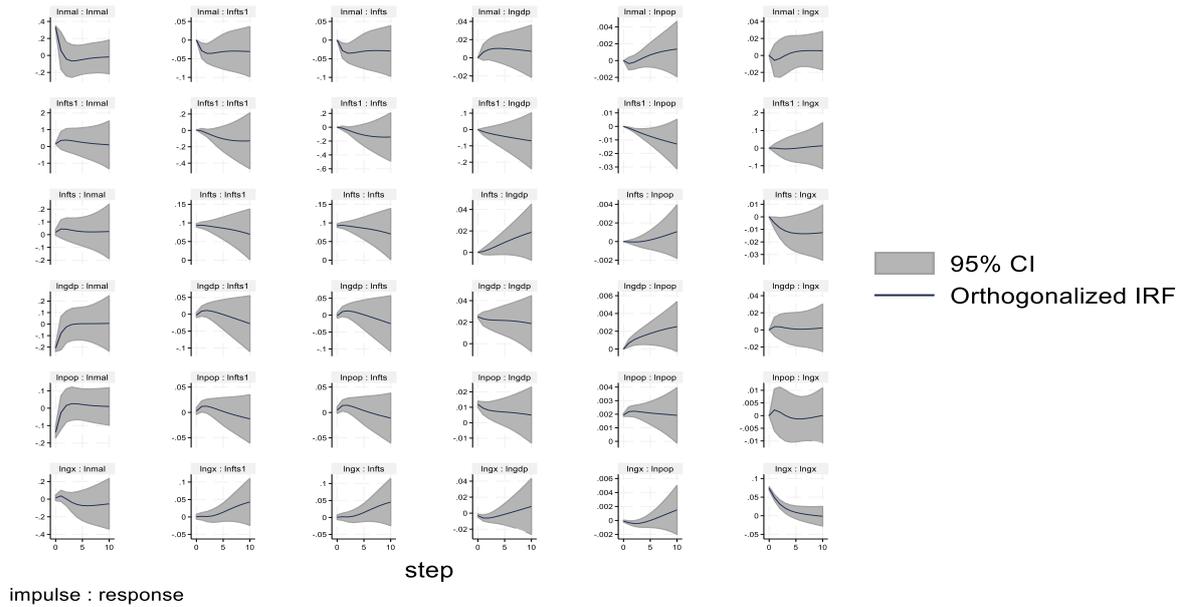
The Impulse Response Function (IRF) analysis of malaria and tuberculosis incidence reveals distinct patterns and impacts of various factors over time. For both malaria and tuberculosis, the initial period shows a high degree of persistence in their own shocks. Malaria incidence starts with a value of 1.000, indicating a strong immediate impact, which then decreases gradually to 0.297 by the tenth period. Tuberculosis shows a similar pattern but at a lower scale, with an initial value of 1.000 that declines slightly to 0.934. This indicates a gradual reduction in the impact of the initial shock for both diseases over time.

Telephone communication (FTS1) has a minimal initial impact on malaria, starting at 0.007 and rising slowly to 0.015 by the tenth period. This suggests a small but progressively strengthening effect of telephone communication on malaria incidence. For tuberculosis, the effect of telephone communication remains negligible throughout, rising from 0.000 to only 0.008, highlighting its limited role in influencing tuberculosis incidence. These findings are consistent with prior research highlighting the role of telephone communication in enhancing health information dissemination and coordination of health services (Asongu & Odhiambo, 2022).

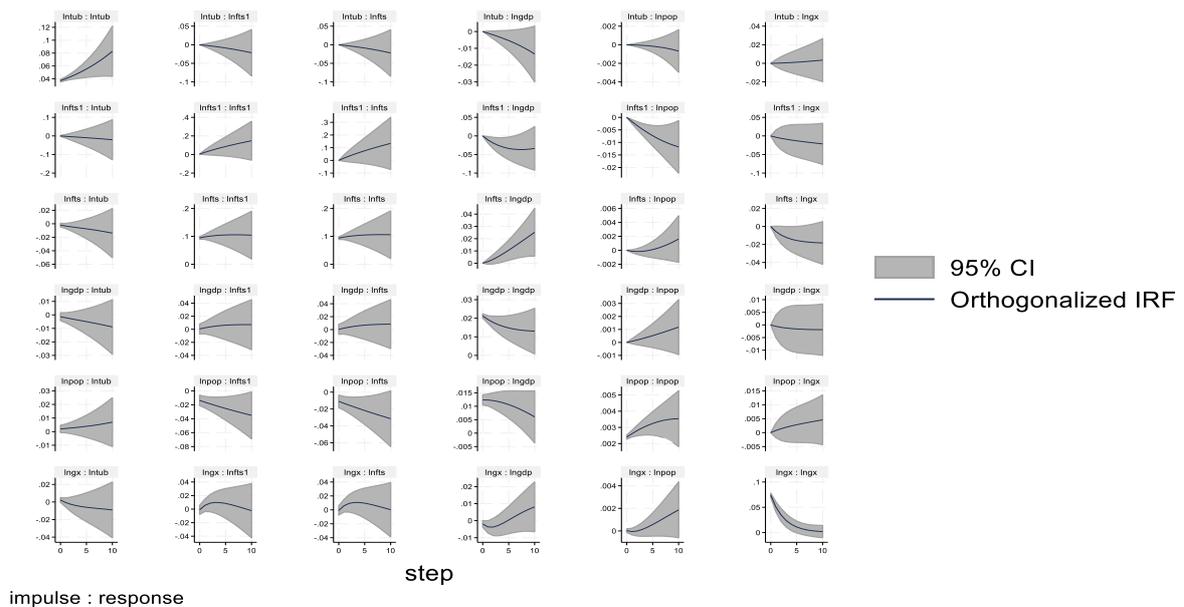
Fixed telephone subscriptions (FTS) show a more pronounced and growing impact on malaria, with the value increasing from 0.222 in the second period to 0.536 by the tenth period. This indicates that improved telecommunication infrastructure significantly contributes to reducing malaria incidence over time. In contrast, the impact of FTS on tuberculosis is much smaller, increasing from 0.000 to 0.022. This suggests that while improved telecommunication may aid in detecting tuberculosis, its effect is less substantial compared to malaria. This supports the literature indicating the broader role of telecommunications infrastructure in enhancing healthcare access and management (GSMA, 2020).

The effect of GDP on malaria is initially modest but grows progressively from 0.008 to 0.031. This indicates that economic growth has a minor initial effect but becomes increasingly relevant over time. For tuberculosis, the impact of GDP is even smaller, starting at 0.000 and rising to 0.004. This suggests that while economic activity might improve healthcare infrastructure, its influence on tuberculosis incidence remains limited. These findings align with the evidence suggesting that economic growth can contribute to improved health outcomes through better infrastructure and resource allocation (Adeola, 2018).

The population size has a more notable impact on malaria, with values increasing from 0.038 to 0.091 over time. This indicates that demographic changes progressively influence malaria incidence. For tuberculosis, the impact of population size is minimal, growing slightly from 0.000 to 0.004. This reflects that population changes have a negligible effect on tuberculosis incidence. This aligns with the findings that demographic factors can significantly impact the spread and control of infectious diseases (Källander et al., 2013).



Government expenditure (GX) has a modest initial effect on malaria, starting at 0.004 and growing to 0.029 by the tenth period. This indicates that increased spending gradually helps in controlling malaria incidence. For tuberculosis, government expenditure shows a more pronounced impact, increasing from 0.000 to 0.027. This suggests that higher government spending significantly enhances healthcare infrastructure and reporting systems, leading to better detection of tuberculosis cases. This supports the literature that emphasizes the importance of adequate government spending in improving healthcare outcomes (Odipo et al., 2024).



Overall, the analysis highlights that factors like fixed telephone subscriptions and government expenditure have a more substantial and growing effect on malaria compared to tuberculosis. Telephone communication and GDP show a more limited and gradual impact on both diseases, but their influence is more significant for malaria than tuberculosis. Population size affects malaria incidence more notably than tuberculosis. These findings suggest that while improvements in telecommunication and increased government spending are beneficial for both diseases, their effects are more pronounced for malaria. Tailored strategies are needed for different diseases to maximize health outcomes and resource allocation effectively.

#### **4.5 Variance decomposition**

Table 5 reports the variance decomposition of telephone communication, ICT use, and digital infrastructure in influencing healthcare performance indicators, specifically malaria and tuberculosis incidence. This decomposition provides insights into how each factor contributes to the variance in health outcomes. The variance decomposition is reported at the 10th period. For instance, malaria incidence (MAL) demonstrates that digital infrastructure, particularly fixed broadband subscriptions (FTS and FTS1), significantly influences malaria rates, accounting for 53.6% and 11.5% of the variance, respectively. This underscores the significance of investing in broadband infrastructure, which can enhance health communication and services, potentially leading to better malaria control (Asongu & Odhiambo, 2022; GSMA, 2020). Fixed broadband subscriptions per 100 people contribute 0.3% to the variance, indicating a positive yet smaller impact. In contrast, ICT expenditure (ICTE) and ICT infrastructure (ICTI) have minimal effects, reflecting their limited direct economic impact on malaria control (Adeola, 2018; Odipo et al., 2024). Government expenditure (GX) and GDP show negligible contributions of 0.1% and 0.8%, respectively, suggesting that while financial resources and economic growth are important, their direct impact on malaria incidence is relatively small compared to the influence of broadband access (WHO, 2017). Population size contributes 5.7% to the variance, indicating that larger populations slightly exacerbate malaria challenges (Källander et al., 2013). These findings highlight the economic importance of prioritizing digital infrastructure investments to improve malaria control in SSA, while also recognizing that economic growth and government spending have a more limited role (Labrique et al., 2013).

Conversely, tuberculosis incidence (TUB) reveals that fixed broadband subscriptions (FTS and FTS1) are the most influential factors, accounting for 58.8% and 13.0% of the variance, respectively. This underscores the significant economic impact of broadband infrastructure on tuberculosis control, as improved digital access can enhance health communication and

services (Asongu & Odhiambo, 2022). Fixed broadband subscriptions per 100 people contribute 1.7% to the variance, reflecting a positive but smaller influence. In contrast, ICT expenditure (ICTE) and ICT infrastructure (ICTI) have a modest impact, with contributions of 3.1% and 5.6%, respectively, suggesting that while important, their direct economic impact is less pronounced (GSMA, 2020; Adeola, 2018). Government expenditure (GX) and GDP show minor contributions of 2.4% and 0.5%, respectively, indicating that while economic factors and financial resources are relevant, their direct effect on tuberculosis incidence is limited compared to the role of digital infrastructure (Odipo et al., 2024; WHO, 2017). Population size contributes 6.4% to the variance, highlighting the challenges of managing tuberculosis in larger populations (Källander et al., 2013). These results emphasize the critical role of digital infrastructure investments in tuberculosis control and suggest that while economic growth and government spending are factors, their direct influence is relatively less significant compared to the impact of broadband access (Labrique et al., 2013).

**Table 5. Variance decomposition**

Period	MAL	FTS1	FTS	ICTE	ICTI	FBS1	FBS	GDP	POP	GX	TUB	FTS1	FTS	ICTE	ICTI	FBS1	FBS	GDP	POP	GX	
1	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.711	0.007	0.209	0.009	0.007	0.002	0.019	0.002	0.032	0.001	0.840	0.000	0.043	0.011	0.015	0.003	0.063	0.002	0.008	0.016	
3	0.518	0.022	0.369	0.007	0.013	0.004	0.010	0.003	0.052	0.001	0.700	0.004	0.111	0.022	0.034	0.009	0.072	0.003	0.017	0.028	
4	0.404	0.040	0.461	0.003	0.016	0.005	0.005	0.003	0.061	0.001	0.564	0.014	0.204	0.029	0.050	0.017	0.056	0.003	0.028	0.034	
5	0.334	0.057	0.507	0.001	0.018	0.005	0.009	0.004	0.063	0.001	0.428	0.031	0.308	0.034	0.061	0.023	0.036	0.002	0.040	0.037	
6	0.290	0.073	0.528	0.001	0.019	0.004	0.017	0.005	0.063	0.001	0.306	0.053	0.406	0.036	0.066	0.025	0.022	0.001	0.050	0.036	
7	0.261	0.086	0.536	0.001	0.019	0.004	0.025	0.006	0.061	0.001	0.208	0.075	0.484	0.036	0.066	0.025	0.016	0.001	0.057	0.033	
8	0.241	0.098	0.538	0.002	0.018	0.003	0.033	0.006	0.060	0.001	0.136	0.096	0.538	0.034	0.063	0.023	0.017	0.002	0.061	0.030	
9	0.226	0.107	0.537	0.002	0.018	0.003	0.039	0.007	0.058	0.001	0.086	0.115	0.571	0.033	0.060	0.020	0.023	0.003	0.064	0.027	
10	0.215	0.115	0.536	0.003	0.018	0.003	0.045	0.008	0.057	0.001	0.054	0.130	0.588	0.031	0.056	0.017	0.031	0.005	0.064	0.024	

Note: FEVD standard errors and confidence intervals based on 200 Monte Carlo simulations. To conserve space, we report the results of the variance decomposition based on the tenth period. The full sample results, encompassing all periods of analysis, will be made available upon request.

#### 4.6 Granger causality tests

The Granger causality tests results in Table 6 provide insights into the causal relationships between economic, technological, and health-related indicators in SSA. The tests reveal that malaria incidence Granger causes tuberculosis incidence (0.002), indicating that changes in malaria trends can predict tuberculosis outcomes. This finding aligns with studies that highlight the interconnected nature of health indicators and the cascading effects of one disease on another (Adeola, 2018). Fixed telephone subscriptions (FTS1) (0.008) and ICT expenditure (0.026) also Granger cause malaria incidence, suggesting that advancements in telephone communication and ICT investments can predict and potentially reduce malaria cases. This supports the literature that emphasizes the role of telephone communication and ICT in improving health outcomes (Labrique et al., 2013; Källander et al., 2013).

Additionally, population changes Granger cause malaria incidence (0.027), and malaria incidence also Granger causes changes in population (0.000), showing a bidirectional relationship. These results resonate with findings that indicate how demographic changes impact health conditions and vice versa (Källander et al., 2013).

For tuberculosis, ICT expenditure (0.019) and ICT goods imports (0.031) Granger cause tuberculosis incidence, highlighting the role of ICT investments in predicting tuberculosis outcomes. This finding is in line with the emphasis on the significance of ICT in healthcare management and disease control (GSMA, 2020; Asongu & Odhiambo, 2022). Financial banking services, both lagged (0.010) and current (0.0046), also Granger cause tuberculosis incidence, indicating that financial developments can influence tuberculosis trends. This supports the existing literature on the impact of financial resources on health outcomes (Adeola, 2018; Odipo et al., 2024).

Population changes Granger cause tuberculosis incidence (0.0139), and tuberculosis incidence also Granger causes population changes (0.032), demonstrating another bidirectional relationship. These dynamics are consistent with the literature highlighting the interactions between population dynamics and disease prevalence (Källander et al., 2013).

Furthermore, malaria incidence Granger causes GDP per capita (0.046) and government expenditure (0.0089), suggesting that malaria trends can predict economic outcomes. This finding aligns with studies that underscore the economic impact of health conditions and the importance of addressing health issues for economic growth (Labrique et al., 2013; WHO, 2017).

These findings underscore the importance of coordinated policy efforts in SSA, where advancements in telephone communication, ICT use, and financial services can significantly impact health outcomes. Integrated strategies that enhance economic growth and technological development can help reduce the prevalence of malaria and tuberculosis, ultimately improving the quality of life and achieving sustainable development goals in the region (GSMA, 2020; Källander et al., 2013; WHO, 2017).

**Table 6. Granger causality tests results**

Null hypothesis	Obs	F-Statistic	Prob.	Decision
TUB does not Granger Cause MAL	690	1.001	0.368	Fail to reject null hypothesis
MAL does not Granger Cause TUB		6.022**	0.002	Reject null hypothesis
FTS1 does not Granger Cause MAL	690	4.749**	0.008	Reject null hypothesis
MAL does not Granger Cause FTS1		0.853	0.426	Fail to reject null hypothesis
FTS does not Granger Cause MAL	690	1.356	0.258	Fail to reject null hypothesis
MAL does not Granger Cause FTS		1.134	0.322	Fail to reject null hypothesis
ICTE does not Granger Cause MAL	690	3.651*	0.026	Reject null hypothesis
MAL does not Granger Cause ICTE		0.464	0.628	Fail to reject null hypothesis
ICTI does not Granger Cause MAL	690	2.465*	0.085	Reject null hypothesis
MAL does not Granger Cause ICTI		1.269	0.281	Fail to reject null hypothesis
FBS1 does not Granger Cause MAL	690	0.762	0.466	Fail to reject null hypothesis
MAL does not Granger Cause FBS1		5.932**	0.002	Reject null hypothesis
FBS does not Granger Cause MAL	690	0.125	0.883	Fail to reject null hypothesis
MAL does not Granger Cause FBS		0.843	0.431	Fail to reject null hypothesis
GDP does not Granger Cause MAL	690	1.024	0.359	Fail to reject null hypothesis
MAL does not Granger Cause GDP		3.078*	0.046	Reject null hypothesis
GX does not Granger Cause MAL	690	0.811	0.445	Fail to reject null hypothesis
MAL does not Granger Cause GX		4.758**	0.009	Reject null hypothesis
POP does not Granger Cause MAL	690	3.629*	0.027	Reject null hypothesis
MAL does not Granger Cause POP		10.888	2.E-05	Fail to reject null hypothesis
FTS1 does not Granger Cause TUB	690	1.717	0.180	Fail to reject null hypothesis
TUB does not Granger Cause FTS1		0.507	0.602	Fail to reject null hypothesis
FTS does not Granger Cause TUB	690	2.252	0.106	Fail to reject null hypothesis
TUB does not Granger Cause FTS		0.515	0.597	Fail to reject null hypothesis
ICTE does not Granger Cause TUB	690	3.951*	0.019	Reject null hypothesis
TUB does not Granger Cause ICTE		1.426	0.241	Fail to reject null hypothesis
ICTI does not Granger Cause TUB	690	3.461*	0.031	Reject null hypothesis
TUB does not Granger Cause ICTI		0.092	0.913	Fail to reject null hypothesis
FBS1 does not Granger Cause TUB	690	4.584*	0.011	Reject null hypothesis
TUB does not Granger Cause FBS1		2.078	0.126	Fail to reject null hypothesis
FBS does not Granger Cause TUB	690	5.425**	0.005	Reject null hypothesis
TUB does not Granger Cause FBS		1.719	0.179	Fail to reject null hypothesis
GDP does not Granger Cause TUB	690	0.394	0.674	Fail to reject null hypothesis
TUB does not Granger Cause GDP		0.692	0.500	Fail to reject null hypothesis
GX does not Granger Cause TUB	690	1.15366	0.316	Fail to reject null hypothesis

TUB does not Granger Cause GX		0.044	0.956	Fail to reject null hypothesis
POP does not Granger Cause TUB	690	4.303	0.013	Reject null hypothesis
TUB does not Granger Cause POP		3.476	0.031	Reject null hypothesis

#### 4.7 Robustness test

Table 7 report the impact of telephone communication, ICT use, and digital infrastructure on healthcare performance indicators such as malaria and tuberculosis incidence in SSA. For malaria, the significant negative impact of fixed telephone subscriptions per 100 people (FTS1) at lower incidence levels aligns with studies by Källander et al. (2013) and Labrique et al. (2013), which highlight the role of telephone communication in enhancing health communication and reducing disease prevalence in resource-constrained settings. However, the diminishing benefits at higher incidence levels, as shown by the positive impact at the 95th percentile, suggest that while telephone communication is effective in initial stages, its efficacy might decrease in areas with very high disease prevalence, indicating a need for more comprehensive interventions.

In tuberculosis, the initial strong negative impact of FTS1 at the 25th and 50th percentiles, followed by a weakened effect at higher incidence levels, is consistent with findings by Asongu and Odhiambo (2022) and Odipo et al. (2024), which emphasize the role of ICT in improving healthcare delivery and disease management but also highlight the challenges in sustaining its impact in high-burden areas.

The positive effect of fixed telephone subscriptions (FTS) on malaria at lower percentiles, turning negative at the 95th percentile, and the similar pattern observed for tuberculosis, align with the studies by Adeola (2018) and GSMA (2020). These studies note that initial improvements in telecommunications infrastructure can lead to better health outcomes, but the relationship may change as disease prevalence and infrastructure development progress.

The consistent reduction in malaria incidence due to ICT goods' exports across all percentiles supports the work of Labrique et al. (2013) and GSMA (2020), which document the benefits of ICT in healthcare through improved access to health technologies. For tuberculosis, the minimal impact of ICT goods exports aligns with findings by Källander et al. (2013), indicating that while ICT is beneficial, its direct influence on tuberculosis is limited and other factors might play a more significant role. The negative effect of ICT goods imports on malaria incidence, as well as the modest negative impact on tuberculosis, corroborates the findings by Asongu and Odhiambo (2022), which highlight the importance of technological imports in supporting health improvements but also indicate that their direct impact may vary based on the disease.

Fixed broadband subscriptions showing significant negative effects on both malaria and tuberculosis incidence across all percentiles align with the studies by Källander et al. (2013) and GSMA (2020). These studies emphasize the critical role of digital infrastructure in enhancing health communication and service delivery, leading to improved disease management.

The positive relationship between GDP and malaria incidence aligns with the findings by Adeola (2018), suggesting that economic growth may correlate with higher malaria rates due to increased economic activities and associated environmental changes. Similarly, the positive effect of GDP on tuberculosis incidence is supported by Odipo et al. (2024), which indicate that wealthier regions may experience higher tuberculosis rates due to better detection and reporting mechanisms.

The varying impact of population size on malaria and tuberculosis incidence supports the findings by Labrique et al. (2013) and Adeola (2018), which highlight the complexities of demographic changes in influencing disease prevalence. The negative impact at lower percentiles and positive impact at higher percentiles for malaria suggest that population growth initially aids in better disease control but becomes a challenge in densely populated areas. For tuberculosis, the significantly negative effect at lower percentiles aligns with studies indicating that less populated areas may benefit more from targeted interventions.

Government expenditure consistently reducing malaria rates and its mixed impact on tuberculosis incidence support the findings by WHO (2017) and Adeola (2018). These studies emphasize the role of government spending in improving health outcomes but also note that increased spending may lead to better detection and reporting of diseases like tuberculosis, thus showing a positive correlation.

**Table 7. Logistic quantile regression**

Var	Incidence of malaria				Incidence of tuberculosis			
	q25	q50	q75	q95	q25	q50	q75	q95
FTS1	-8.170 (9.853)	-1.233 (3.661)	2.044 (2.881)	13.570** (7.355)	-28.501** (10.058)	-20.047** (6.115)	-9.478** (3.912)	3.110 (2.988)
FTS	7.606 (9.867)	0.853 (3.695)	-2.246 (2.950)	-14.162** (7.414)	29.051** (10.067)	20.432** (6.154)	9.898** (3.967)	-2.154 (3.025)
ICTE	-0.667*** (0.100)	-0.765*** (0.098)	-0.777*** (0.081)	-0.487** (0.181)	-0.015 (0.121)	-0.023 (0.207)	-0.013 (0.129)	-0.029 (0.169)
ICTI	-0.260** (0.137)	-0.442*** (0.108)	-0.499*** (0.135)	-0.794** (0.254)	-0.195** (0.105)	-0.254** (0.130)	-0.149** (0.089)	-0.005 (0.128)
FBS1	-1.286*** (0.366)	-0.863 (0.685)	-1.729** (0.502)	-1.142** (0.640)	-0.927** (0.446)	-0.567 (0.799)	-0.981** (0.425)	-2.022** (1.225)

FBS	1.088** (0.348)	0.722 (0.680)	1.634** (0.493)	1.073** (0.634)	0.551 (0.423)	0.276 (0.804)	0.803** (0.424)	1.908 (1.215)
GDP	0.901** (0.338)	0.747*** (0.192)	0.794*** (0.152)	0.505 (0.488)	1.789*** (0.165)	1.716*** (0.454)	1.471*** (0.247)	0.798** (0.463)
POP	-9.503 (9.901)	-2.359 (3.461)	0.066 (2.964)	12.627** (7.410)	-30.468** (10.028)	-21.768*** (5.931)	-11.635** (3.950)	-0.690 (2.404)
GX	-1.249*** (0.231)	-1.543*** (0.229)	-2.217*** (0.325)	-2.113** (0.478)	0.986*** (0.238)	0.249 (0.295)	0.745** (0.309)	0.615** (0.346)
Consta nt	16.864 (19.709)	5.215 (6.677)	0.117 (5.585)	-21.859 (14.845)	45.220** (20.079)	31.094** (11.829)	12.705 (7.868)	-1.407 (5.581)

Note:

- Significance Levels: \*\*p < 0.05, \*\*\*p < 0.01
- Standard Errors are in parentheses

Figures 2a-d support the robustness test in Table 7. The plots provide valuable insights into the relationship between malaria incidence, telephone communication, ICT use, and digital infrastructure in SSA. The first plot shows that an increase in fixed telephone subscriptions per 100 people (FTS1) and total fixed telephone subscriptions (FTS) is associated with a significant decrease in malaria incidence. Specifically, the plot indicates that as FTS1 increases from -2 to 1 and FTS rises from 3 to 7, malaria incidence (Mal) decreases from 2 to -2. This suggests that enhancing telecommunication infrastructure can improve healthcare outcomes by facilitating better health information dissemination and access to healthcare services (GSMA, 2020). The second plot illustrates that higher ICT goods' exports (ICTE) and ICT goods' imports (ICTI) correlate with reduced malaria rates. The plot shows that as ICTE and ICTI increase from -1 to 2, malaria incidence (Mal) decreases from 2 to -2. This indicates that increased ICT use supports improved health outcomes by enhancing access to health technologies and communication tools essential for effective malaria control (Asongu & Le Roux, 2017; GSMA, 2020). The third plot highlights the critical role of digital infrastructure, showing that higher fixed broadband subscriptions per 100 people (FBS1) and total fixed broadband subscriptions (FBS) are linked to a substantial reduction in malaria incidence. The plot demonstrates that as FBS1 increases from -3 to 0 and FBS rises from 2 to 7, malaria incidence (Mal) decreases from 2 to -2. This underscores the importance of digitalization in public health strategies, as better broadband access enables more effective health communication and service delivery (Labrique et al., 2013; DeRenzi et al., 2012).

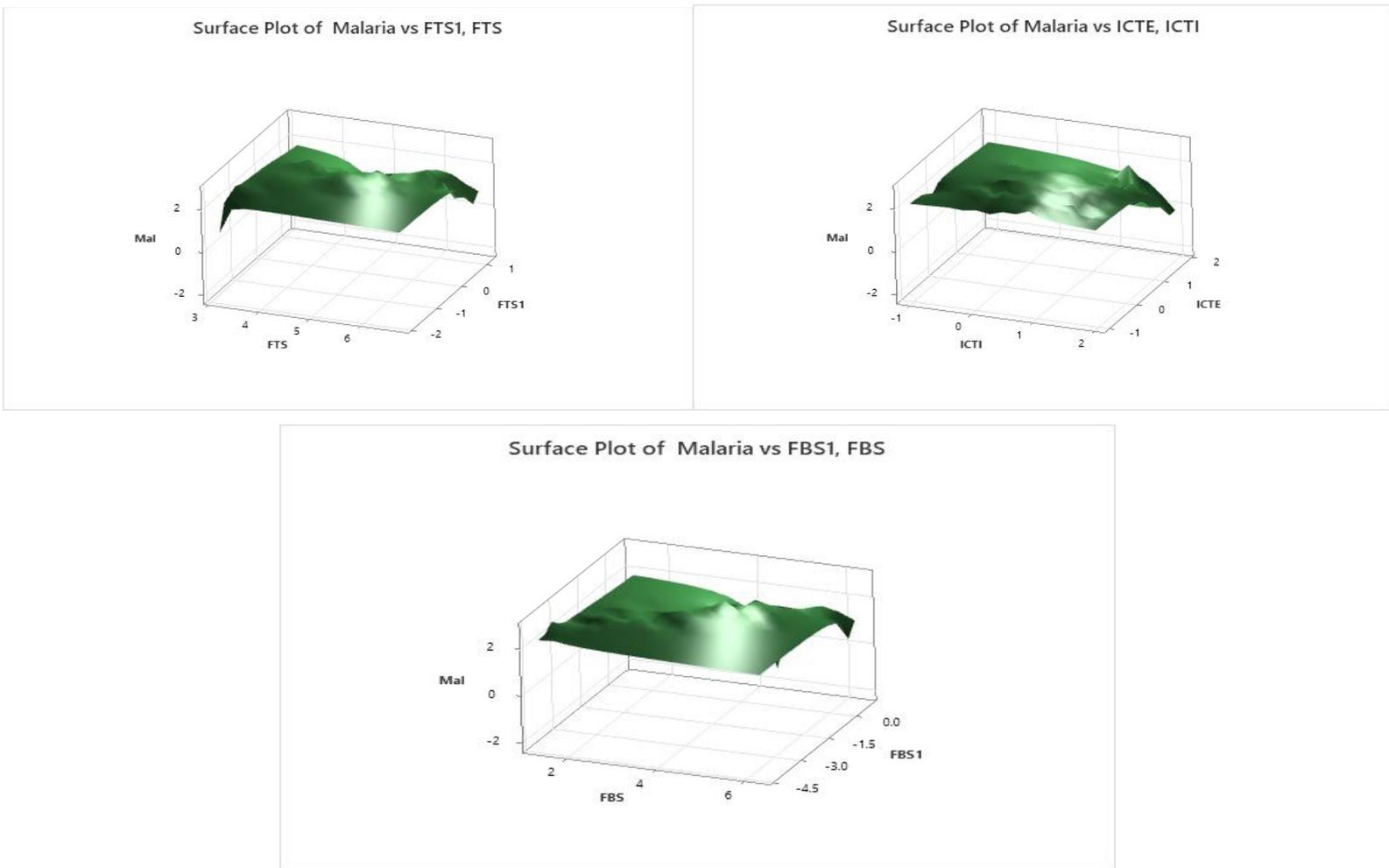


Figure 2a: Plots of Malaria Incidence vs. telephone communication, ICT use, and digital infrastructure in SSA

Figure 2b show the relationship between tuberculosis incidence, telephone communication, ICT use, and digital infrastructure in SSA. The plot of tuberculosis versus fixed telephone subscriptions per 100 people (FTS1) and total fixed telephone subscriptions (FTS) shows that as FTS1 increases from -2 to 1 and FTS rises from 3 to 7, tuberculosis incidence generally decreases, indicating that improvements in telecommunication infrastructure are associated with lower tuberculosis rates (GSMA, 2020). Similarly, the plot of tuberculosis versus ICT goods exports (ICTE) and ICT goods imports (ICTI) reveals that as ICTE and ICTI increase from -1 to 2, tuberculosis incidence declines from 3.0 to 1.5, suggesting that enhanced ICT infrastructure and trade contribute to better tuberculosis control (Asongu & Le Roux, 2017). Finally, the plot of tuberculosis versus fixed broadband subscriptions per 100 people (FBS1) and total fixed broadband subscriptions (FBS) demonstrates that as FBS1 increases from -3 to 0 and FBS rises from 2 to 7, tuberculosis incidence decreases from 3.0 to 1.5, highlighting the role of improved broadband access in enhancing tuberculosis management (Asongu & Odhiambo, 2022). These findings underscore the importance of investing in digital infrastructure to support healthcare improvements in SSA, showing that advancements in telephone communication, ICT use, and broadband infrastructure significantly reduce tuberculosis incidence and support better health management and disease prevention strategies in the region (Labrique et al., 2013; DeRenzi et al., 2012).

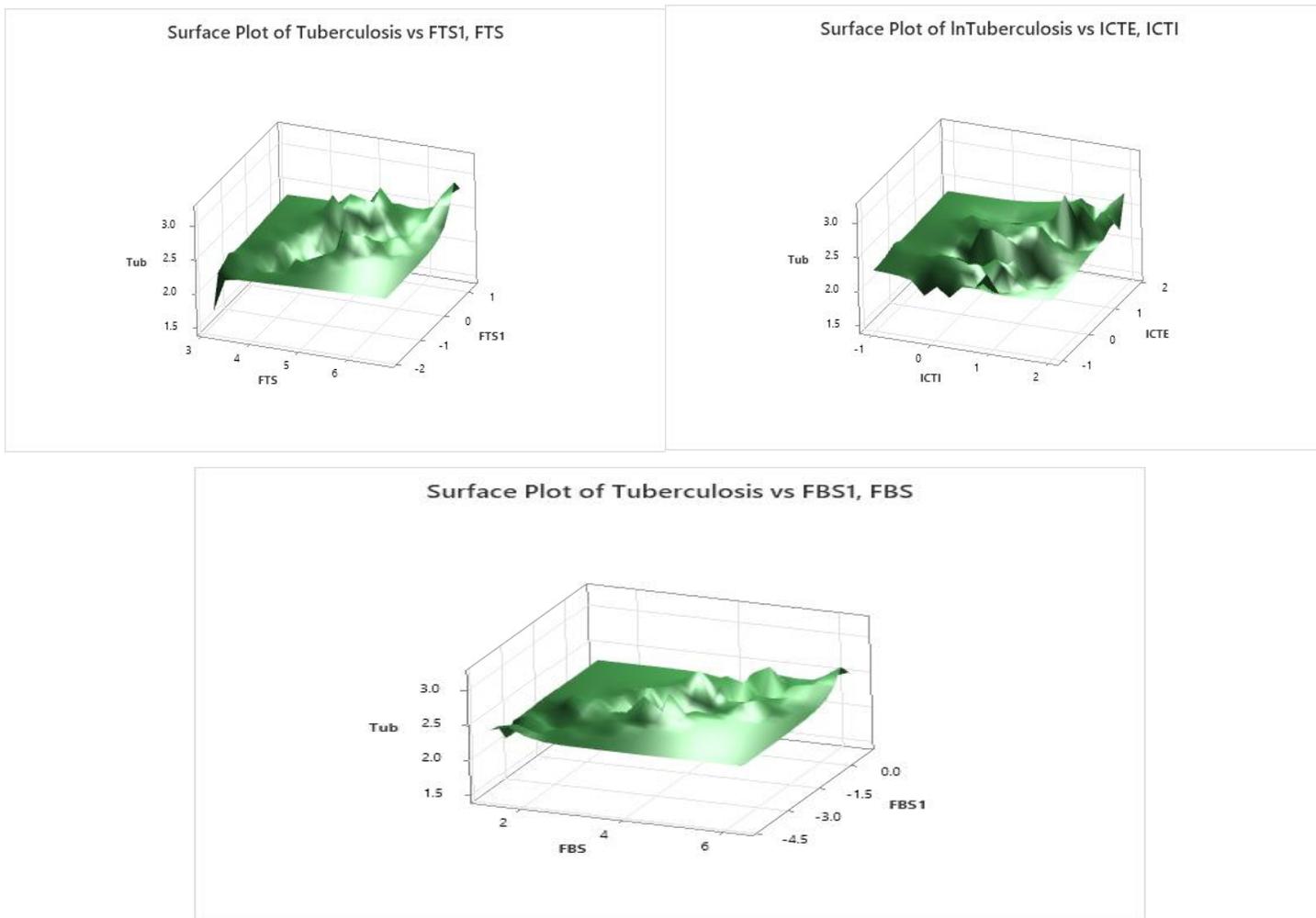
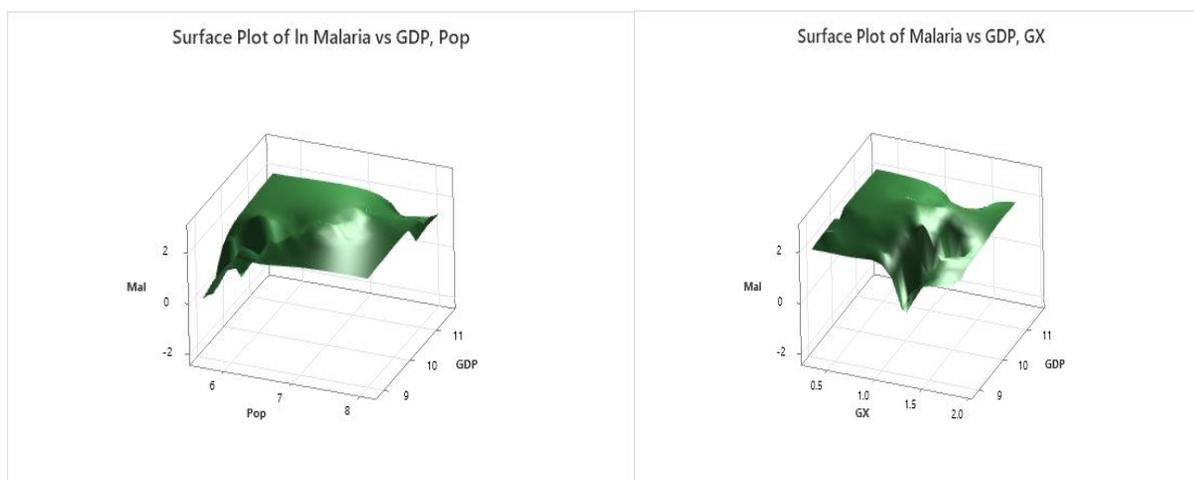
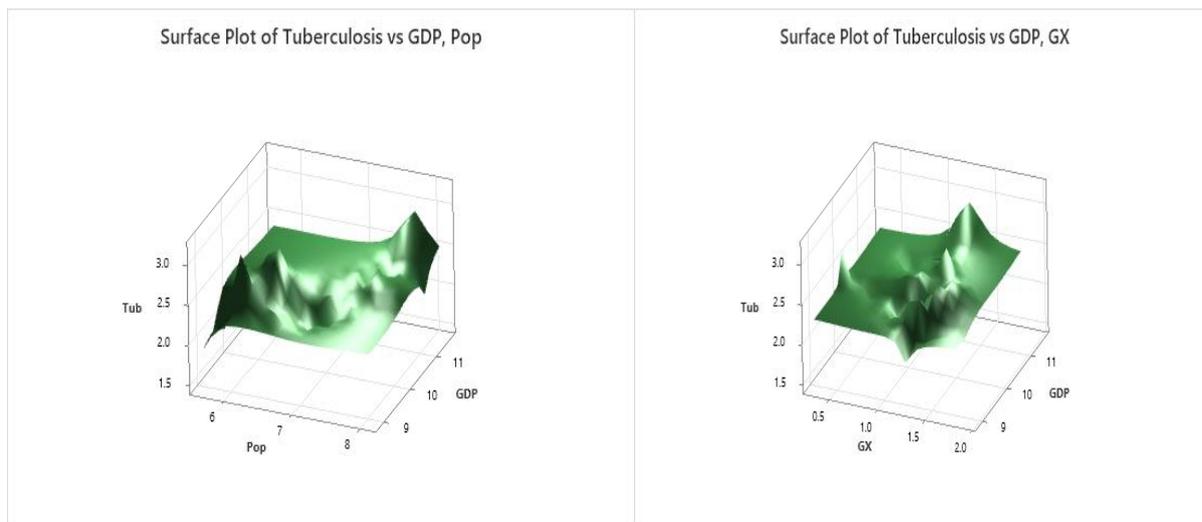


Figure 2b: Plots of Tuberculosis Incidence vs. telephone communication, ICT use, and digital infrastructure in SSA



**Figure 2c: Plots of Malaria Incidence vs. GDP, Population and Government Final Expenditure in SSA**

Figure 2c shows the relationships between malaria incidence and various economic and demographic indicators in SSA. The first plot shows the interaction between malaria incidence, GDP per capita, and population size. As GDP increases from 6 to 11 and the population size rises from 7 to 9, malaria incidence generally decreases from 2 to -2. This suggests that higher economic growth and larger population sizes, possibly due to better resource allocation and improved healthcare services, are associated with lower malaria rates. These findings are consistent with the literature, which highlights that economic development can lead to improved healthcare infrastructure and access to medical services, thereby reducing the burden of diseases such as malaria (Odipo et al., 2024). The second plot examines the relationship between malaria incidence, GDP per capita, and government final expenditure. It demonstrates that as government expenditure increases from 10 to 20 and GDP rises from 9 to 11, malaria incidence decreases from 2 to -2. This indicates that increased government spending on healthcare and economic growth play crucial roles in reducing malaria incidence. The figure emphasizes the importance of sustained economic development and strong government expenditure in combating malaria in SSA. These observations align with the literature, which stresses that government investments in healthcare are critical for effective disease management and control, especially in resource-limited settings (Labrique et al., 2013). Government expenditure on healthcare improves infrastructure, enables better delivery of health services, and supports public health interventions essential for reducing malaria incidence (GSMA, 2020).



**Figure 2d: Plots of Tuberculosis Incidence vs. GDP, Population and Government Final Expenditure in SSA**

The first plot shows the relationship between tuberculosis incidence, GDP per capita, and population size. As GDP increases from 6 to 11 and the population size rises from 7 to 9, tuberculosis incidence appears to fluctuate but generally decreases from around 3.0 to 1.5. This indicates that economic growth and demographic changes, possibly due to improved healthcare access and better living conditions, can help reduce tuberculosis rates. These findings are supported by the broader literature, which emphasizes the impact of economic development on health outcomes (Asongu & Le Roux, 2017). Improved economic conditions typically lead to better access to healthcare services, healthier living environments, and greater resources for disease prevention and treatment, contributing to lower tuberculosis rates. The second plot examines the interaction between tuberculosis incidence, GDP per capita, and government final expenditure. The figure shows that as government expenditure increases from 10 to 20 and GDP rises from 9 to 11, tuberculosis incidence decreases from about 3.0 to 1.5. This highlights the significant role of government spending on healthcare and economic growth in controlling and reducing tuberculosis incidence. These findings align with the literature, which underscores the importance of robust economic support and government interventions in managing public health challenges, especially in regions with limited resources like SSA (Bloom et al., 2004). Government expenditure on healthcare can enhance healthcare infrastructure, increase access to medical services, and improve public health campaigns, all of which are crucial for controlling diseases such as tuberculosis (DeRenzi et al., 2012).

## **5. Conclusion and policy recommendations**

This study utilized a comprehensive approach, including PVAR GMM-style estimation, impulse response function (IRF) analysis, variance decomposition, and Granger causality methodologies. It covered data from 30 countries from 1998 to 2022 to investigate the relationship between telephone communication, ICT metrics, digitalization, and healthcare performance in SSA. The empirical results substantiate our hypotheses across various dimensions. First, the findings confirm that telephone communication advancements, represented by fixed telephone subscriptions, significantly bolster economic growth, government expenditure, and population growth, aligning with our hypothesis that improved telephone communication infrastructure supports broader socio-economic and healthcare outcomes. Second, the finding supports the hypothesis that ICT metrics, such as ICT goods exports and imports, positively influence health performance, with increased ICT engagement correlating with reduced malaria incidence. However, the effect on tuberculosis is less consistent, indicating a need for further exploration. Lastly, the study affirms that digitalization, exemplified by fixed broadband subscriptions, has a substantial impact on health performance, particularly in reducing both malaria and tuberculosis incidences. These findings underscore the critical role of technological advancements in enhancing healthcare systems and achieving economic and health improvements in the region. Policymakers are encouraged to prioritize investments in telecommunications and digital infrastructure to drive comprehensive progress across economic, social, and health domains.

### **5.1 Theoretical implications**

The study highlights the profound theoretical implications of digital infrastructure on health outcomes, reinforcing the Health Belief Model (HBM), by demonstrating that advancements in digital infrastructure, such as fixed broadband subscriptions and fixed telephone services, significantly impact disease management. This supports the Technology Acceptance Model (TAM), by emphasizing how improved communication channels can enhance health education and service delivery, leading to better disease control. Additionally, the study's findings on economic growth suggest a refined relationship with health outcomes, where its direct impact is overshadowed by the effects of digital infrastructure and healthcare resources, aligning with developmental health economics. The results underscore the importance of robust infrastructure for effective disease management, supporting the Diffusion of Innovations theory. Furthermore, the differential impact of population size on malaria and tuberculosis incidence reflects demographic transition and epidemiological transition theories, highlighting the need for disease-specific strategies. Policy implications advocate for integrated health policies that prioritize digital infrastructure investments while

addressing economic and resource allocation considerations, and for targeted interventions tailored to the unique needs of each disease.

In summary, findings confirm the HBM model because users adopt telephone communication, ICT use, and digitalization frameworks in view of the perceived benefits in health services. The findings are also consistent with TAM because prior to accepting a given ICT platform, users are aware of anticipated rewards in terms of health performance; anticipations that are confirmed in these findings. The Diffusion of Innovations theory is also confirmed in this study because users enjoy benefits of ICT, especially in terms of how the diffusion of ICT is linked to better health services.

## **5.2 Practical implications**

The practical implications of the study emphasize the need for targeted investments in digital infrastructure to improve health outcomes, particularly in managing diseases like malaria and tuberculosis. Enhanced digital infrastructure, such as increased broadband subscriptions and fixed telephone services, is shown to significantly reduce malaria and tuberculosis rates by improving health communication and access to services. Policymakers should prioritize expanding digital infrastructure in healthcare strategies to facilitate better disease monitoring, education, and service delivery. Additionally, while economic growth and government expenditure are important, their impact is less direct compared to digital infrastructure. Therefore, practical strategies should include both increasing digital health investments and optimizing resource allocation to ensure effective disease management. Tailored interventions that address the specific needs of different diseases and demographic factors are crucial for maximizing health benefits.

## **5.3 Limitation and future research direction**

The study's limitations include potential biases in the data sources and the generalizability of the findings across diverse contexts within Sub-Saharan Africa. The reliance on aggregate indicators may obscure regional variations in disease dynamics and infrastructure development. Additionally, the impact of telephone communication and ICT use on health outcomes might be influenced by other confounding factors not fully accounted for in the analysis. Future research should aim to address these limitations by incorporating more granular and region-specific data, exploring the role of additional variables such as local healthcare access and socio-economic conditions, and conducting longitudinal studies to better understand the long-term effects of digital infrastructure on health outcomes. Moreover, investigating the interplay between different types of digital technologies and health interventions could provide deeper insights into optimizing strategies for disease prevention and control.

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## Appendices

**Table 1. Descriptive and multicollinearity test**

Variable	Obs	Mean	St d.			VIF	Tolerance
			dev.	Min	Max		
MAL	750	1.904	0.902	-2.142	2.851		
TUB	750	2.322	0.376	1.491	3.201	1.430	0.698
FTS1	750	0.004	0.544	-1.942	1.174	2.950	0.339
FTS	750	4.964	0.597	3.184	6.740	6.220	0.161
ICTE	750	0.349	0.791	-1.000	1.844	3.610	0.277
ICTI	750	1.015	0.553	-1.021	1.986	2.680	0.372
FBS1	750	-1.066	0.931	-4.333	0.760	2.700	0.370
FBS	750	3.926	1.004	1.322	6.290	3.590	0.279
GDP	750	10.077	0.545	8.861	11.557	11.940	0.084
POP	750	6.960	0.573	5.644	8.091	2.000	0.501
GX	750	1.140	0.190	0.311	1.793	1.260	0.796

**Table 2. cointegration test**

Johansen Fisher Panel Cointegration Test					Kao cointegration		
Hypothesized	Fisher Stat.*		Fisher Stat.*				
No. of CE(s)	(from trace test)	Prob.	(from max-eigen test)	Prob.		t-	Prob.
None	1808.***	0.000	1142.***	0.000	ADF	-2.184	0.015
					Residual	0.052	
At most 1	1332.***	0.000	667.5***	0.000	variance		
At most 2	798.8***	0.000	401.1***	0.000	HAC variance	0.021	
At most 3	479.2***	0.000	255.8***	0.000			
At most 4	296.3***	0.000	189.0***	0.000			
At most 5	178.6***	0.000	151.7***	0.000			
At most 6	97.90***	0.001	97.90***	0.002			
Pedroni Residual Cointegration Test							
	Statistic	Prob.	Statistic	Prob.			
Panel v-Statistic	-3.479	0.999	-2.271	0.988			
Panel rho-Statistic	3.527	0.999	3.735	0.999			

Panel PP-				
Statistic	-7.259***	0.000	-3.226***	0.000
Panel ADF-				
Statistic	-2.791**	0.003	0.091	0.536
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-				
Statistic	5.714	1.000		
Group PP-				
Statistic	-4.636***	0.000		
Group ADF-				
Statistic	1.796	0.963		

Notes: Significance Levels: \*\*p < 0.05, \*\*\*p < 0.01

**Table 3: Individual cross section results by countries**

Individual cross section results				
Cross Sections	Trace Test		Max-Eign Test	
	Statistics	Prob.**	Statistics	Prob.**
Angola	257.2587	0.0000	77.0600	0.0000
Benin	230.3624	0.0000	91.3392	0.0000
Botswana	279.7849	0.0000	130.9690	0.0000
Burkina Faso	233.8428	0.0000	100.4058	0.0000
Cabo Verde	289.0495	0.0000	122.0513	0.0000
Cameroon	242.3862	0.0000	86.4888	0.0000
Chad	260.8589	0.0000	102.5398	0.0000
Equatorial Guinea	284.7345	0.0000	85.4212	0.0000
Eritrea	270.3847	0.0000	104.4045	0.0000
Eswatini	329.1810	0.0000	147.9191	0.0000
Ethiopia	214.5595	0.0000	85.9128	0.0000
Gabon	416.9061	0.0000	170.9116	0.0000
Gambia, The	279.4107	0.0000	109.5775	0.0000
Ghana	212.3147	0.0000	74.9728	0.0000
Kenya	303.1355	0.0000	120.0119	0.0000
Liberia	228.2062	0.0000	89.8619	0.0000

Madagascar	272.9466	0.0000	115.1436	0.0000
Mali	230.6304	0.0000	104.2394	0.0000
Mauritania	201.9890	0.0000	70.7457	0.0000
Namibia	322.1520	0.0000	115.5296	0.0000
Niger	329.5478	0.0000	133.5790	0.0000
Rwanda	249.8079	0.0000	94.5770	0.0000
Senegal	254.3626	0.0000	89.9100	0.0000
South Africa	242.7567	0.0000	71.8368	0.0000
Sudan	207.6657	0.0000	79.1169	0.0000
Tanzania	218.1057	0.0000	69.8897	0.0000
Togo	229.6468	0.0000	90.7944	0.0000
Uganda	228.7767	0.0000	73.7338	0.0000
Zambia	270.8784	0.0000	89.9481	0.0000
Zimbabwe	242.2337	0.0000	93.3460	0.0000

Note: List of countries