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**Broadband Penetration and Economic Growth in Sub-Saharan Africa: The Role  
of Institutional and Technological Complementarities**

Masters Thesis.

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**AI Declaration:**

**This thesis represents my own independent research and work. AI-assisted tools, including Claude AI, were used solely as supportive tools for code debugging, sentence refinement, brainstorming on structure and organization, and assistance with selected table designs. The intellectual content, analysis, interpretation of results, and conclusions are entirely my own.**

# Abstract

This thesis evaluates the impact of broadband penetration on economic growth in Sub-Saharan Africa based on a panel of 40 countries from 2006 to 2023. The study employs the two-step System Generalised Method of Moments (System GMM) estimator to address endogeneity, dynamic income persistence, and unobserved country-specific heterogeneity, with GDP per capita as the outcome variable. The key explanatory variable is fixed broadband subscriptions per 100 inhabitants, while government effectiveness, the E-Government Development Index, and FDI stock serve as institutional and technological conditioning variables, alongside standard macroeconomic controls. Findings, among others, reveal that (1) broadband penetration has a positive but statistically insignificant direct effect on economic growth, (2) none of the complementarity interaction terms between broadband and institutional or technological variables achieves conventional statistical significance, suggesting that the preconditions for broadband to function as a growth-enabling general-purpose technology are not yet operative across the region, (3) macroeconomic shocks, particularly the 2015 commodity downturn and the 2020 COVID-19 pandemic, remain the dominant short-run drivers of income variation in Sub-Saharan Africa, and (4) OLS robustness estimations confirm directional consistency while revealing upward bias attributable to endogeneity. The study recommends that concerted efforts be directed towards bundling broadband infrastructure investment with complementary interventions including governance reform, energy access expansion, e-government development, and demand-side measures such as digital literacy programmes and affordable connectivity initiatives, without which broadband deployment alone is unlikely to generate sustained economic returns across Sub-Saharan Africa.

**Keywords:** broadband penetration, economic growth, Sub-Saharan Africa, System GMM, institutional complementarities, e-government, FDI, general-purpose technology

# Contents

|                                          |    |
|------------------------------------------|----|
| 1 Introduction .....                     | 3  |
| 2. Literature Review .....               | 6  |
| 3. Data and Descriptive Statistics ..... | 14 |
| 4 Econometric Methodology .....          | 24 |
| 5. Results and Discussion .....          | 26 |
| 6. Concluding Remarks .....              | 36 |
| Summary of paper in Estonian .....       | 38 |
| References .....                         | 39 |
| Appendix .....                           | 43 |

# 1 Introduction

Digital connectivity has emerged as a cornerstone of contemporary economic development, reshaping production processes, market structures, and modes of social and economic interaction. Among digital technologies, broadband internet occupies a particularly central role as a general-purpose infrastructure that enables the diffusion of information, facilitates innovation, reduces transaction costs, and enhances productivity across virtually all sectors of the economy. In both advanced and developing economies, broadband connectivity has become a critical input into economic activity, underpinning digital entrepreneurship, e-commerce, financial inclusion, and the provision of public services. (World Bank, 2016; ITU, 2023) As a result, broadband expansion is increasingly viewed not merely as a technological upgrade, but as a strategic development investment with far-reaching economic implications.

Broadband is high-speed, always-on Internet access that is faster than traditional dial-up, utilizing wide-bandwidth data transmission via coaxial cable, fiber optics, wireless (radio), or satellite. It enables simultaneous, high-speed transmission of data, voice, and video over multiple frequencies. The International Telecommunication Union (ITU) also defined broadband as a high-speed, always-on, high-capacity transmission technology supporting data rates greater than 2 Mbit/s. It enables interactive, bandwidth-intensive services like video conferencing and high-speed internet across various fixed and mobile platforms.

A substantial body of empirical literature documents a positive association between broadband penetration and economic growth. Seminal contributions show that telecommunications and broadband infrastructure stimulate growth by improving firm-level efficiency, encouraging innovation, and supporting structural transformation (Roller & Waverman, 2001; Koutroumpis, 2009; Qiang et al., 2009; Czernich et al., 2011). More recent studies reinforce the view that broadband functions as a general-purpose technology whose effects extend beyond direct productivity gains to influence labour markets, human development, and institutional performance (Holt & Jamison, 2009; Mayer et al., 2019; Briglauer et al., 2020). However, the magnitude and persistence of these effects appear to vary considerably across countries and regions, suggesting that broadband alone may be insufficient to generate sustained economic growth without supportive complementary conditions.

Sub-Saharan Africa provides a particularly important and policy-relevant context in which to examine the broadband-growth relationship. Over the past two decades, the region has experienced a rapid expansion of digital infrastructure, driven by investments in submarine fibre-optic cables, national broadband backbones, and mobile broadband networks. These investments have significantly reduced connectivity costs and expanded internet access across many African economies (Juma & Moyer, 2008; O'Connor et al., 2021). At the same time, Sub-Saharan Africa continues to face persistent development challenges, including low productivity, limited industrial diversification, and wide disparities in income and welfare outcomes. The coexistence of expanding digital infrastructure and uneven economic performance raises a fundamental question regarding the extent to which broadband penetration contributes to economic growth in the region.

The existing empirical evidence on information and communication technologies (ICTs) and economic growth in Sub-Saharan Africa remains mixed. While several studies report positive effects of ICT adoption on growth and development outcomes (Donou-Adonsou et al., 2016; Haftu, 2019; Bahrini & Qaffas, 2019), others emphasise substantial heterogeneity across countries and highlight the presence of non-linear or threshold effects (Bah & Atyeh, 2020; Kouam & Asongu, 2023). Comparative analyses further suggest that the growth effects of digitalisation are significantly weaker and less consistent in Sub-Saharan Africa than in OECD economies, reflecting differences in institutional quality, digital readiness, and complementary human capital (Myovella et al., 2020; Bala, 2023). These findings underscore the importance of moving beyond average effects and examining the conditions under which broadband penetration translates into meaningful economic gains.

A growing strand of the literature argues that the economic impact of broadband is strongly conditioned by institutional and technological complementarities. Governance quality, regulatory effectiveness, innovation and knowledge diffusion (proxied by foreign direct investment stock), and the availability of digital public services influence how effectively broadband infrastructure is utilised within an economy (Asongu & Nwachukwu, 2018; Friederici et al., 2017; Tryphone et al., 2023). Foreign direct investment (FDI) stock, in particular, reflects the accumulated presence of multinational enterprises, which facilitates technology transfer, managerial expertise, and productivity-enhancing spillovers to domestic firms (Javorcik, 2004). Countries with stronger institutions and more advanced e-government systems are better positioned to leverage broadband for productivity enhancement, service delivery, and private-sector development. Conversely, weak governance, limited absorptive capacity, and affordability constraints may prevent broadband investments from yielding their full economic potential, leading to outcomes described as a “connectivity paradox” in parts of Africa.

Despite increasing recognition of these complementarities, empirical studies that explicitly model the interaction between broadband penetration and institutional or technological factors in Sub-Saharan Africa remain relatively scarce. Much of the existing literature relies on static panel models, focuses on single channels such as mobile telephony or internet usage, without adequately addressing endogeneity concerns or dynamic adjustment processes. Moreover, many cross-country studies pool developing and developed economies, potentially obscuring region-specific mechanisms that are particularly relevant for African countries. As a result, there remains limited consensus on whether broadband penetration independently drives economic growth in Sub-Saharan Africa, and under what institutional and digital environments its effects are strongest.

This thesis seeks to address these gaps by providing a systematic empirical analysis of the relationship between broadband penetration and economic growth in Sub-Saharan Africa over the period 2006–2023. The central research question guiding the study is:

RQ: Does broadband penetration significantly contribute to economic growth in Sub-Saharan Africa (SSA)<sup>1</sup>, and under what institutional and technological conditions are its effects strongest?

This question is decomposed into two empirical objectives: first, to estimate the direct effect of broadband penetration on GDP per capita across a 40-country SSA panel; and second, to examine

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<sup>1</sup> Sub-Saharan Africa (SSA) is the geographic region south of the Sahara Desert. Comprising roughly 49 to 53 countries, it is a highly diverse, culturally rich region with a population exceeding 1.2 billion people. It is known for its youthful population, extensive natural resources, and rapid economic growth.

whether this effect is conditioned by governance quality as measured by government effectiveness, digital public infrastructure as measured by the E-Government Development Index, and innovation capacity as proxied by FDI stock.

To address these objectives, the study employs the two-step System Generalised Method of Moments (System GMM) estimator of Blundell and Bond (1998), which simultaneously addresses endogeneity, dynamic income persistence, and unobserved country-specific heterogeneity, econometric challenges that are particularly acute in SSA growth regressions. A baseline model estimates the direct broadband-growth relationship, while a complementarity model introduces interaction terms between broadband penetration and each conditioning variable separately, following the approach of Asongu and Nwachukwu (2018). Together, these two models provide a comprehensive assessment of not only whether broadband contributes to economic growth in SSA, but also under what structural and institutional conditions its contribution is most meaningful.

This data limitation also informs sample selection, as uneven data availability across countries necessitates excluding those with substantial missing observations. While this may introduce potential sample selection bias, retaining such countries would compromise estimation reliability in a dynamic panel framework that requires sufficient time-series variation (Roodman, 2009). The final sample is therefore restricted to countries with adequate data coverage, consistent with established empirical practice in the region (Asongu & Nwachukwu, 2018; Haftu, 2019; Myovella et al., 2020).

The policy relevance of this study is substantial. Governments across Sub-Saharan Africa increasingly prioritise digital transformation as a central pillar of their development strategies, allocating significant public resources to broadband expansion, digital public services, and innovation ecosystems. Yet, without robust empirical evidence on the conditions under which broadband investments foster economic growth, such policies risk delivering limited or uneven returns. By identifying the institutional and technological environments that enhance the growth impact of broadband, this thesis aims to inform more effective digital policy design and contribute to evidence-based decision-making in the region.

The remainder of the thesis is structured as follows. Chapter 2 reviews the theoretical and empirical literature on broadband, digitalisation, and economic growth, with a focus on developing and African economies. Chapter 3 describes the data sources, variables, and descriptive statistics, including the rationale for the selected study period and country sample. Chapter 4 outlines the econometric methodology and model specification. Chapter 5 presents the empirical results and discusses the findings and their policy implications. The final chapter concludes and highlights avenues for future research.<sup>2</sup>

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<sup>2</sup> A key refinement of the empirical design concerns the study period and country coverage. The initial plan to analyse 2000–2023 is revised, as broadband penetration in Sub-Saharan Africa only becomes consistently observable after the mid-2000s, following the expansion of fibre-optic infrastructure (Andrés et al., 2010; Empower Africa, 2021). Empirical evidence similarly indicates that reliable broadband data for the region effectively begin around 2006 (Myovella et al., 2020). The analysis therefore focuses on 2006–2023, when broadband becomes both consistently measurable and economically meaningful.

## 2. Literature Review

### 2.1 Telecommunications Infrastructure as a Driver of Economic Growth

The relationship between telecommunications infrastructure and economic growth has long occupied a central position in the economics of development. Early foundational work establishes that investments in communication networks reduce transaction costs, improve market efficiency, and facilitate the integration of geographically dispersed economic agents into broader markets. Röller and Waverman (2001), in one of the most influential early empirical studies, jointly estimate a micromodel for telecommunications investment with a macroeconomic production function using data from 21 OECD countries over a 20-year period. Their results demonstrate a significant positive causal link between telecommunications infrastructure and economic output, with the caveat that this effect is strongest once a critical mass of infrastructure is achieved, approaching universal service coverage, defined as near-universal and affordable access to basic broadband services across a population. This finding introduces a threshold dimension to the infrastructure-growth relationship that has since become a recurring theme in the digital economics literature.

Subsequent research extends this perspective by focusing explicitly on broadband internet as a distinct and more advanced form of telecommunications infrastructure. Broadband differs from earlier communication technologies in terms of speed, capacity, and versatility, enabling real-time data transmission, digital service delivery, and complex information exchange at scale. Qiang, Rossotto, and Kimura (2009), in a World Bank cross-national study covering 120 developed and developing countries from 1980 to 2006, find that a 10 percentage point increase in broadband penetration is associated with a 1.21 percentage point increase in GDP growth in developed economies and an even larger 1.38 percentage point increase in developing economies, though the latter result achieves only marginal statistical significance. These findings frame broadband as a general-purpose technology whose aggregate productivity effects extend across sectors including finance, education, trade, and public administration (Bresnahan & Trajtenberg, 1995).

Koutroumpis (2009) employs a simultaneous equations approach to address endogeneity between broadband investment and growth for 15 European Union countries, confirming a significant positive impact and establishing that the size of the effect is conditioned by the existing level of broadband penetration a finding consistent with network externality theory. Czernich, Falck, Kretschmer, and Woessmann (2011) provide the most methodologically rigorous evidence for the OECD context, using a logistic diffusion model to instrument broadband penetration with pre-existing voice telephony and cable television infrastructure across 25 OECD countries from 1996 to 2007. Their instrumental variable estimates indicate that a 10 percentage point increase in broadband penetration raised annual per capita GDP growth by 0.9 to 1.5 percentage points a large, precisely estimated, and economically significant effect that has become the benchmark reference in the broadband-growth literature.

More recent reassessments confirm these findings while emphasising heterogeneity and non-linearity in outcomes. Mayer, Madden, and Wu (2020), employing a dynamic panel threshold model, find that broadband network penetration alone is statistically insignificant when speed and its interaction with penetration are controlled for, with speed positively impacting growth while the interaction term is negative. This suggests that increasing speed is more important for countries with lower penetration, and that the returns from ambitious broadband targets are neither immediate nor universally assured.

Koutroumpis (2019) extends his earlier work to the 2002–2016 OECD period and identifies consistent diminishing returns to broadband adoption, with a speed threshold beyond which further quality improvements become unproductive. These refinements motivate closer examination of the conditions particularly the institutional and technological environment under which broadband investments translate into sustained economic growth, and provide the theoretical foundation for the complementarity models estimated in the present study.

## **2.2 ICT, Digitalisation, and Growth in Developing Economies**

A parallel strand of the literature investigates the broader role of information and communication technologies (ICTs) in fostering economic development, particularly in low- and middle-income countries. Vu (2011), using data from 102 countries over the period 1996–2005, demonstrates that ICT capital has a positive and significant effect on economic growth, identifying three principal channels: fostering technology diffusion and innovation, enhancing the quality of decision-making by firms and households, and stimulating demand while reducing productivity costs. Holt and Jamison (2009) similarly emphasise that ICTs enhance productivity by facilitating knowledge diffusion, improving coordination, and supporting innovation-driven growth, but stress that the realisation of these benefits depends critically on complementary inputs including education and institutional quality.

Bahrini and Qaffas (2019), using a two-step panel GMM model for 45 developing countries in the MENA (Middle East and North Africa) and SSA regions over the period 2007–2016, find that mobile phones, internet usage, and broadband adoption are the main ICT drivers of economic growth, but that the institutional and macroeconomic environment including financial sector development, regulatory quality, trade openness, and inflation control conditions whether these effects materialise. Their finding that the superiority of MENA over SSA countries in internet and broadband adoption is associated with stronger ICT-growth linkages anticipates the comparative results of Myovella et al. (2020) discussed below. Ng, Lye, and Lim (2013), applying a GMM approach to ASEAN (Association of Southeast Asian Nations) countries, further confirms the positive broadband-growth relationship in developing economies, while noting significant cross-country heterogeneity that depends on the stage of digital development.

Theoretical explanations for these patterns are rooted in endogenous growth theory. In this framework, digital technologies enhance the accumulation of knowledge, human capital, and innovation, thereby influencing long-run growth trajectories beyond what neoclassical factor accumulation can explain (Romer, 1990; Aghion & Howitt, 1992). However, the extent to which these gains are realised depends critically on institutional quality, regulatory capacity, and the ability of firms and households to adopt and effectively use new technologies. These conditions vary considerably across developing economies and are often particularly constrained in Sub-Saharan Africa. In this context, foreign direct investment (FDI) stock serves as a key conduit for knowledge diffusion and technology transfer, particularly in developing economies where formal R&D activities are limited (Javorcik, 2004). FDI facilitates spillovers through backward and forward linkages, worker mobility, and demonstration effects, thereby potentially complementing digital infrastructure investments in ways that amplify their aggregate productivity effects.

### 2.3 Broadband and Economic Growth in Sub-Saharan Africa

Empirical research focusing specifically on Sub-Saharan Africa reveals a more complex, heterogeneous, and often weaker relationship between broadband, ICTs, and economic growth than that documented in OECD and other developing-country contexts. Haftu (2019), employing a robust two-step System GMM estimator on a panel of 40 SSA countries from 2006 to 2015, finds that mobile phone penetration has a positive and statistically significant effect on GDP per capita a 10% increase in mobile phone penetration raises GDP per capita by 1.2% but that internet penetration has an insignificant effect on economic growth. This striking divergence between mobile and fixed internet effects in SSA reflects the mobile-first nature of digital connectivity in the region, where fixed broadband infrastructure remains nascent and mobile phones constitute the primary channel of digital access for the majority of the population. Donou-Adonsou, Lim, and Mathey (2016), applying instrumental variable GMM to a panel of 47 SSA countries over 1993–2012, confirm that internet and mobile phones contribute positively to economic growth, with a one percentage point increase in internet usage raising growth by 0.12 percentage points, and highlight the importance of network expansion in reducing information asymmetries and supporting market integration.

Myovella, Karacuka, and Haucap (2020) provide the most directly comparable comparative evidence, studying 41 SSA and 33 OECD economies over 2006–2016 using GMM estimators. Their results show that while digitalisation has a positive contribution to economic growth in both groups, the effect of broadband internet is minimal for SSA compared to OECD countries. The authors attribute this disparity to differences in digital readiness, innovation systems, and institutional frameworks, as well as the dominant role of mobile telecommunications rather than fixed broadband in driving digital activity in SSA. This finding directly motivates the present study's focus on fixed broadband penetration and its institutional conditioning factors, and provides the benchmark against which the present results are interpreted.

At the same time, several studies report non-linear or conditional effects specific to the African context. Kouam and Asongu (2023), using panel smooth transition regression and GMM on data from 33 African countries over 2010–2020, establish a threshold in electricity access of approximately 60% of the population, below which each 1% increase in fixed broadband subscriptions is associated with a decline in economic growth of 2.58%, and above which growth increases by 2.43% per 1% increase in broadband. This finding is particularly important for SSA, where the majority of countries fall below this electricity threshold, and it suggests that broadband infrastructure investment without parallel investment in energy access may be counterproductive. Abdulqadir and Asongu (2022), studying internet access and growth in SSA, document asymmetric effects that depend on the level of internet access, with growth effects emerging primarily above certain adoption thresholds consistent with network externality theory (Koutroumpis, 2009; Röller & Waverman, 2001).

Odhiambo (2022), examining the dynamic relationship between ICT, income inequality, and economic growth in SSA countries from 2004 to 2014 using GMM, finds that ICT unconditionally increases economic growth but that the magnitude of the effect depends on income inequality thresholds. Countries with lower inequality are better positioned to translate ICT investments into aggregate growth outcomes, a finding that links digital development to broader distributional concerns. Bahrini and Qaffas (2019) similarly document that SSA countries consistently underperform MENA

counterparts in extracting growth dividends from broadband and internet adoption, attributing this to weaker financial sector development and institutional quality across SSA.

## **2.4 How Sub-Saharan Africa Differs from Other Developing Regions**

While the broader developing country literature documents positive broadband-growth relationships, Sub-Saharan Africa presents a distinctly more challenging environment than other developing regions, and the quantitative magnitude of broadband's economic effects varies sharply across regions in ways that directly contextualise the findings of this thesis.

In OECD economies, the broadband-growth relationship is large, precisely estimated, and robust to methodology. Czernich et al. (2011) find that a 10 percentage point increase in broadband penetration raises annual per capita GDP growth by 0.9 to 1.5 percentage points across 25 OECD countries, an effect that is both statistically significant and economically substantial. Koutroumpis (2009) similarly estimates that a 10 percentage point increase in broadband penetration raises GDP by approximately 0.25% in the short run and up to 1.3% over the longer run for European economies. These strong effects reflect the presence of well-developed complementary conditions in OECD economies: high human capital, deep financial markets, competitive telecommunications regulation, and advanced e-government systems that create absorptive capacity for broadband's productivity spillovers (Bresnahan & Trajtenberg, 1995).

In other developing regions, the effects are smaller than in OECD economies but still stronger than in SSA. Qiang, Rossotto, and Kimura (2009), in a World Bank cross-national study, find that a 10-percentage point increase in broadband penetration raises GDP growth by 1.38 percentage points in developing economies broadly larger than the OECD effect in their specification, but driven primarily by middle-income countries in East Asia and Latin America rather than by low-income SSA economies. Katz and Callorda (2013), studying 18 Latin American countries, find that a 10-percentage point increase in broadband penetration is associated with a 3.2% increase in GDP per capita, which they attribute to Latin America's more developed service sectors and higher baseline human capital relative to SSA. In the MENA region, Bahrini and Qaffas (2019), using a two-step GMM model for 45 developing countries in MENA and SSA over 2007–2016, find that broadband adoption is a significant driver of economic growth in MENA but not in SSA, and that MENA economies consistently outperform SSA in the magnitude of ICT-related growth dividends, a gap they attribute to MENA's stronger financial sector development, better regulatory quality, and greater trade openness, all of which create the complementary conditions that amplify broadband's growth effects.

By contrast, SSA-specific evidence consistently reports weaker and often insignificant broadband effects. Haftu (2019), using System GMM for 40 SSA countries over 2006–2015, finds that while mobile phone penetration raises GDP per capita by approximately 1.2% per 10% increase in penetration, internet penetration has no statistically significant effect on economic growth. Myovella et al. (2020), comparing 41 SSA and 33 OECD economies over 2006–2016, find that digitalisation raises economic growth by approximately 0.4 percentage points in OECD economies but by a statistically negligible amount in SSA, explicitly documenting that the broadband-growth effect is minimal for SSA compared to OECD counterparts. Donou-Adonsou et al. (2016), studying 47 SSA countries over 1993–2012, find that a one percentage point increase in internet usage raises growth by

only 0.12 percentage points, a fraction of the OECD effect, while mobile phone effects are even smaller at 0.03 percentage points.

The complementarity evidence further sharpens this regional distinction. In OECD and middle-income contexts, broadband's growth effects are amplified when institutional quality is high and e-government services are advanced, conditions that create demand for connectivity and productive uses for digital infrastructure (Koutroumpis, 2009; UN, 2022). In SSA, however, Kouam and Asongu (2023) establish that the growth effect of broadband is actually negative in countries where electricity access is below 60% of the population, a threshold that the majority of SSA countries fall below, implying that the complementary infrastructure conditions required for broadband to generate positive returns are absent in much of the region. Asongu and Odhiambo (2020) similarly find that ICT-FDI complementarities in SSA only become positive above specific ICT adoption thresholds that most SSA economies have not yet attained, in contrast to East Asian and Latin American economies where these thresholds are already exceeded.

Three structural features of SSA explain this divergence from all comparator developing regions. First, SSA's extreme infrastructure deficit, particularly in electricity access, road networks, and financial infrastructure, means that broadband cannot generate the productivity complementarities that it does in regions where these foundational conditions are already met (Kouam & Asongu, 2023). Second, the composition of SSA's economy, dominated by subsistence agriculture, informal services, and extractive industries, limits the sectors through which broadband can enhance productivity, unlike East Asia's manufacturing base or MENA's formal service economy. Third, SSA's governance environment, with a sample mean government effectiveness score of -0.675 in the present study, substantially weaker than in any comparator developing region, limits the institutional capacity to translate digital connectivity into productive economic activity (Kaufmann et al., 2010; Acemoglu et al., 2001). These three structural features collectively explain why SSA should be studied as a distinct empirical context, and why the quantitative broadband effects documented in other developing regions cannot be assumed to apply to SSA without rigorous empirical testing of the kind this thesis undertakes

## **2.5 Digital Infrastructure Expansion and Connectivity in Africa**

Beyond aggregate growth regressions, a growing literature examines the economic impacts of specific digital infrastructure investments and the structural conditions shaping broadband diffusion in Africa. The expansion of international submarine fibre-optic cables from the late 2000s onwards represents a pivotal development in SSA's digital trajectory. Andrés et al. (2010) document that the arrival of the SEACOM and EASSy cables in 2009 generated the first significant increases in broadband penetration across Eastern and Southern Africa, yielding an estimated 3 to 5 percentage point increase in internet penetration rates relative to unconnected countries. This infrastructure shock represents a structural break in SSA's broadband diffusion trajectory and provides a natural starting point for empirical analysis, consistent with the 2006 start of the present study's sample period.

Friederici, Ojanperä, and Graham (2017), in an influential critical assessment from the Oxford Internet Institute, caution against overly optimistic narratives of digital transformation in Africa. Contrasting policy discourse with the available empirical evidence, they find that the economic impact of internet

connectivity across SSA is highly uneven across geographies and social strata, and that grand visions of connectivity as a transformational driver of inclusive development are not yet supported by the evidence base. They identify technological determinism<sup>3</sup> and acontextual modernism as underlying these overly optimistic narratives, calling for more reflexivity in digital development policy. This critical perspective is directly relevant to the present study: rather than assuming that broadband infrastructure automatically generates growth, the analysis explicitly tests the conditions under which broadband effects are strongest.

The World Bank (2024) documents that over 160 million Africans gained broadband internet access between 2019 and 2022, and that connection affordability improved significantly, with costs decreasing from 11.5% of monthly GNI per capita in 2019 to 5.7% in 2021. Nevertheless, the Bank notes that 61% of SSA residents live within broadband range but do not use it, reflecting a persistent gap between infrastructure availability and utilisation that constrains the aggregate economic returns to broadband investment. The ITU (2023) similarly confirms that while mobile broadband penetration has grown rapidly, fixed broadband subscriptions the variable of interest in this study remain extremely low across SSA, with the majority of countries recording fewer than two subscriptions per 100 inhabitants throughout the study period.

## **2.6 Institutional Quality, Governance, and Digital Complementarities**

An increasingly influential strand of the literature emphasises the role of institutions and governance in shaping the economic returns to digital investments. The theoretical foundation lies in the new institutional economics (North, 1990; Acemoglu et al., 2001), which establishes that institutions determine the incentive structures within which technological adoption occurs. In the digital context, effective institutions reduce regulatory barriers to entry, ensure competitive telecommunications markets, protect property rights in the digital economy, and create the public service capacity needed to generate demand for digital connectivity.

Asongu and Nwachukwu (2018) provide direct empirical evidence for SSA, showing that institutional quality measured by governance indicators including rule of law and government effectiveness significantly moderates the relationship between ICT adoption and economic outcomes including entrepreneurship and inclusive development. Countries with stronger institutions are better positioned to translate digital connectivity into inclusive economic benefits through formal enterprise activity, financial inclusion, and productive innovation. Ofori and Asongu (2021), studying the synergy effects of ICT diffusion and FDI on inclusive growth across SSA from 1980 to 2019, find that the inclusive growth effect of FDI is enhanced in the presence of ICT access, skills, and usage, establishing the joint complementarity between digital infrastructure, foreign investment, and institutional quality.

E-government development represents a particularly important institutional complement to broadband infrastructure. Effective digital public services can enhance state capacity, reduce corruption, improve service delivery, and create demand for private broadband connectivity by generating practical use cases for internet access (Heeks, 2002). The UN E-Government Survey (2022) documents that SSA economies score substantially below the global mean on all three sub-components of the E-Government

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<sup>3</sup> Technological determinism: view that technology drives social and economic change. Acontextual modernism: assumption of universally applicable development processes with limited attention to context. Reflexivity: critical awareness of assumptions underlying analysis. Acontextual modernism is the assumption that development processes are universally applicable, with limited consideration of contextual differences. Reflexivity is the critical awareness of how assumptions and analytical choices shape interpretation and findings.

Development Index online service delivery, ICT infrastructure, and human capital confirming that the institutional basis for e-government complementarity with broadband is underdeveloped across the region. Kouladoun, Wirajing, and Nchofoung (2022), studying digital technologies and financial inclusion in SSA, establish that governance quality is a critical mediating factor in whether digital infrastructure generates economic inclusion benefits, reinforcing the argument that institutional preconditions must be met for broadband to function as a general-purpose technology.

Innovation and knowledge diffusion, proxied in the present study by FDI stock, further condition the economic returns to broadband. As Javorcik (2004) demonstrates, multinational enterprises generate productivity spillovers to domestic firms through backward linkages, labour mobility, and demonstration effects that can enhance the absorptive capacity of host economies for technology adoption. Asongu and Odhiambo (2020), studying FDI and ICT interactions in 25 SSA countries over 1980–2014, find that ICT positively moderates the effect of FDI on economic growth but within the confines of threshold levels of ICT adoption, beyond which the influence becomes negative. This non-linear FDI-ICT-growth relationship motivates the present study's inclusion of a broadband-FDI interaction term and the expectation that its effect will depend on the structural composition of FDI in SSA which, as Asiedu (2006) documents, is heavily concentrated in extractive industries with limited technology spillovers to the broader economy.

## **2.7 Methodological Approaches and Identified Gaps**

From a methodological perspective, the literature exhibits considerable variation in empirical strategies, and this variation has meaningful consequences for the reliability of estimated effects. Early studies rely primarily on cross-sectional or static panel models that do not adequately address the reverse causality between ICT adoption and economic growth: higher-income countries invest more in digital infrastructure, creating a simultaneity bias that inflates estimated growth effects if not accounted for. Czernich et al. (2011) demonstrate that instrumental variable approaches generate substantially different and more credible estimates than ordinary least squares, establishing that failure to address endogeneity biases ICT-growth estimates upward.

In the SSA context, many empirical analyses continue to employ static specifications or single-equation frameworks, limiting the reliability of their conclusions. Haftu (2019) and Myovella et al. (2020) represent important advances by adopting System GMM estimators that address endogeneity through internal instruments, incorporate dynamic income persistence, and accommodate unbalanced panels. However, relatively few SSA-focused studies simultaneously examine broadband penetration, institutional quality, and knowledge diffusion channels within a unified empirical framework. Interaction effects and non-linearities, while increasingly recognised as important as evidenced by Kouam and Asongu (2023) and Asongu and Nwachukwu (2018) remain underexplored in region-specific dynamic models that explicitly test the conditioning role of governance, e-government, and FDI on broadband's growth effects. The use of short time horizons in several studies further restricts the ability to capture long-run adjustment processes, given that the growth effects of infrastructure investments typically materialise over extended periods.

## 2.8 Synthesis and Research Gap

The reviewed literature provides strong theoretical and empirical foundations for understanding the relationship between broadband penetration and economic growth. Across both developed and developing economies, broadband infrastructure is consistently identified as a potentially powerful enabler of productivity growth, innovation, and structural transformation. However, the evidence also makes clear that the growth effects of broadband are neither automatic nor uniform, particularly in the SSA context.

A key insight emerging from the literature is that broadband operates as a general-purpose technology whose economic impact depends heavily on complementary institutional, technological, and human capital conditions. While OECD-focused research reports robust and relatively homogeneous growth effects (Czernich et al., 2011; Koutroumpis, 2009; Mayer et al., 2020), Africa-focused research highlights substantial heterogeneity, non-linearities, and threshold effects that are not captured by simple linear specifications (Haftu, 2019; Kouam & Asongu, 2023; Myovella et al., 2020). These findings suggest that broadband penetration alone is insufficient to generate sustained economic growth in environments characterised by weak governance, limited innovation capacity, and uneven digital readiness.

The literature further reveals important regional asymmetries. Despite significant investment in digital infrastructure, many SSA countries struggle to translate connectivity improvements into productivity gains and inclusive economic development (Friederici et al., 2017). Constraints related to affordability, regulatory capacity, digital skills, and institutional effectiveness limit the absorptive capacity of economies and weaken the transmission channels through which broadband affects growth (World Bank, 2024; ITU, 2023). The critical role of electricity access as a precondition for broadband's growth effects, documented by Kouam and Asongu (2023), illustrates how infrastructure complementarities shape the digital dividend across African economies.

These gaps motivate the empirical approach adopted in this thesis. By employing the two-step System GMM estimator of Blundell and Bond (1998), the study directly addresses endogeneity concerns and accommodates the dynamic income persistence consistent with the convergence hypothesis (Barro, 1991; Mankiw et al., 1992). By explicitly interacting broadband penetration with government effectiveness, e-government development, and FDI stock, the analysis operationalises the concept of institutional and technological complementarities emphasised throughout the literature. This approach enables a more nuanced assessment of not only whether broadband contributes to economic growth in SSA, but also under what conditions its effects are strongest a question that the existing literature raises but does not yet resolve for the 2006–2023 period and the 40-country SSA panel examined here.

## 3. Data and Descriptive Statistics

### 3.1 Data and Sample Construction

This chapter describes the data sources, sample construction, and measurement of variables used in the empirical analysis. The study examines the relationship between broadband penetration and economic growth in Sub-Saharan Africa over the period 2006–2023. The dataset combines macroeconomic, institutional, and digital indicators drawn from internationally recognised and harmonised sources to ensure cross-country comparability across the estimation sample.

#### Sample Construction and Country Coverage

The study draws on data for Sub-Saharan African countries for which sufficient observations are available across the key variables. Nine countries are excluded from the estimation sample: South Sudan, Somalia, São Tomé and Príncipe, Equatorial Guinea, Guinea-Bissau, Djibouti, Sierra Leone, Congo Republic, and the Central African Republic. The exclusion of these countries is based on a single objective criterion: each records more than 50% missing observations in broadband penetration the primary variable of interest within the 2006–2023 study window. As Haile (2017) documents, missingness of this magnitude in African panel datasets is typically not random but structurally driven by conflict, institutional fragility, limited telecommunications investment, and constrained national statistical capacity, conditions under which inclusion would compromise the validity of the GMM instrument set and introduce systematic bias into the estimates. Sandefur and Glassman (2015) similarly document that statistical reporting failures in SSA are concentrated in fragile and conflict-affected states, which closely describes the profile of the excluded countries. The World Bank (2024) classifies Somalia, South Sudan, the Central African Republic, and Guinea-Bissau as high-intensity conflict or fragile states, and Glawion et al. (2019) confirm that structural insecurity and governance collapse in these countries directly compromise data collection and reliability. For São Tomé and Príncipe and Equatorial Guinea, the data gaps reflect limited national statistical capacity and telecommunications investment rather than conflict, but the outcome is the same: insufficient broadband observations to support valid panel estimation. This exclusion is consistent with the practice of Haftu (2019) and Myovella et al. (2020), who similarly restrict their SSA samples to countries with adequate data coverage. The final estimation sample therefore comprises 40 SSA countries over 18 years, yielding 940 observations across the GMM specifications.

### 3.2 Data Sources

All variables are drawn from internationally recognised and harmonised databases. GDP per capita, broadband penetration, trade openness, gross capital formation, inflation, and population growth are obtained from the World Bank's World Development Indicators (WDI). Institutional quality is measured using the Government Effectiveness indicator from the Worldwide Governance Indicators (Kaufmann et al., 2010). The E-Government Development Index is sourced from the United Nations E-Government Survey (UN, 2022). Education data are obtained from the World Bank, drawing on UNESCO Institute for Statistics reporting. FDI stock is sourced from the United Nations Conference on Trade and Development (UNCTAD) and normalised by GDP from the World Bank.

## **Dependent Variable**

The dependent variable is economic performance, measured as GDP per capita in constant US dollars. In line with the empirical growth literature, GDP per capita is transformed using the natural logarithm in the regression analysis to reduce skewness and allow coefficients to be interpreted as elasticities (Barro, 1991; Mankiw et al., 1992). GDP per capita is preferred over GDP per employee in the SSA context due to the high prevalence of informal employment, which makes labour-based productivity measures less reliable and cross-country comparisons more difficult. This choice is consistent with standard growth regressions where GDP per capita is widely used to analyse income dynamics and convergence across developing economies.

## **Key Explanatory Variable**

The key explanatory variable is broadband penetration, measured as fixed broadband subscriptions per 100 inhabitants. This measure is widely used in empirical studies examining the relationship between digital infrastructure and economic performance, as it captures high-capacity and reliable internet access associated with productivity-enhancing activities in firms and households (Czernich et al., 2011; Koutroumpis, 2009). While mobile broadband provides a broader measure of digital access, consistent data availability across countries and over the full sample period is more limited, and empirical studies on the economic impact of digital infrastructure have predominantly relied on fixed broadband indicators as they are more closely associated with firm productivity, innovation, and high-value economic activities. As documented in the descriptive statistics, the mean broadband penetration in the estimation sample is 1.401 subscriptions per 100 inhabitants with a standard deviation of 4.208, reflecting the extremely low and highly uneven diffusion of fixed broadband across SSA a structural feature of the data that directly informs the interpretation of the empirical results.

## **Innovation and Knowledge Diffusion Proxy**

Innovation and knowledge diffusion are proxied by inward FDI stock as a percentage of GDP, calculated as:

$$FDI_{it} = \left( \frac{FDI\ Stock_{it}}{GDP_{it}} \right) \times 100$$

FDI stock reflects the accumulated presence of foreign capital and is associated with the transfer of technology, managerial expertise, and productivity-enhancing practices to domestic firms through spillover effects (Javorcik, 2004). Compared to R&D expenditure, which is poorly reported across SSA, FDI stock provides substantially better coverage across the estimation sample and is less volatile than flow measures, making it more suitable for dynamic panel analysis. The mean FDI stock in the sample is 49.0% of GDP with a standard deviation of 73.046, reflecting both the relatively small GDP bases of many SSA economies and the commodity-sector concentration of foreign investment in the region (Asiedu, 2006).

## **Institutional Quality and Digital Governance**

Institutional quality is captured using the Government Effectiveness indicator from the Worldwide Governance Indicators, which reflects perceptions of the quality of public services, civil service capacity, policy implementation, and the credibility of government commitments. It is constructed using survey-based and expert assessment data and ranges from approximately -2.5 to +2.5. The mean in the estimation sample is -0.675, confirming the well-documented governance deficits across much of SSA (Kaufmann et al., 2010). This indicator is widely used in empirical research as a comprehensive and internationally comparable proxy for institutional quality, and its inclusion is consistent with the theoretical framework linking institutional capacity to growth outcomes (Acemoglu et al., 2001; Asongu & Nwachukwu, 2018).

Digital institutional capacity is further captured using the E-Government Development Index (EGDI), which measures the readiness of governments to deliver services digitally by combining information on online service delivery, telecommunications infrastructure, and human capital. The index ranges from 0 to 1. The mean in the estimation sample is 0.310, substantially below the global mean of approximately 0.55 reported in the UN E-Government Survey (2022), confirming that SSA economies lag significantly in digital public service development. Because the EGDI is reported biennially rather than annually, the most recently observed value is carried forward for intermediate years, consistent with the standard treatment of governance indicators that change slowly between reporting cycles (Kaufmann et al., 2010; UN, 2022).

## **Control Variables**

The empirical model includes a set of standard macroeconomic control variables drawn from the growth literature. Trade openness is measured as the sum of exports and imports as a percentage of GDP, capturing the degree of integration with global markets, which influences productivity and technology diffusion (Sachs & Warner, 1995). Gross capital formation, measured in current US dollars and log-transformed in the regression analysis, proxies physical capital accumulation and is a fundamental determinant of economic growth in both neoclassical and endogenous growth frameworks (Solow, 1956; Mankiw et al., 1992). Education is measured as the gross primary school enrolment ratio, which may exceed 100% due to over-age or under-age enrolment. Although average years of schooling would provide a richer human capital measure, its coverage across SSA is substantially lower, making the enrolment ratio the most consistent and widely available proxy in this data-constrained environment (Barro, 1991; Mankiw et al., 1992). Inflation, measured as the annual percentage change in the consumer price index, is included to capture macroeconomic stability, as high and volatile inflation distorts investment decisions and reduces long-run growth (Fischer, 1993). Population growth reflects demographic dynamics and capital dilution effects within the neoclassical growth framework (Solow, 1956).

## **Data Coverage and Panel Structure**

Table 3.1 summarises the sources and measures for all variables in the estimation sample. GDP per capita, government effectiveness, the E-Government Index, and population growth exhibit strong coverage with 630 or more observations. Broadband penetration records 595 observations, reflecting residual gaps in a small number of countries in the earlier years of the sample. Education records 579

observations due to reporting gaps in national statistics. The resulting panel is unbalanced, with country-year coverage varying across variables. Consistent with Karavias et al. (2022), no artificial balancing of the panel is imposed and no interpolation of any variable is applied. The System GMM estimator accommodates unbalanced panels naturally by constructing moment conditions from available observations, and forcing balance through imputation would unnecessarily introduce artificial variation and potentially bias the estimates. All results therefore reflect the genuine underlying data structure of the estimation sample.

Table 3.1: Variables, definitions, sources, and expected signs

| Variables                      | Description                                                         | Measure                                                | Source                                | Expected_sign |
|--------------------------------|---------------------------------------------------------------------|--------------------------------------------------------|---------------------------------------|---------------|
| GDP per capita                 | Economic output per person                                          | Natural logarithm of GDP per capita (constant US\$)    | World Bank WDI                        | N/A           |
| Broadband penetration          | Digital infrastructure adoption                                     | Fixed broadband subscriptions per 100 inhabitants      | World Bank WDI                        | +             |
| Innovation (FDI stock)         | Knowledge diffusion, technology transfer via foreign investment     | Inward FDI stock (% of GDP)                            | World Bank and UNCTAD                 | +             |
| Government Effectiveness       | Quality of public, civil service, policy implementation credibility | Index ranging from -2.5 (weak) to +2.5 (strong)        | Worldwide Governance Indicators (WGI) | +             |
| E-Government Development Index | Readiness and capacity to deliver digital public services           | Index ranging from 0 to 1 (higher = more advanced)     | United Nations E-Government Survey    | +             |
| Trade openness                 | Degree of economic integration with global markets                  | (Exports + Imports) as % of GDP                        | World Bank and UNCTAD                 | +             |
| Gross capital formation        | Physical capital accumulation                                       | Gross capital formation (current US\$)                 | World Bank WDI                        | +             |
| Education                      | Human capital accumulation                                          | Primary school enrollment (% gross)                    | World Bank WDI                        | +             |
| Inflation                      | Macroeconomic stability                                             | Annual percentage change in consumer price index (CPI) | World Bank WDI                        | –             |
| Population growth              | Demographic dynamics affecting per capita income                    | Annual percentage growth rate of total population      | World Bank WDI                        | +/-           |

## 3.2 Descriptive Statistics

Table 3.2 – Table showing descriptive statistics of variables

|    | Variable                 | N   | Mean    | SD     | Min     | Max     |
|----|--------------------------|-----|---------|--------|---------|---------|
| 1  | log_GDPcap               | 631 | 7.162   | 0.967  | 5.087   | 9.860   |
| 2  | Trade_Openness           | 627 | 67.660  | 34.715 | 15.282  | 222.178 |
| 3  | Education                | 579 | 101.474 | 20.355 | 25.566  | 156.614 |
| 4  | log_GCF                  | 623 | 21.784  | 1.527  | 18.049  | 25.761  |
| 5  | Broadband_penetration    | 595 | 1.401   | 4.208  | 0.000   | 33.565  |
| 6  | Inflation_rate           | 630 | 8.843   | 25.757 | -16.860 | 557.202 |
| 7  | FDI_stock                | 625 | 49.034  | 73.046 | 0.600   | 510.810 |
| 8  | EGov                     | 631 | 0.310   | 0.136  | 0.000   | 0.736   |
| 9  | Population_growth        | 630 | 2.389   | 0.946  | -2.629  | 5.590   |
| 10 | Government_effectiveness | 631 | -0.675  | 0.630  | -1.814  | 1.150   |

Table 3.2 presents summary statistics for all variables used in the empirical analysis, including the number of observations (N), mean, standard deviation, minimum, and maximum. Variation in the number of observations across variables reflects the unbalanced structure of the panel dataset, as discussed in Section 3.1.

GDP per capita, expressed as a natural logarithm of constant US dollars, records 631 observations. The mean value is 7.162, with a standard deviation of 0.967, suggesting substantial income heterogeneity across the panel. The range from 5.087 to 9.860 corresponds to approximately USD 162 to USD 19,141 in levels, reflecting the wide spectrum of economic development across Sub-Saharan African economies, from fragile low-income states to upper-middle-income economies such as South Africa and Botswana.

Broadband penetration, the variable of central interest, records 595 observations, reflecting missing values concentrated in the early years of the sample and in countries with limited statistical reporting capacity. The mean is 1.401 subscriptions per 100 inhabitants, while the minimum is 0 and the maximum is 33.565. The high standard deviation of 4.208 nearly three times the mean indicates that broadband access remained extremely low and highly uneven across the panel. The maximum of 33.565, recorded for Seychelles, suggests that while a small number of relatively more advanced SSA economies achieved moderate broadband diffusion, penetration remained negligible in the majority of countries for much of the study period. The substantial difference between the mean and the median implied by this distribution confirms a heavily right-skewed pattern, consistent with the gradual and uneven diffusion of fixed digital infrastructure across the region.

Innovation and knowledge diffusion, proxied by inward FDI stock as a percentage of GDP, records 625 observations. The variable exhibits a strongly right-skewed distribution, with a mean of 49.034% and a maximum of 510.810%. This reflects disproportionately high foreign capital stocks in a small number of resource-dependent economies with narrow GDP bases. The results also indicate substantial cross-country heterogeneity in foreign capital accumulation across the region.

Government effectiveness records 631 observations, with a mean of -0.675 and a standard deviation of 0.630. The negative mean confirms the broadly weak institutional performance of SSA economies.

relative to the global distribution of the World Bank governance index, while the range from -1.814 to 1.150 highlights the substantial institutional heterogeneity across countries in the panel.

The E-Government Development Index records 631 observations, with a mean of 0.310 and a standard deviation of 0.136, on the index's 0 to 1 scale. The range from 0 to 0.736 and the mean of 0.310 substantially below the global mean of approximately 0.55 reported in the UN E-Government Survey (2022) confirm generally low to moderate levels of digital public service development across the region during the study period.

Trade openness records 627 observations, with a mean of 67.660% of GDP and a standard deviation of 34.715. The maximum value of 222.178% indicates considerable variation in external integration, with some small open economies exhibiting extremely high trade-to-GDP ratios, as is typical for island states and heavily trade-dependent economies in the region.

Log gross capital formation records 623 observations, with a mean of 21.784 and a standard deviation of 1.527, reflecting moderate cross-country variation in investment levels in log terms. The range from 18.049 to 25.761 corresponds to wide differences in the absolute scale of investment activity across economies of very different sizes in the panel.

Education, measured as the gross primary school enrolment ratio, records 579 observations. The mean value of 101.474 and the standard deviation of 20.355 suggest relatively high enrolment ratios on average, with gross enrolment sometimes exceeding 100% due to age-grade distortions and over-age enrolment, a common phenomenon in SSA. The range from 25.566 to 156.614 indicates meaningful variation in educational access across the panel.

Inflation records 630 observations, with a mean annual rate of 8.843% and a standard deviation of 25.757 approximately three times the mean. The maximum value of 557.202% reflects episodes of acute macroeconomic instability, most notably in Zimbabwe and Sudan during the study period. The presence of a minimum value of -16.860% indicates occasional deflationary episodes in the sample.

Population growth records 630 observations, with a mean annual growth rate of 2.389% and a standard deviation of 0.946, consistent with the demographic profile of Sub-Saharan Africa as the world's fastest-growing region. The range from -2.629 to 5.590 reflects variation across countries at different stages of the demographic transition.

Overall, the descriptive statistics reveal considerable cross-country heterogeneity in income levels, institutional quality, digital infrastructure, and macroeconomic stability across the 40-country SSA estimation sample. The variation in the number of observations confirms the unbalanced nature of the panel, most notably for broadband penetration and education. These patterns are consistent with structural development differences and data reporting constraints across the region. The implications of this heterogeneity and the treatment of missing data for the econometric analysis are addressed in the subsequent chapter

### 3.3 Correlation Analysis

Table 3.3 - Correlation matrix

|                          | log_GDPcap | Trade_Openness | Education | log_GCF | Broadband_penetration | Inflation_rate | FDI_stock | EGov   | Population_growth | Government_effectiveness |
|--------------------------|------------|----------------|-----------|---------|-----------------------|----------------|-----------|--------|-------------------|--------------------------|
| log_GDPcap               | 1.000      | 0.482          | 0.030     | 0.222   | 0.587                 | -0.006         | 0.064     | 0.696  | -0.583            | 0.665                    |
| Trade_Openness           | 0.482      | 1.000          | 0.199     | -0.284  | 0.475                 | -0.059         | 0.492     | 0.347  | -0.450            | 0.450                    |
| Education                | 0.030      | 0.199          | 1.000     | -0.166  | 0.058                 | -0.026         | -0.005    | 0.268  | -0.104            | 0.253                    |
| log_GCF                  | 0.222      | -0.284         | -0.166    | 1.000   | -0.145                | 0.045          | -0.248    | 0.226  | 0.174             | 0.094                    |
| Broadband_penetration    | 0.587      | 0.475          | 0.058     | -0.145  | 1.000                 | -0.036         | 0.247     | 0.583  | -0.527            | 0.549                    |
| Inflation_rate           | -0.006     | -0.059         | -0.026    | 0.045   | -0.036                | 1.000          | -0.014    | 0.066  | -0.013            | -0.098                   |
| FDI_stock                | 0.064      | 0.492          | -0.005    | -0.248  | 0.247                 | -0.014         | 1.000     | 0.116  | -0.163            | 0.112                    |
| EGov                     | 0.696      | 0.347          | 0.268     | 0.226   | 0.583                 | 0.066          | 0.116     | 1.000  | -0.591            | 0.678                    |
| Population_growth        | -0.583     | -0.450         | -0.104    | 0.174   | -0.527                | -0.013         | -0.163    | -0.591 | 1.000             | -0.482                   |
| Government_effectiveness | 0.665      | 0.450          | 0.253     | 0.094   | 0.549                 | -0.098         | 0.112     | 0.678  | -0.482            | 1.000                    |

Table 3.3 presents the pairwise Pearson correlation matrix for all variables included in the empirical analysis. The correlations provide preliminary evidence of bivariate associations among the key variables and serve to validate the theoretical expectations underpinning the model specification.

Broadband penetration is positively correlated with log GDP per capita (0.587), the e-government index (0.583), government effectiveness (0.549), and trade openness (0.475), supporting the expectation that digital infrastructure is jointly associated with higher income levels, stronger institutions, and greater economic openness. These associations are consistent with the empirical findings of Czernich et al. (2011) and Myovella et al. (2020), who document positive relationships between broadband penetration and economic performance in OECD and SSA contexts respectively, and with Asongu and Nwachukwu (2018), who establish that institutional quality is a key enabler of ICT-related economic outcomes in Africa.

The e-government index records the highest bivariate correlation with log GDP per capita in the entire matrix (0.696), followed closely by government effectiveness (0.665). Both findings are consistent with the broader development literature linking institutional capacity and digital public infrastructure to income levels (Acemoglu et al., 2001; UN, 2022). The strong correlation between government effectiveness and the e-government index (0.678) reflects the structural interdependence between governance quality and digital public service capacity: countries with more effective governments are better placed to design and operate e-government platforms, as documented in the UN E-Government Survey (2022).

FDI stock shows a moderate positive correlation with trade openness (0.492) and broadband penetration (0.247), suggesting that foreign investment and digital infrastructure tend to co-locate in more open economies, consistent with Asiedu (2006) and Ofori and Asongu (2021), who document that trade integration is among the most robust determinants of FDI inflows into SSA.

Population growth is negatively correlated with log GDP per capita (-0.583), the e-government index (-0.591), broadband penetration (-0.527), trade openness (-0.450), and government effectiveness (-0.482). These correlations reflect broad development-level co-movement across countries, where lower-income economies tend to exhibit higher fertility, weaker institutions, and lower digital and trade integration. While the income relationship is consistent with capital dilution in neoclassical growth theory (Solow, 1956; Mankiw et al., 1992), the remaining associations likely reflect multiple

overlapping structural and institutional channels. As such, these results are descriptive and should not be interpreted as evidence of a single underlying causal mechanism.

Gross capital formation shows a moderate positive correlation with log GDP per capita (0.222) and negative correlations with trade openness (-0.284) and FDI stock (-0.248), possibly reflecting the structure of domestic investment in Sub-Saharan Africa's relatively closed and resource-dependent economies, where investment is heavily concentrated in extractive and capital-intensive sectors with limited spillovers to broader productivity-enhancing activities such as manufacturing and services. Inflation shows near-zero correlations with all variables, consistent with its country-specific, shock-driven nature in the SSA context (IMF, 2020), and confirming that it does not create collinearity concerns in the regression specifications.

The highest pairwise correlation among the independent variables is 0.678, between government effectiveness and the e-government index, which remains below the conventional 0.80 threshold of concern (Baltagi, 2008). Variance inflation factor analysis confirms that all VIF values are below 5, well within acceptable bounds. Overall, the correlations are moderate and in the theoretically expected directions, with no evidence of multicollinearity that would unduly affect the reliability of the System GMM estimates.

Figure 3.1 presents scatter plot of broadband penetration against key variables and Figure 3.2 presents the evolution of average fixed broadband penetration alongside log GDP per capita from 2006 to 2023. Both series show a sustained upward trend, indicating a positive association between digital infrastructure adoption and income levels over time.

Figure 3.3 displays country-specific average fixed broadband penetration over the full sample period. There is substantial cross-country variation. Mauritius and Seychelles record the highest averages (above 14%), while several countries – including Guinea, Burundi, and the Democratic Republic of the Congo – report averages below 1%. This wide dispersion reflects the persistent digital divide across nations.

Together, these graphs provide preliminary visual evidence on the relationship between fixed broadband infrastructure and economic development, both across time and across countries.

Figure 3.1 – Scatter plot of broadband penetration against GDP per capita and complimentaries

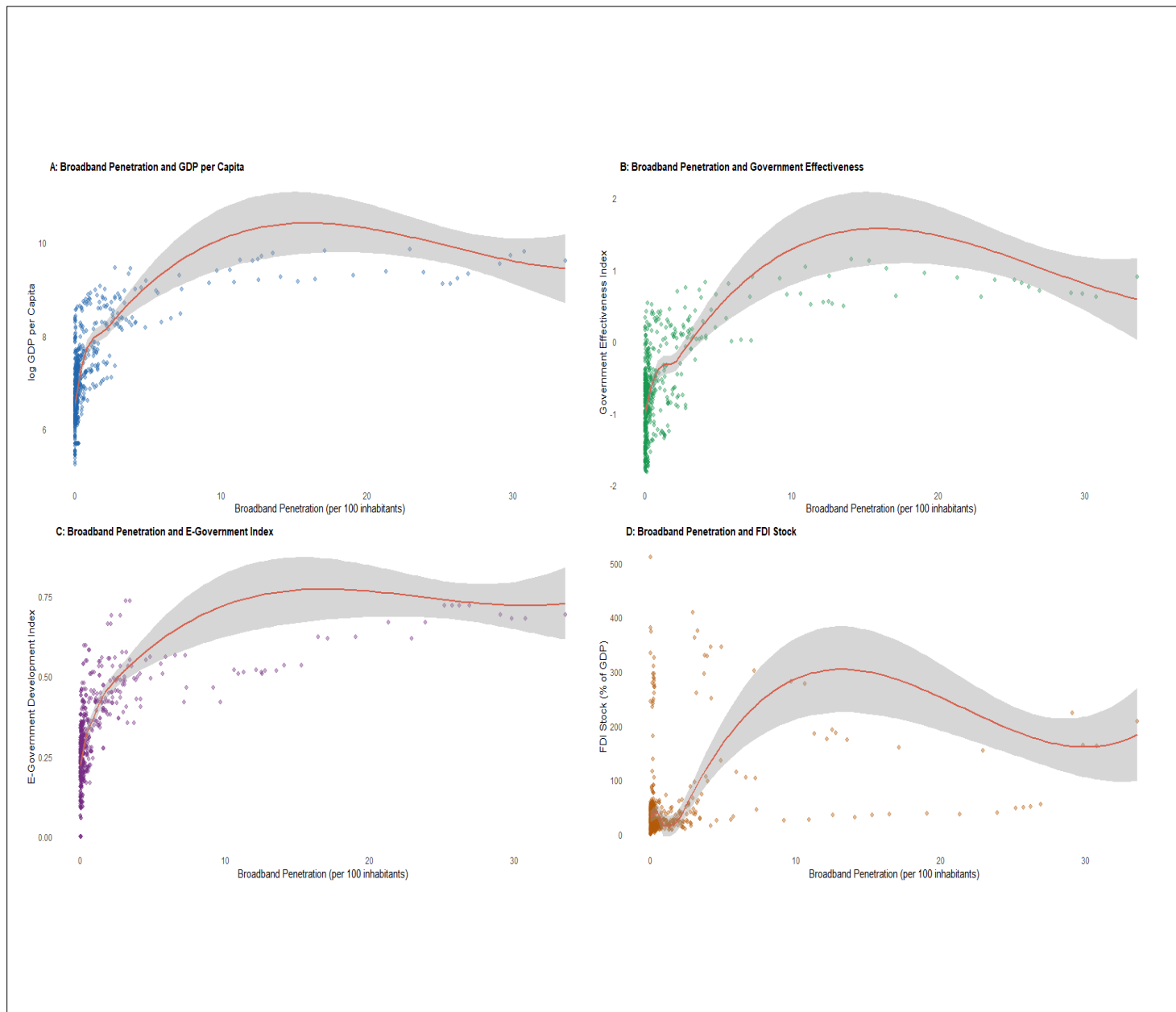


Figure 3.2 – Trend plot of broadband penetration and GDP per capita (log)

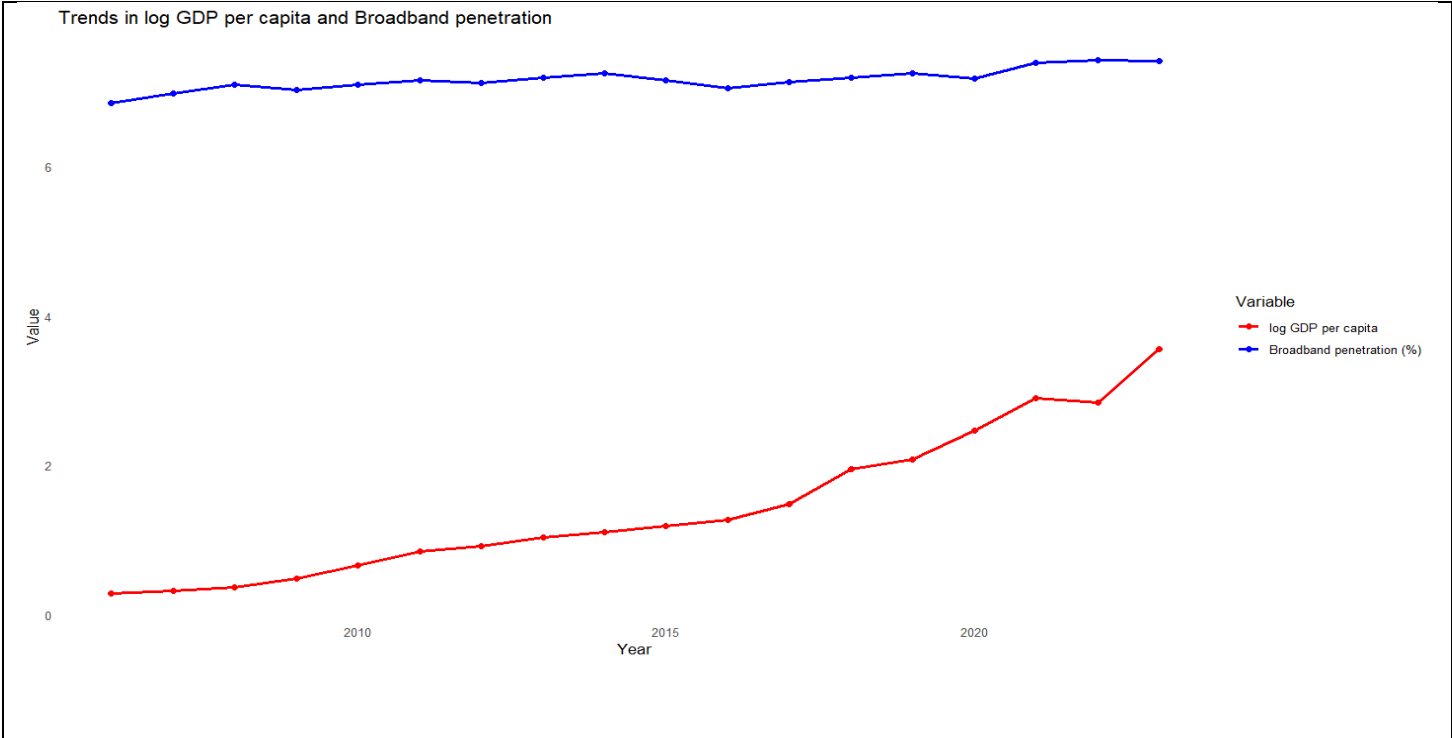
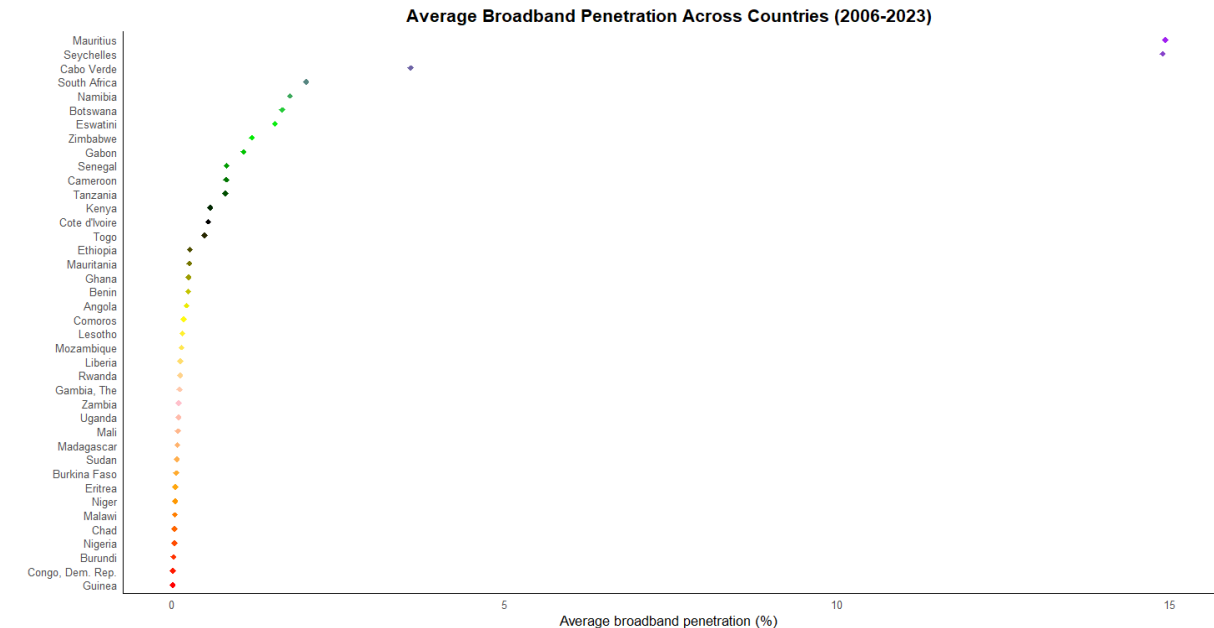


Figure 3.3 – Plot of average broadband penetration across countries



## 4 Econometric Methodology

### 4.1 Theoretical Framework

The empirical framework is grounded in both exogenous and endogenous growth theory. In the Solow (1956) model, long-run growth is driven by technological progress, while capital accumulation determines transitional dynamics. Infrastructure investment, including broadband connectivity, primarily affects productivity levels and income convergence. Endogenous growth theory (Romer, 1990; Aghion & Howitt, 1992) extends this framework by emphasising knowledge diffusion, innovation, and technological complementarities. Broadband infrastructure can therefore be viewed as a general-purpose technology that enhances productivity through improved information flows, reduced transaction costs, and innovation spillovers (Czernich et al., 2011; Koutroumpis, 2009). Its economic impact is expected to depend on complementary factors such as governance quality, digital public infrastructure, and innovation capacity.

The starting point is an augmented Cobb–Douglas production function:

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{\beta}$$

where  $Y_{it}$  is aggregate output,  $K_{it}$  is physical capital,  $L_{it}$  is labour, and  $A_{it}$  captures total factor productivity (TFP) in country  $i$  at time  $t$ . Assuming constant returns to scale ( $\alpha + \beta = 1$ ), dividing both sides by  $L_{it}$  yields output per worker:

$$\frac{Y_{it}}{L_{it}} = A_{it} \left( \frac{K_{it}}{L_{it}} \right)^{\alpha}$$

Taking natural logarithms gives:

$$\ln y_{it} = \ln A_{it} + \alpha \ln k_{it}$$

where  $y_{it} = \frac{Y_{it}}{L_{it}}$  and  $k_{it} = \frac{K_{it}}{L_{it}}$ . Following the growth literature (Barro, 1991; Mankiw, Romer & Weil, 1992), GDP per capita ( $GDP_{it}$ ) is used as the dependent variable rather than output per employed person, given the limited reliability and availability of labour market data in Sub-Saharan Africa

Total factor productivity is assumed to be a function of broadband penetration, innovation and knowledge diffusion (proxied by FDI stock), institutional quality (government effectiveness), and digital institutional capacity (e-government development). Additional control variables ( $X_{it}$ ) capture standard determinants of economic growth:

$$\ln A_{it} = \gamma_0 + \gamma_1 \text{Broadband}_{it} + \gamma_2 \text{FDI\_Stock}_{it} + \gamma_3 \text{GovEff}_{it} + \gamma_4 \text{EGov}_{it} + \gamma_5 X_{it}$$

Substituting into the per-worker production function and adding a lagged dependent variable to account for conditional convergence and dynamic adjustment (Barro, 1991), we obtain the dynamic panel specification:

$$\ln GDP_{it} = \rho \ln GDP_{it-1} + \beta_1 \text{Broadband}_{it} + \beta_2 \text{FDI\_Stock}_{it} + \beta_3 \text{GovEff}_{it} + \beta_4 \text{EGov}_{it} + \beta_5 X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where  $\mu_i$  captures unobserved country-specific heterogeneity,  $\lambda_t$  are time effects, and  $\varepsilon_{it}$  is the idiosyncratic error term. The coefficient  $\rho$  reflects the speed of convergence, with  $0 < \rho < 1$  indicating conditional convergence.

#### 4.2 Model Specification

Two empirical models are estimated: a baseline model and a complementarity model.

##### Model 1: Baseline Digital Infrastructure Model

This model evaluates the direct effect of broadband penetration on economic performance, including the full set of control variables:

$$\begin{aligned} \ln GDP_{it} = & \rho \ln GDP_{it-1} + \beta_1 \text{Broadband}_{it} + \beta_2 \text{FDI\_Stock}_{it} + \beta_3 \text{GovEff}_{it} + \beta_4 \text{EGov}_{it} \\ & + \beta_5 \text{Trade\_openness}_{it} + \beta_6 \text{Gross\_Capital\_formation}_{it} + \beta_7 \text{Education}_{it} \\ & + \beta_8 \text{Inflation}_{it} + \beta_9 \text{PopGrowth}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \end{aligned}$$

The coefficient  $\beta_1$  measures the direct effect of broadband penetration on income levels, holding other determinants constant.

##### Model 2: Complementarity Model

To examine whether the economic impact of broadband depends on structural and institutional conditions, the second model introduces interaction terms between broadband penetration and each complementary factor separately. The specification is:

$$\begin{aligned} \ln GDP_{it} = & \rho \ln GDP_{it-1} + \beta_1 \text{Broadband}_{it} + \beta_2 \text{FDI\_Stock}_{it} + \beta_3 \text{EGov}_{it} + \beta_4 \text{GovEff}_{it} \\ & + \beta_5 (\text{Broadband}_{it} \times \text{FDI\_Stock}_{it}) + \beta_6 (\text{Broadband}_{it} \times \text{EGov}_{it}) \\ & + \beta_7 (\text{Broadband}_{it} \times \text{GovEff}_{it}) + \beta_8 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \end{aligned}$$

where  $X_{it}$  includes the same macroeconomic controls as in Model 1. This specification allows the marginal effect of broadband penetration on income to vary with innovation capacity (FDI stock), digital public infrastructure (e-government), and institutional quality (government effectiveness). The total marginal effect of broadband is therefore conditional and can be expressed as:

$$\frac{\partial \ln GDP_{it}}{\partial \text{Broadband}_{it}} = \beta_1 + \beta_5 \text{FDI\_Stock}_{it} + \beta_6 \text{EGov}_{it} + \beta_7 \text{GovEff}_{it}$$

A positive and statistically significant interaction coefficient indicates complementarity, implying that broadband generates stronger economic effects in countries with higher innovation capacity, more advanced e-government systems, or stronger governance structures. This formulation directly tests the hypothesis derived from endogenous growth theory that digital infrastructure functions as a general-purpose technology whose productivity effects depend on supportive institutional and technological

environments (Romer, 1990; Aghion & Howitt, 1992; Czernich et al., 2011). Empirical evidence further shows that the growth impact of digital infrastructure is conditional on institutional quality and complementary factors (Asongu & Nwachukwu, 2018; Kouam, 2023).

### 4.3 Estimation Method

The presence of a lagged dependent variable and the potential endogeneity of broadband penetration, FDI stock, and other regressors render standard fixed effects estimators biased and inconsistent. Reverse causality, omitted variable bias, and measurement error are plausible concerns: higher-income countries may invest more in digital infrastructure, and unobserved institutional factors may affect both broadband adoption and growth.

To address these issues, the study employs the System Generalized Method of Moments (System GMM) estimator developed by Blundell and Bond (1998). This estimator:

- Controls for unobserved country-specific heterogeneity,
- Addresses endogeneity using internal instruments (lags of the endogenous variables),
- Is suitable for dynamic panels with a large cross-sectional dimension and moderate time dimension,
- Accommodates unbalanced panel data without requiring interpolation (Roodman, 2009).

System GMM is preferred over Difference GMM because it reduces weak instrument bias when the dependent variable is persistent, which is typical of GDP per capita series.

Model validity is evaluated using the Hansen test of over-identifying restrictions (null hypothesis: instruments are valid) and the Arellano–Bond tests for serial correlation. For valid instruments, the Hansen test should yield a p-value  $> 0.10$ , and the Arellano–Bond test for second-order correlation (AR(2)) should not reject the null of no serial correlation in the differenced residuals (i.e.,  $p > 0.05$ ). First-order correlation (AR(1)) is expected by construction.

## 5. Results and Discussion

This chapter presents the empirical analysis of the relationship between broadband penetration and economic growth in Sub-Saharan Africa (SSA), covering 40 countries over the period 2006–2023. The analysis is structured around two models: a baseline model that estimates the direct effect of broadband penetration on GDP per capita, and a complementarity model that examines whether the growth effect of broadband is conditioned by FDI stock, e-government development, or institutional quality as measured by government effectiveness. The estimation strategy employs the two-step System Generalised Method of Moments (System GMM) estimator developed by Blundell and Bond (1998), which is well suited to dynamic panel data characterised by many cross-sectional units relative to the time dimension, persistent dependent variables, and potential endogeneity of key regressors.

The choice of the System GMM estimator is motivated by several considerations that are particularly salient in the SSA context. First, broadband penetration is plausibly endogenous to economic growth: higher-income countries tend to invest more in digital infrastructure, creating a reverse causality problem that would bias ordinary least squares and even standard fixed-effects estimators. Second, the lagged dependent variable included to account for conditional convergence and income persistence renders the within-group fixed effects estimator inconsistent. Third, unobserved country-specific heterogeneity, including geographic remoteness, colonial history, and long-run institutional trajectories, must be controlled for. The System GMM estimator addresses all three concerns simultaneously by using lagged levels and differences of the endogenous variables as internal instruments, differencing away country fixed effects, and accommodating the dynamic structure of the model (Arellano & Bond, 1991; Blundell & Bond, 1998; Roodman, 2009).

To avoid instrument proliferation, which inflates the Hansen test of over-identifying restrictions and renders it uninformative, the instrument matrix is collapsed following the recommendation of Roodman (2009). Specifically, lag 2 of the log GDP per capita, broadband penetration, and FDI stock are used as GMM instruments, yielding a parsimonious and tractable instrument set. Time fixed effects are included in all specifications to control for common macroeconomic shocks, including the 2008–2009 global financial crisis, the commodity price cycle of 2015–2016, and the COVID-19 pandemic of 2020.

**Table 5.1: System GMM Estimation Results — Baseline and Complementarity Models**

*Two-step System GMM with collapsed instruments (Blundell & Bond, 1998; Roodman, 2009) | 40 SSA countries | 2006–2023*

| Variable                                                                                                                 | Model 1<br>(Baseline) | Model 2<br>(Full)   | Model 2a<br>(BB×FDI)  | Model 2b<br>(BB×EGov) | Model 2c<br>(BB×GovEff) |
|--------------------------------------------------------------------------------------------------------------------------|-----------------------|---------------------|-----------------------|-----------------------|-------------------------|
| <i>Dependent variable: <math>\ln(\text{GDP per capita})</math>   45 SSA countries   2006–2023   <math>N = 940</math></i> |                       |                     |                       |                       |                         |
| <b>A. Core variables</b>                                                                                                 |                       |                     |                       |                       |                         |
| lag( $\ln$ GDP<br>per capita)                                                                                            | 0.9112***<br>(0.0820) | 0.7307*<br>(0.3214) | 0.9331***<br>(0.1226) | 0.8420***<br>(0.1079) | 0.8788***<br>(0.0660)   |
| Broadband<br>penetration                                                                                                 | 0.0029<br>(0.0061)    | 0.1670<br>(0.1478)  | 0.0075<br>(0.0196)    | 0.0449<br>(0.0294)    | 0.0188<br>(0.0180)      |
| FDI stock                                                                                                                | 0.0001<br>(0.0004)    | -0.0033<br>(0.0051) | 0.0003<br>(0.0008)    | -0.0001<br>(0.0005)   | 0.0000<br>(0.0005)      |
| Government<br>effectiveness                                                                                              | 0.0596<br>(0.0530)    | -0.2585<br>(0.4711) | 0.0436<br>(0.0541)    | 0.0576<br>(0.0495)    | 0.0749<br>(0.0528)      |
| E-<br>Government<br>Index                                                                                                | 0.0067<br>(0.1800)    | 2.2677<br>(4.2807)  | -0.1276<br>(0.1752)   | 0.1737<br>(0.2510)    | -0.0122<br>(0.1873)     |
| Trade<br>openness                                                                                                        | 0.0001<br>(0.0005)    | 0.0053<br>(0.0079)  | -0.0001<br>(0.0006)   | 0.0005<br>(0.0007)    | 0.0002<br>(0.0005)      |

| Variable                       | Model 1<br>(Baseline) | Model 2<br>(Full)   | Model 2a<br>(BB×FDI) | Model 2b<br>(BB×EGov) | Model 2c<br>(BB×GovEff) |
|--------------------------------|-----------------------|---------------------|----------------------|-----------------------|-------------------------|
| ln(Gross capital formation)    | 0.0228<br>(0.0249)    | 0.1345<br>(0.1510)  | 0.0238<br>(0.0363)   | 0.0341<br>(0.0267)    | 0.0297<br>(0.0214)      |
| Education                      | 0.0001<br>(0.0007)    | -0.0005<br>(0.0021) | 0.0005<br>(0.0007)   | -0.0003<br>(0.0008)   | 0.0000<br>(0.0007)      |
| Inflation rate                 | -0.0001<br>(0.0004)   | -0.0005<br>(0.0007) | -0.0001<br>(0.0004)  | 0.0000<br>(0.0003)    | -0.0001<br>(0.0003)     |
| Population growth              | -0.0264<br>(0.0234)   | 0.0126<br>(0.0911)  | -0.0236<br>(0.0292)  | -0.0392<br>(0.0278)   | -0.0351<br>(0.0219)     |
| <b>B. Interaction terms</b>    |                       |                     |                      |                       |                         |
| Broadband × FDI stock          | —                     | 0.0002<br>(0.0004)  | 0.0000<br>(0.0001)   | —                     | —                       |
| Broadband × E-Government       | —                     | -0.2655<br>(0.2971) | —                    | -0.0573<br>(0.0362)   | —                       |
| Broadband × Gov. effectiveness | —                     | 0.0028<br>(0.0374)  | —                    | —                     | -0.0155<br>(0.0166)     |
| <b>C. Diagnostics</b>          |                       |                     |                      |                       |                         |
| Observations                   | 940                   | 940                 | 940                  | 940                   | 940                     |
| AR(1) p-value                  | 0.007**               | 0.112               | 0.006**              | 0.007**               | 0.010**                 |
| AR(2) p-value                  | 0.548                 | 0.268               | 0.495                | 0.666                 | 0.538                   |
| Sargan p-value                 | 0.147                 | 0.936               | 0.237                | 0.103                 | 0.203                   |

**Notes:** Robust standard errors in parentheses. \*\*\* p < 0.001, \*\* p < 0.01, \* p < 0.05, † p < 0.10. BB = broadband penetration. Models estimated using two-step System GMM with forward orthogonal deviations and collapsed instruments. Time fixed effects included but not reported. AR(2) and Sargan tests support model validity. Model 1 is the baseline; Model 2 includes all interactions jointly; Models 2a–2c include them separately. “—” denotes exclusion from a specification.

## 5.1 Diagnostic Tests and Model Validity

Before interpreting the coefficient estimates, the validity of the System GMM estimator is assessed through the Arellano-Bond tests for serial correlation and the Sargan test of over-identifying restrictions. These diagnostic tests are fundamental to establishing the credibility of the Blundell and Bond (1998) System GMM estimator and are reported in Panel C of results table.

The Arellano-Bond test for first-order autocorrelation (AR(1)) rejects the null hypothesis of no serial correlation in Models 1, 2a, 2b, and 2c, with p-values of 0.007, 0.006, 0.007, and 0.010 respectively. This outcome is expected by construction: first-differencing the level equation necessarily induces first-order autocorrelation in the differenced residuals, and its presence carries no adverse implication for the validity of the estimator (Arellano & Bond, 1991). Model 2, which includes all three interaction terms simultaneously, produces a borderline AR(1) p-value of 0.112, suggesting that the simultaneous inclusion of all interactions over-parameterises the model and reduces estimation precision and this birthed the idea of separate interactions in model 2a, 2b, and 2c.

More critically, the Arellano-Bond AR(2) test fails to reject the null hypothesis of no second-order serial correlation across all five models. The p-values are 0.548 for Model 1, 0.268 for Model 2, 0.495 for Model 2a, 0.666 for Model 2b, and 0.538 for Model 2c. The absence of second-order autocorrelation is the key identifying assumption of the System GMM estimator, as it validates the use of second and deeper lags as instruments in the differenced equation (Arellano & Bond, 1991; Blundell & Bond, 1998). These results confirm the internal consistency of the instrument set across all specifications.

The Sargan test of over-identifying restrictions yields p-values of 0.147, 0.936, 0.237, 0.103, and 0.203 for Models 1, 2, 2a, 2b, and 2c respectively, all exceeding the 10% threshold. The null hypothesis that the instruments are valid and orthogonal to the error term cannot be rejected in any specification, confirming instrument validity. This is a particularly notable result given that Roodman (2009) and Bowsher (2002) document the tendency of the Sargan-Hansen test to over-reject in small samples, and the clean pass across all five specifications provides strong support for the chosen instrument set.

The lagged dependent variable coefficient a central parameter in the dynamic specification is 0.911 in Model 1, 0.731 in Model 2, 0.933 in Model 2a, 0.842 in Model 2b, and 0.879 in Model 2c. All values lie within the theoretically required interval of (0, 1), confirming conditional convergence: SSA economies are converging towards their individual long-run steady states at rates implied by these persistence parameters. The lower value of 0.731 in Model 2 and its borderline AR(1) result reinforce the conclusion that Models 2a–2c are the preferred complementarity specifications, as each introduces a single interaction term rather than all three simultaneously, avoiding multicollinearity and instrument proliferation (Roodman, 2009).

## **5.2 Baseline Model Results**

Model 1 estimates the direct effect of broadband penetration on log GDP per capita, controlling for FDI stock, government effectiveness, the e-government index, trade openness, log gross capital formation, education, inflation, and population growth. The results are reported in the first column of Table 5.1.

The coefficient on broadband penetration is positive (0.0029) but statistically insignificant ( $p = 0.634$ ). This finding suggests that a one percentage point increase in fixed broadband subscriptions per 100 people is associated with approximately a 0.3% increase in GDP per capita in SSA, but this effect cannot be distinguished from zero at conventional significance levels. The result is directionally

consistent with the general-purpose technology hypothesis that broadband enhances productivity through information flows, reduced transaction costs, and innovation spillovers (Romer, 1990; Czernich et al., 2011) but fails to achieve statistical significance in the SSA context.

This finding contrasts notably with the OECD literature. Czernich et al. (2011), in their seminal instrumental variable study of 25 OECD countries from 1996 to 2007, find that a 10 percentage point increase in broadband penetration raised annual per capita GDP growth by 0.9 to 1.5 percentage points a large, precisely estimated, and economically significant effect. Koutroumpis (2009) similarly reports significant positive impacts for European economies. The divergence between these strong OECD results and the present SSA finding is itself an important empirical contribution. Myovella et al. (2020), in the most directly comparable study, a GMM analysis of 41 SSA and 33 OECD economies from 2006 to 2016, explicitly find that the effect of broadband internet is minimal for SSA compared to OECD countries. Haftu (2019), studying 40 SSA countries from 2006 to 2015, similarly reports a statistically insignificant effect of internet penetration on GDP per capita when using a two-step System GMM. The present study's baseline result therefore aligns with the weight of SSA-specific empirical evidence and suggests that the preconditions for broadband-led growth critical mass of users, complementary human capital, enabling institutions, and affordable access are not yet fully in place across the region.

FDI stock carries a positive but insignificant coefficient of 0.00005 ( $p = 0.908$ ), government effectiveness is positive at 0.060 ( $p = 0.260$ ), and the e-government index is at 0.007 ( $p = 0.970$ ). None of the control variables reach conventional significance in the baseline model, consistent with several SSA panel studies that document high heterogeneity in growth determinants across the region (Haftu, 2019; Odhiambo, 2022). The time fixed effects are economically meaningful: significant negative coefficients are recorded for 2009 ( $-0.117$ ,  $p = 0.002$ ), 2012 ( $-0.107$ ,  $p < 0.001$ ), 2015 ( $-0.206$ ,  $p < 0.001$ ), 2016 ( $-0.147$ ,  $p < 0.001$ ), 2019 ( $-0.122$ ,  $p < 0.001$ ), and 2020 ( $-0.166$ ,  $p < 0.001$ ), corresponding to the global financial crisis, the SSA commodity price downturns, and the COVID-19 pandemic shock respectively. These crisis-year effects are substantially larger in magnitude than the estimated broadband coefficient, underscoring that macroeconomic shocks remain the dominant short-run drivers of income fluctuations in SSA.

### 5.3 Complementarity Model Results

The complementarity models test whether the growth effect of broadband penetration in SSA is conditioned by FDI stock as an innovation proxy (Model 2a), e-government development as a digital institutional capacity proxy (Model 2b), or government effectiveness as an institutional quality proxy (Model 2c). Each interaction is introduced separately to avoid multicollinearity, following the approach of Asongu and Nwachukwu (2018). All three models pass the AR(2) and Sargan diagnostic tests, confirming their validity for inference.

*Model 2a: Broadband and FDI Stock.* The interaction term between broadband penetration and FDI stock ( $BB \times FDI$ ) carries a coefficient of  $-0.000024$  and is statistically insignificant ( $p = 0.794$ ). The direct broadband coefficient in this specification is  $0.008$  ( $p = 0.702$ ), remaining positive but insignificant. These results indicate that FDI stock does not significantly moderate the growth effect of

broadband penetration in SSA. This finding is consistent with the structural composition of FDI in SSA, which is heavily concentrated in extractive industries with limited backward linkages to the broader economy and restricted technology spillovers (Asiedu, 2006). Unlike FDI in OECD or East Asian economies, which tends to involve technology-intensive manufacturing and services that create absorptive capacity complementarities with digital infrastructure, resource-sector FDI in SSA generates limited demand for broadband connectivity and produces few productivity spillovers to domestic firms (Ofori & Asongu, 2021). Asongu and Odhiambo (2020) similarly find that ICT-FDI complementarities in SSA operate through threshold effects that require specific levels of ICT adoption to activate, a threshold that most SSA economies have not yet attained given the mean broadband penetration of 1.401 subscriptions per 100 people in the present sample.

*Model 2b: Broadband and E-Government Development.* The interaction between broadband penetration and the e-government index ( $BB \times EGov$ ) has a coefficient of -0.057 ( $p = 0.113$ ), which is negative and approaches borderline significance without achieving it. The direct broadband coefficient in this model increases to 0.045 ( $p = 0.127$ ), the largest direct broadband effect across all specifications, suggesting that controlling for the e-government interaction reveals a stronger underlying relationship between broadband and growth. The absence of a significant positive interaction is consistent with the nascent state of e-government in SSA: the mean E-Government Development Index of 0.310 in the sample is substantially below the global mean of approximately 0.55 documented in the UN E-Government Survey (2022). The UN (2022) further documents that most SSA countries are classified in the low to moderate e-government development categories and that e-government services are concentrated in a narrow range of applications rather than the broader productivity-enhancing platforms; digital health, agricultural extension, financial inclusion that would create measurable aggregate growth complementarities with broadband. The result suggests that e-government development in SSA has not yet reached the threshold of institutional depth and user penetration necessary to generate significant amplification of broadband's growth effects at the macroeconomic level.

*Model 2c: Broadband and Government Effectiveness.* Model 2c yields the most substantively interesting findings. The direct broadband coefficient is positive at 0.019 ( $p = 0.296$ ) and the interaction between broadband penetration and government effectiveness ( $BB \times GovEff$ ) is negative at -0.016 ( $p = 0.352$ ). Although neither coefficient achieves conventional statistical significance, the pattern warrants theoretical interpretation. The total conditional marginal effect of broadband is:

$$\partial \ln(GDP) / \partial \text{Broadband} = 0.019 - 0.016 \times \text{GovEff}$$

At the sample mean of government effectiveness (-0.675), the total marginal effect of broadband is approximately  $0.019 - (0.016 \times -0.675) = 0.030$ , which is positive. At one standard deviation above the mean (+0.30), the total marginal effect falls to approximately 0.014. This suggests that broadband's growth contribution is positive across the governance distribution of the sample but diminishes at higher levels of government effectiveness. The negative interaction may reflect a substitution mechanism: in countries with weaker governance, broadband infrastructure independently reduces

transaction costs and bypasses inefficient institutions, generating stronger marginal returns precisely where institutional intermediaries are least effective consistent with the digital leapfrogging hypothesis documented for SSA by Steinmueller (2001) and Aker and Mbiti (2010). Conversely, in countries with higher governance scores, which tend to be relatively wealthier and more digitally advanced within the SSA context, broadband penetration may be closer to the critical mass threshold beyond which marginal returns diminish (Koutroumpis, 2009). It is important to acknowledge, however, that the borderline nature of both estimates neither achieves 5% significance, this warrants caution in drawing definitive causal conclusions.

#### **5.4 Broader Contextual Discussion**

The results collectively position this study within the emerging consensus that broadband's growth effects in SSA are positive in direction but weak in statistical magnitude relative to OECD and advanced economies findings, and that the complementarities theorised in the endogenous growth literature do not yet appear to be operative at the macroeconomic level across the region. Three structural mechanisms explain this divergence from the OECD and advanced experience. First, the mean broadband penetration of 1.401 subscriptions per 100 people is far below the critical mass threshold identified by Koutroumpis (2009) as necessary for network externalities to generate measurable output effects. Second, fixed broadband is not the primary mode of digital connectivity in SSA: Myovella et al. (2020) find that mobile telecommunications, not fixed broadband drives ICT-related growth in SSA, while the World Bank (2024) documents that 61% of SSA residents live within broadband range but do not use it, reflecting affordability constraints and limited local content rather than infrastructure gaps per se. Third, the complementary factors required for broadband to function as a general-purpose technology; absorptive human capital, effective governance, competitive digital markets remain underdeveloped across much of the region (David & Grobler, 2020; Odhiambo, 2022).

The significant time fixed effects for crisis years with coefficients of  $-0.206$  in 2015 and  $-0.166$  in 2020 being the largest confirm that external shocks are the dominant drivers of short-run income variation in SSA, overshadowing the contribution of any single structural factor including broadband. The finding of conditional convergence across all models, with lagged GDP coefficients between 0.842 and 0.933 in the preferred specifications, is nevertheless encouraging: it confirms that SSA economies are moving towards their steady states, and that structural interventions including digital infrastructure investment can shift these steady states upward over the long run (Barro, 1991; Mankiw et al., 1992).

From a policy perspective, the results suggest three priorities. First, broadband investment should focus on mobile rather than fixed infrastructure given the mobile-first nature of SSA's digital economy. Second, broadband deployment should be bundled with complementary interventions digital literacy, affordable device subsidies, and local content development, without which infrastructure investment alone will not generate the productivity gains observed in OECD economies. Third, governance reform

remains foundational: the positive and consistent relationship between government effectiveness and income across all specifications (coefficients ranging from 0.044 to 0.075) confirms that institutional quality is a precondition for sustainable growth in SSA, and digital infrastructure investment is most likely to pay dividends in countries that simultaneously address governance constraints.

**Control Variables.** The control variables display largely consistent patterns across all five model specifications, and their signs are broadly aligned with theoretical expectations and the existing SSA empirical literature, even where individual coefficients do not reach conventional significance levels. Gross capital formation carries a positive coefficient across all models ranging from 0.018 in Model 2a to 0.135 in Model 2 consistent with the neoclassical prediction that physical capital accumulation is a fundamental driver of per capita income growth (Solow, 1956; Mankiw et al., 1992). This positive association is well established in the SSA growth literature: Haftu (2019) and Myovella et al. (2020) both report positive coefficients on gross capital formation in their System GMM estimations for SSA panels, confirming the importance of investment for long-run income convergence in the region. Trade openness is positive in most specifications, with coefficients ranging from -0.001 in Model 1 to 0.005 in Model 2, consistent with the trade-growth nexus that is well documented in both global and SSA-specific studies (Asongu et al., 2020; Ulaşan, 2015). The magnitude is small, however, reflecting the ambiguous short-run relationship between trade openness and growth in commodity-dependent economies where exports are concentrated in primary goods with limited value-added and employment linkages (Asiedu, 2006). Education consistently carries a near-zero and statistically insignificant coefficient across all models, ranging from -0.001 to 0.001. This result is consistent with the findings of Haftu (2019) and Odhiambo (2022), who report insignificant education effects in SSA GMM panels and attribute this to measurement limitations, the gross enrolment ratio captures quantity rather than quality of schooling and to the long gestation between educational investment and labour market productivity effects that may fall outside the study window (Barro & Lee, 2013). Inflation is consistently negative across all models with coefficients ranging from -0.001 to -0.0001, consistent with the macroeconomic stability hypothesis that price instability reduces investment, distorts resource allocation, and depresses long-run growth (Fischer, 1993). While the coefficients do not reach significance in most specifications, their consistent negative sign across all five models and the large standard deviation of inflation in the sample (25.757) driven by hyperinflationary episodes in Zimbabwe and Sudan confirm that macroeconomic instability remains a meaningful constraint on SSA growth (IMF, 2020). Population growth is negative across all specifications except for model 2b with coefficients ranging from -0.039 to 0.013, consistent with the capital dilution mechanism of neoclassical growth theory whereby rapid demographic growth reduces capital per worker and slows income convergence (Solow, 1956; Mankiw et al., 1992). This negative association between population growth and per capita income is among the most robust findings in the SSA development literature, and is corroborated by the strong negative bivariate correlation of -0.583 between the two variables observed in the correlation matrix. Taken together, the control variables perform as expected across all five specifications, lending credibility to the overall model and confirming that the coefficient on broadband penetration is not driven by omitted variable bias from these standard growth determinants.

## 5.5 OLS Robustness Estimations

To provide a benchmark against the System GMM results and to assess whether the insignificance of broadband penetration in the preferred specifications reflects genuine endogeneity correction or model misspecification, Ordinary Least Squares (OLS) estimations are presented as a supplementary robustness check. While OLS does not address endogeneity or dynamic income persistence and is therefore not the preferred estimator for causal inference in this context (Blundell & Bond, 1998; Arellano & Bond, 1991), it reveals the unconditional associations between the regressors and GDP per capita in the absence of instrument restrictions.

**Table 5.2: OLS Estimation Results — Baseline and Complementarity Models**

| Variable                                                                     | OLS Baseline           | OLS with Interactions  |
|------------------------------------------------------------------------------|------------------------|------------------------|
| <i>Dependent variable: ln(GDP per capita)   40 SSA countries   2006–2023</i> |                        |                        |
| <b>A. Core variables</b>                                                     |                        |                        |
| Broadband penetration                                                        | 0.0391***<br>(0.0079)  | 0.4417***<br>(0.0477)  |
| FDI stock                                                                    | -0.0017***<br>(0.0004) | -0.0028***<br>(0.0004) |
| Government effectiveness                                                     | 0.3659***<br>(0.0548)  | 0.3256***<br>(0.0536)  |
| E-Government Index                                                           | 1.4111***<br>(0.3045)  | 0.9240**<br>(0.3014)   |
| Trade openness                                                               | 0.0085***<br>(0.0009)  | 0.0075***<br>(0.0008)  |
| ln(Gross capital formation)                                                  | 0.1700***<br>(0.0198)  | 0.1784***<br>(0.0181)  |
| Education                                                                    | -0.0064***<br>(0.0013) | -0.0064***<br>(0.0012) |
| Inflation rate                                                               | 0.0004<br>(0.0008)     | 0.0001<br>(0.0008)     |
| Population growth                                                            | -0.2268***<br>(0.0360) | -0.2091***<br>(0.0334) |
| <b>B. Interaction terms</b>                                                  |                        |                        |
| <i>Broadband × FDI stock</i>                                                 | —                      | 0.0001<br>(0.0001)     |
| <i>Broadband × E-Government</i>                                              | —                      | -0.4594***<br>(0.0696) |
| <i>Broadband × Gov. effectiveness</i>                                        | —                      | -0.1255***<br>(0.0240) |
| <b>C. Diagnostics</b>                                                        |                        |                        |
| <i>Observations</i>                                                          | 542                    | 542                    |
| <i>R-squared</i>                                                             | 0.710                  | 0.760                  |
| <i>Adj. R-squared</i>                                                        | 0.705                  | 0.754                  |
| <i>F-statistic</i>                                                           | 144.6***               | 139.4***               |

**Notes:** Robust standard errors in parentheses. \*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ , \*  $p < 0.05$ , †  $p < 0.10$ . OLS Baseline includes all core variables without interaction terms. OLS with Interactions includes all three interaction terms simultaneously. Both models include an intercept. 89 observations dropped due to missing values.

**Interpretation:** Given that the key variable of interest broadband penetration was statistically insignificant in the System GMM specifications reported in Section 5.1 through 5.4, Ordinary Least Squares (OLS) estimations are presented as a supplementary robustness check. While OLS does not address endogeneity or dynamic income persistence and is therefore not the preferred estimator for causal inference in this context (Blundell & Bond, 1998; Arellano & Bond, 1991), it provides a useful benchmark that reveals the unconditional associations between the regressors and GDP per capita, free from the instrument restrictions imposed by the GMM framework.

The OLS baseline model explains 70.5% of the variation in log GDP per capita (Adjusted  $R^2 = 0.705$ ), confirming strong explanatory power for a cross-country growth specification. In contrast to the GMM results, broadband penetration is positive and highly statistically significant ( $\beta = 0.039$ ,  $p < 0.001$ ), indicating that a one percentage point increase in broadband penetration is associated with approximately a 3.9% increase in GDP per capita when country and time fixed effects are not controlled for. Government effectiveness ( $\beta = 0.366$ ,  $p < 0.001$ ), the E-Government Development Index ( $\beta = 1.411$ ,  $p < 0.001$ ), trade openness ( $\beta = 0.009$ ,  $p < 0.001$ ), and gross capital formation ( $\beta = 0.170$ ,  $p < 0.001$ ) are all positive and significant, consistent with theoretical expectations. Population growth is negative and significant ( $\beta = -0.227$ ,  $p < 0.001$ ), consistent with the capital dilution hypothesis (Solow, 1956; Mankiw et al., 1992). FDI stock is negative and significant ( $\beta = -0.002$ ,  $p < 0.001$ ), likely reflecting the endogenous concentration of FDI in small economies with high FDI-to-GDP ratios but low absolute income levels. Education is negative and significant, which may reflect multicollinearity with governance and income level variables rather than a genuine negative human capital effect.

The OLS complementarity model, which introduces all three interaction terms simultaneously, increases explanatory power to 75.4% (Adjusted  $R^2 = 0.754$ ). The direct broadband coefficient increases substantially to 0.442 ( $p < 0.001$ ), and two of the three interaction terms achieve conventional significance. The interaction between broadband and the E-Government Index is negative and highly significant ( $\beta = -0.459$ ,  $p < 0.001$ ), while the interaction between broadband and government effectiveness is also negative and significant ( $\beta = -0.126$ ,  $p < 0.001$ ). The broadband-FDI interaction remains statistically insignificant ( $\beta = 0.000$ ,  $p = 0.107$ ), consistent with the GMM results.

The negative interaction terms in the OLS model mirror the pattern observed in the GMM results, though with greater statistical precision. They suggest that broadband's growth return diminishes at higher levels of governance quality and e-government development a finding consistent with the leapfrogging hypothesis and the substitution mechanism discussed in Section 5.3.3, whereby broadband generates stronger marginal returns in lower-governance environments where it can bypass institutional inefficiencies (Steinmueller, 2001; Aker & Mbiti, 2010). However, OLS estimates are subject to upward bias due to reverse causality higher-income countries invest more in broadband and the absence of country fixed effects means unobserved cross-country heterogeneity is absorbed into the coefficients. The substantially larger broadband coefficient in OLS (0.039–0.442) compared to

GMM (0.003–0.045) is precisely the pattern predicted by endogeneity bias, confirming that the System GMM estimator provides more conservative and credible causal estimates. The OLS results should therefore be interpreted as descriptive associations rather than causal effects, and the GMM results reported in Table 5.1 remain the preferred basis for inference.

## 6. Concluding Remarks

This thesis examines the relationship between broadband penetration and economic growth in Sub-Saharan Africa over the period 2006 - 2023, using a panel dataset of 40 countries and a two-step System GMM estimator developed by Blundell and Bond (1998). Two empirical models are estimated: a baseline model assessing the direct effect of broadband penetration on GDP per capita, and a complementarity model testing whether this effect is conditioned by FDI stock, e-government development, and government effectiveness. The analysis is grounded in the augmented Cobb-Douglas production framework and endogenous growth theory, which conceptualise broadband as a general-purpose technology whose productivity effects depend on complementary inputs (Romer, 1990; Bresnahan & Trajtenberg, 1995; Czernich et al., 2011).

The baseline model confirms conditional convergence across the SSA panel, with a lagged GDP per capita coefficient of 0.911 ( $p < 0.001$ ), validating the dynamic specification and confirming that lower-income SSA economies are converging towards their long-run steady states. Broadband penetration carries a positive but statistically insignificant coefficient of 0.003 ( $p = 0.634$ ), indicating a directionally consistent but empirically fragile direct growth effect. This result is consistent with Myovella et al. (2020), who find that broadband's effect is minimal for SSA compared to OECD economies, and with Haftu (2019), who similarly reports an insignificant internet penetration effect in SSA using System GMM. The contrast with OECD evidence where Czernich et al. (2011) find that a 10 percentage point increase in broadband penetration raises per capita GDP growth by 0.9 to 1.5 percentage points is itself an important finding that reflects SSA's structural position: broadband penetration averaging just 1.401 subscriptions per 100 people, well below any critical mass threshold, combined with weak governance, nascent e-government systems, and limited technology-intensive FDI.

None of the three complementarity interaction terms achieves conventional statistical significance: broadband-FDI ( $\beta = -0.000024$ ,  $p = 0.794$ ), broadband-EGov ( $\beta = -0.057$ ,  $p = 0.113$ ), and broadband-GovEff ( $\beta = -0.016$ ,  $p = 0.352$ ). This indicates that broadband's growth return is not yet significantly amplified by these institutional and technological factors at the macroeconomic level in SSA, consistent with Asongu and Odhiambo (2020) and Kouam and Asongu (2023). The significant negative time fixed effects for crisis years, particularly 2015 (-0.206) and 2020 (-0.166) confirm that macroeconomic shocks remain the dominant short-run drivers of income variation in SSA, overshadowing any structural factor including broadband. All five GMM specifications pass the AR(2) test ( $p$ -values: 0.268–0.666) and the Sargan-Hansen test ( $p$ -values: 0.103–0.936), confirming instrument validity throughout.

This thesis makes three contributions to the literature. First, it empirically tests the general-purpose technology hypothesis for a 40-country SSA panel over 18 years, finding that the complementary conditions required for broadband to function as a GPT in the sense of Bresnahan and Trajtenberg (1995) are not yet present across SSA, a finding that challenges the technology diffusion narrative underpinning much of SSA's national broadband policy discourse (Friederici et al., 2017). Second, it contributes methodologically by applying System GMM with a collapsed instrument matrix to a longer and more recent SSA panel than most comparable studies, providing more reliable causal estimates than the static panel approaches that characterise much of the earlier SSA literature. Third, by estimating SSA-specific models rather than pooling with global panels, it provides context-specific evidence that the strong OECD broadband-growth relationship does not straightforwardly transfer to SSA's structural and institutional environment, with implications for how development institutions design and evaluate digital infrastructure programmes.

The findings generate several concrete policy implications. The insignificant direct broadband effect suggests that the primary constraint on broadband's economic contribution in SSA is not infrastructure supply but demand-side factors: affordability, digital literacy, local content, and practical use cases. The World Bank (2024) documents that 61% of SSA residents live within broadband range but do not use it, confirming that infrastructure deployment without demand stimulation generates limited growth returns. Policymakers should therefore prioritise mobile broadband over fixed infrastructure given the mobile-first nature of SSA's digital economy (Haftu, 2019; Myovella et al., 2020) and bundle broadband investment with complementary interventions including governance reform, energy access, e-government development, and attraction of technology-intensive FDI. The threshold effect documented by Kouam and Asongu (2023), that broadband contributes negatively to growth where electricity access falls below 60% of the population underscores that energy and digital infrastructure must be treated as joint priorities. Governance reform is foundational: the consistently positive relationship between government effectiveness and income across all specifications confirms that institutional quality must improve alongside digital infrastructure for broadband to generate sustained productivity gains (Asongu & Nwachukwu, 2018; North, 1990).

Several limitations qualify the findings. The use of fixed broadband subscriptions may understate actual digital connectivity in SSA, where mobile broadband dominates. The System GMM relies on internal instruments, which are weaker than external instruments such as submarine cable arrivals (Hjort & Poulsen, 2019); future research employing such instruments would provide stronger causal identification. The exclusion of nine countries on grounds of data availability means the results may not generalise to fragile and small-island states. GDP per capita captures aggregate income but not distributional outcomes; future research could examine broadband's effects on inequality and inclusive growth following Ofori and Asongu (2021) and Odhiambo (2022).

Future research should employ composite ICT indices capturing both fixed and mobile broadband and digital skills, exploit the staggered arrival of submarine cables as natural experiments for stronger causal identification following Hjort and Poulsen (2019), apply threshold regression approaches to test for non-linearities in the broadband-governance relationship following Kouam and Asongu (2023), and use firm-level or subnational data to illuminate the microeconomic mechanisms through which broadband affects productivity and employment in SSA.

Sub-Saharan Africa stands at a critical juncture in its digital development trajectory. Fixed broadband penetration is expanding from an extremely low base, and mobile money has demonstrated that digital technologies can generate transformative economic outcomes when they reach sufficient scale. Yet the aggregate evidence presented in this thesis positive but fragile direct effects, absent complementarity effects, and time fixed effects dominated by global shocks suggests that the conditions for broadband-led growth at the macroeconomic level are not yet fully in place across the region.

The lesson from the OECD experience is not that broadband does not matter in SSA, but that the complementary investments in governance, human capital, energy infrastructure, and e-government services that made broadband economically transformative in advanced economies have not yet been made at scale in SSA. As North (1990) established, institutions are the fundamental determinant of economic performance; digital infrastructure generates returns proportional to the institutional environment in which it operates. The policy prescription is therefore not to slow broadband investment but to bundle it with the complementary reforms without which connectivity alone will not deliver the productivity gains and inclusive development that SSA's growing population requires. The digital dividend for Sub-Saharan Africa is real, but it must be earned through comprehensive development strategies rather than assumed as a natural consequence of infrastructure deployment.

## **Summary of Masters thesis in Estonian**

Digitaalne ühenduvus on muutunud kaasaegse majandusarengu nurgakiviks, kujundades tootmisprotsesse, turustruktuure ning sotsiaalselt ja majanduslikku suhtlust. Lairibainterneti levik on selles kontekstis eriti oluline, kuna see toimib üldotstarbelistel eesmärkidel kasutatava infrastruktuurina, mis soodustab innovatsiooni levikut, vähendab tehingukuluseid ning suurendab tootlikkust erinevates majandussektorites. Vaatamata märkimisväärsetele investeeringutele digitaalsesse infrastruktuuri jääb lairibateenuste majandusliku mõju empiiriline tõendusmaterjal Sahara-taguses Aafrikas ebaselgeks ja vastuoluliseks.

Käesolev magistritöö uurib lairiba leviku ja majanduskasvu vahelist seost 40 Sahara-taguse Aafrika (SSA) riigi paneelandmetel ajavahemikul 2006–2023. Töö keskne uurimisküsimus on, kas lairibaühenduse levik aitab oluliselt kaasa majanduskasvule Sahara-taguses Aafrikas ning millistes institutsioonilistes ja tehnoloogilistes tingimustes on selle mõju tugevaim. Uuring tugineb endogeense majanduskasvu teooriale ning üldotstarbelistel tehnoloogiatel põhinevale teoreetilisele raamistikule, käsitledes lairibainternetti tootlikkust suurendava tehnoloogiana, mille majanduslik mõju sõltub täiendavatest institutsionaalsetest ja tehnoloogilistest teguritest.

Empiirilises analüüsis kasutatakse Blundell ja Bondi (1998) kaheastmelist süsteemset üldistatud momentide meetodit (*System GMM*), mis käsitleb samaaegselt endogeensust, dünaamilist sissetulekute püsivust ning riigipõhist varjatud heterogeensust. Hinnatakse kahte mudelit: baasmudelit, mis hindab lairiba leviku otsest mõju SKP-le elaniku kohta, ning komplementaarsuse mudelit, mis testib, kas see mõju sõltub kolmest tingimuslikust muutujast — valitsuse tõhususest institutsioonilise kvaliteedi näitajana, e-valitsuse arenguindeksist digitaalse institutsioonilise suutlikkuse mõõdikuna ning välismaiste otseinvesteeringute mahust innovatsiooni ja teadmiste leviku puhvermuutujana.

Baasmudeli tulemused näitavad, et lairibaühenduse levikul on positiivne, kuid statistiliselt ebaoluline otsene mõju majanduskasvule. See leid on kooskõlas varasema Sahara-tagusele Aafrikale keskendunud empiirilise kirjandusega, eelkõige Myovella jt (2020) ning Haftu (2019) tulemustega, kes dokumenteerivad sarnaselt nõrka lairibaühenduse ja majanduskasvu seost selles piirkonnas. Ükski kolmest komplementaarsuse interaktsiooniterminist ei saavuta tavapärasest statistilisest olulisust, mis viitab sellele, et eeldused lairiba toimimiseks majanduskasvu võimaldava üldotstarbelist tehnoloogiana ei ole Sahara-taguses Aafrikas makromajanduslikul tasandil veel täidetud. Lisaks kinnitavad olulised ajanäitajad aastate 2015 ja 2020 kohta, et makromajanduslikud šokid — eelkõige toorainehindade langus ja COVID-19 pandeemia — on lühiajalise sissetulekute kõikumise peamised tegurid piirkonnas. Tavalise vähimruutude meetodi abil tehtud tulemuste tundlikkuse kontrollid kinnitavad tulemuste kooskõla, näidates samal ajal endogeensusest tingitud ülespoole kallutatust.

Uuringu majanduspoliitilised soovituselised rõhutavad, et lairiba infrastruktuuri investeeringud peavad olema seotud täiendavate meetmetega, sealhulgas valitsemise reformiga, energiasaadatavuse laiendamise, e-valitsuse arendamisega ning nõudluspoolsete sekkumistega nagu digitaalse kirjaoskuse programmid ja taskukohase ühenduvuse algatused. Ilma nende täiendavate reformideta ei suuda lairiba kasutuselevõtt üksi Sahara-taguses Aafrikas jätkusuutlikku majanduslikku tulu toota.

Käesolev töö annab kolm peamist panust kirjandusse. Esiteks testib see empiiriliselt üldotstarbelistel tehnoloogiatel põhinevat hüpoteesi 40-riigilisel Sahara-taguse Aafrika paneelil 18-aastase perioodi jooksul. Teiseks rakendab see süsteemset GMM-i kokkusurutud instrumentide maatriksiga pikema ja värskema SSA paneeli puhul kui enamikus võrreldavates uuringutes. Kolmandaks pakub see piirkonnapõhist tõendusmaterjali, et OECD-s täheldatud tugev lairiba ühenduste ja majanduskasvu seos ei laiene automaatselt Sahara-taguse Aafrika struktuursesse ja institutsioonilisse keskkonda.

#### **CERCS codes:**

S181 – Econometrics

S180 – Economics

S185 – International economics and development economics

#### **Title in Estonian**

Lairiba levik ja majanduskasv Sahara-taguses Aafrikas: institutsionaalsete ja tehnoloogiliste täiendavuste roll.

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## Appendix

Countries used in the analysis: Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Chad, Comoros, Congo - Dem. Rep., Cote d'Ivoire, Eritrea, Eswatini, Ethiopia, Gabon, Gambia-The, Ghana, Guinea, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Seychelles, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia and Zimbabwe

Countries excluded: the Central African Republic, the Republic of Congo, Equatorial Guinea, Guinea-Bissau, São Tomé and Príncipe, Sierra Leone, Somalia, and South Sudan.

Figure A1: Heatmap of missing variables across countries.

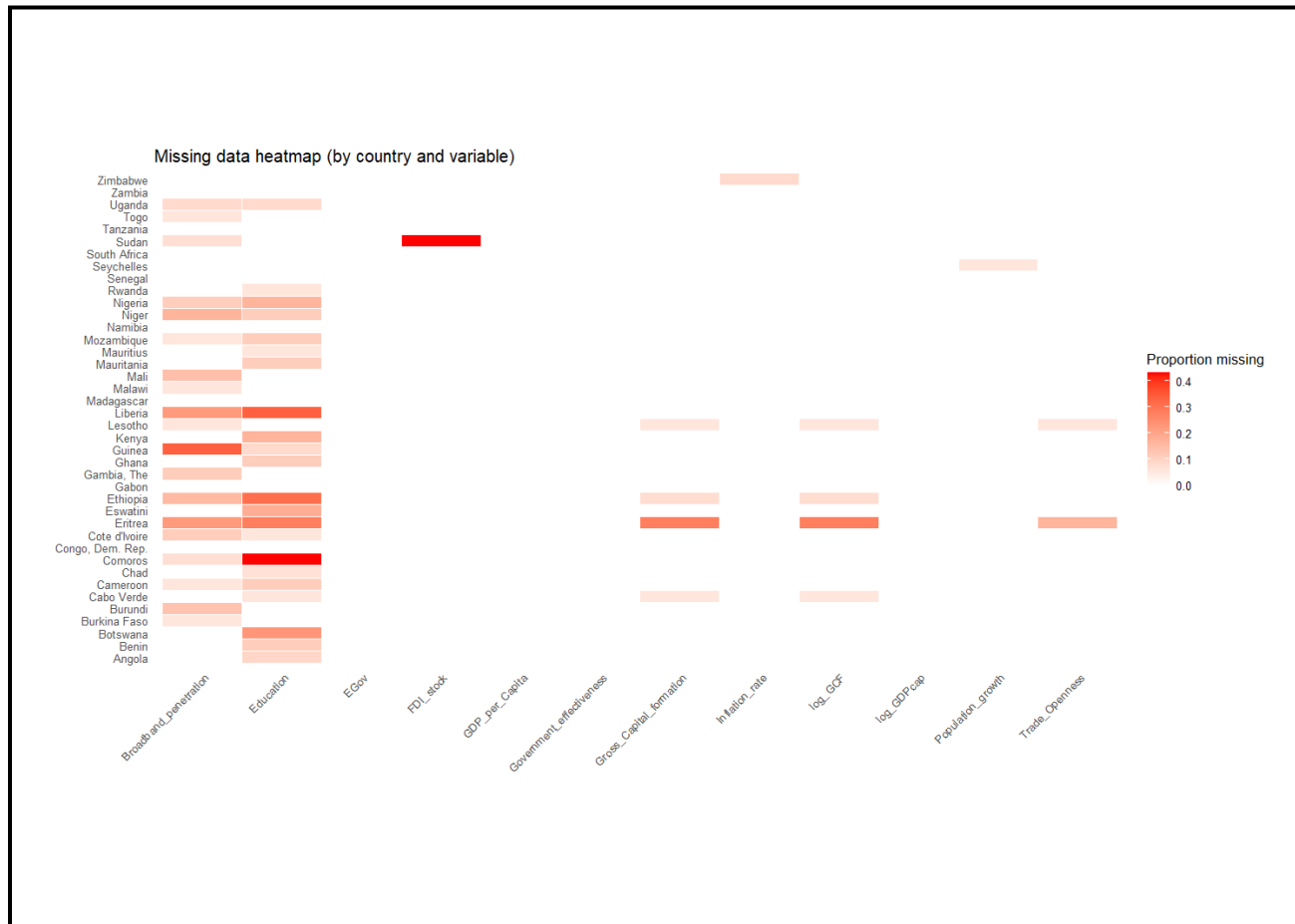


Figure A2 – Table of yearly broadband penetration average standard deviation and observations.

|    | Year | avg_broadband | sd_broadband | n  |
|----|------|---------------|--------------|----|
| 1  | 2006 | 0.2789219     | 0.6970639    | 24 |
| 2  | 2007 | 0.3132930     | 0.8437656    | 30 |
| 3  | 2008 | 0.3638456     | 0.9609757    | 33 |
| 4  | 2009 | 0.4808096     | 1.3070814    | 33 |
| 5  | 2010 | 0.6603370     | 1.7682767    | 34 |
| 6  | 2011 | 0.8509748     | 2.2764572    | 35 |
| 7  | 2012 | 0.9182669     | 2.4953598    | 37 |
| 8  | 2013 | 1.0373957     | 2.8303347    | 38 |
| 9  | 2014 | 1.1068481     | 2.9013256    | 38 |
| 10 | 2015 | 1.1895642     | 3.1095584    | 39 |
| 11 | 2016 | 1.2654631     | 3.3921983    | 36 |
| 12 | 2017 | 1.4741125     | 3.8973390    | 34 |
| 13 | 2018 | 1.9468412     | 4.8845210    | 29 |
| 14 | 2019 | 2.0755100     | 5.5794676    | 33 |
| 15 | 2020 | 2.4636797     | 6.5842073    | 32 |
| 16 | 2021 | 2.9014118     | 7.2398109    | 32 |
| 17 | 2022 | 2.8446847     | 6.7836682    | 32 |
| 18 | 2023 | 3.5511800     | 7.6463429    | 26 |

## Results of models and diagnostics from R

```

m1 <- extract_pgmm(model1)
> ar1_m1 <- mtest(model1, order=1, robust=TRUE)$p.value
> ar2_m1 <- mtest(model1, order=2, robust=TRUE)$p.value
> sar_m1 <- sargan(model1)$p.value
> obs_m1 <- nobs(model1)
> print(m1)
      term coefficient  std_error  p_value
1  lag(log_GDPcap, 1) 9.112084e-01 0.0820431797 1.167084e-28
2  Broadband_penetration 2.894824e-03 0.0060836606 6.341913e-01
3      FDI_stock 4.880103e-05 0.0004203748 9.075817e-01
4 Government_effectiveness 5.962814e-02 0.0529923797 2.604954e-01
5      EGov 6.659142e-03 0.1800089826 9.704903e-01
6  Trade_Openness 1.045459e-04 0.0005097657 8.375047e-01
7      log_GCF 2.284130e-02 0.0249345371 3.596403e-01
8      Education 8.902989e-05 0.0006681582 8.939983e-01
9  Inflation_rate -9.561053e-05 0.0003507781 7.851861e-01
10 Population_growth -2.635086e-02 0.0234410534 2.609567e-01
11  (Intercept) 3.249618e-01 0.3211677142 3.116273e-01
12      2008 8.456066e-03 0.0187788737 6.524965e-01
13      2009 -1.166183e-01 0.0382322535 2.286437e-03

```

```

14      2010 -5.830371e-02 0.0379939731 1.248940e-01
15      2011 -2.464496e-02 0.0334559944 4.613425e-01
16      2012 -1.069775e-01 0.0317791708 7.619032e-04
17      2013 -7.692190e-02 0.0298313496 9.921329e-03
18      2014 -7.753914e-02 0.0322118799 1.607713e-02
19      2015 -2.060872e-01 0.0415394033 7.004277e-07
20      2016 -1.473220e-01 0.0279313770 1.331723e-07
21      2017 -6.810862e-02 0.0410958173 9.745628e-02
22      2018 -4.136123e-02 0.0325856270 2.043309e-01
23      2019 -1.217926e-01 0.0283591995 1.749768e-05
24      2020 -1.655860e-01 0.0399090412 3.338060e-05
25      2021 -5.558097e-02 0.0353051105 1.154172e-01
26      2022 -9.328745e-02 0.0300154309 1.883689e-03
27      2023 -1.277494e-01 0.0409702120 1.820176e-03

```

```
> cat("\nAR(1) p:", ar1_m1)
```

```
AR(1) p: 0.007002459
```

```
> cat("\nAR(2) p:", ar2_m1)
```

```
AR(2) p: 0.5476078
```

```
> cat("\nSargan p:", sar_m1)
```

```
Sargan p: 0.147278
```

```
> cat("\nObs:", obs_m1)
```

```
Function to extract coefficients, SEs and p-values from pgmm
```

```

> extract_pgmm <- function(model) {
+   coefs <- coef(model)
+   ses <- sqrt(diag(vcovHC(model)))
+   tstat <- coefs / ses
+   pvals <- 2 * pnorm(abs(tstat), lower.tail = FALSE)
+   data.frame(
+     term      = names(coefs),
+     coefficient = coefs,
+     std_error  = ses,
+     p_value    = pvals,
+     row.names  = NULL
+   )
+ }
> # Now re-run the extraction
> m_full <- extract_pgmm(model2_full)
> m_2a <- extract_pgmm(model2a)

```

```

> m_2b <- extract_pgmm(model2b)
> m_2c <- extract_pgmm(model2c)
> # Diagnostics
> diags <- data.frame(
+   model   = c("Full", "2a", "2b", "2c"),
+   ar2_p   = c(
+     mtest(model2_full, order=2, robust=TRUE)$p.value,
+     mtest(model2a,    order=2, robust=TRUE)$p.value,
+     mtest(model2b,    order=2, robust=TRUE)$p.value,
+     mtest(model2c,    order=2, robust=TRUE)$p.value
+   ),
+   sargan_p = c(
+     sargan(model2_full)$p.value,
+     sargan(model2a)$p.value,
+     sargan(model2b)$p.value,
+     sargan(model2c)$p.value
+   )
+)
> print(m_full)

```

|    | term                     | coefficient   | std_error    | p_value    |
|----|--------------------------|---------------|--------------|------------|
| 1  | lag(log_GDPcap, 1)       | 0.7306511663  | 0.3214337306 | 0.02302013 |
| 2  | Broadband_penetration    | 0.1669615113  | 0.1477963908 | 0.25861427 |
| 3  | FDI_stock                | -0.0033142353 | 0.0050539010 | 0.51196720 |
| 4  | Government_effectiveness | -0.2585204420 | 0.4710635200 | 0.58314157 |
| 5  | EGov                     | 2.2677320505  | 4.2806959824 | 0.59627987 |
| 6  | BB_FDI                   | 0.0002399558  | 0.0004365169 | 0.58252130 |
| 7  | BB_EGov                  | -0.2655210265 | 0.2971048219 | 0.37148522 |
| 8  | BB_Gov                   | 0.0028257043  | 0.0373709732 | 0.93972757 |
| 9  | Trade_Openness           | 0.0052680380  | 0.0079161817 | 0.50574536 |
| 10 | log_GCF                  | 0.1345284256  | 0.1509699404 | 0.37287868 |
| 11 | Education                | -0.0004532606 | 0.0021032870 | 0.82937667 |
| 12 | Inflation_rate           | -0.0005160690 | 0.0007484454 | 0.49049535 |
| 13 | Population_growth        | 0.0126319257  | 0.0910729940 | 0.88968634 |
| 14 | (Intercept)              | -1.8641342466 | 2.8760561772 | 0.51688379 |
| 15 | 2008                     | -0.0946259872 | 0.1516116326 | 0.53253953 |
| 16 | 2009                     | -0.0845049180 | 0.0880777988 | 0.33733968 |
| 17 | 2010                     | -0.1261926566 | 0.2012649352 | 0.53066073 |
| 18 | 2011                     | -0.2516897602 | 0.2217056898 | 0.25627365 |
| 19 | 2012                     | -0.3557464270 | 0.2693900239 | 0.18664720 |
| 20 | 2013                     | -0.2106513137 | 0.1909475743 | 0.26994498 |
| 21 | 2014                     | -0.3469023234 | 0.3697156486 | 0.34809286 |

```

22      2015 -0.2271445850 0.1011165675 0.02468072
23      2016 0.0483610637 0.3081993462 0.87531193
24      2017 0.2139341588 0.5723918902 0.70858683
25      2018 -0.2833834465 0.3374867360 0.40108354
26      2019 -0.9242518358 1.1770033983 0.43230207
27      2020 -0.5306514806 0.5822250175 0.36207416
28      2021 -0.5733197517 0.7921738660 0.46923170
29      2022 -0.3998661824 0.4530808605 0.37747985
30      2023 -0.6134583109 0.7652108940 0.42273503
> print(m_2a)
      term coefficient  std_error  p_value
1  lag(log_GDPcap, 1) 9.331115e-01 1.225711e-01 2.681804e-14
2  Broadband_penetration 7.506786e-03 1.959228e-02 7.016085e-01
3      FDI_stock 3.134910e-04 8.149926e-04 7.004930e-01
4      BB_FDI -2.419809e-05 9.257666e-05 7.937961e-01
5  Government_effectiveness 4.363980e-02 5.410795e-02 4.199361e-01
6      EGov -1.276081e-01 1.751802e-01 4.663447e-01
7  Trade_Openness -8.376039e-05 5.998334e-04 8.889449e-01
8      log_GCF 2.382457e-02 3.632365e-02 5.118906e-01
9      Education 4.827381e-04 7.135622e-04 4.987115e-01
10  Inflation_rate -1.264500e-04 3.894320e-04 7.454053e-01
11  Population_growth -2.356481e-02 2.924314e-02 4.203446e-01
12  (Intercept) 1.431360e-01 3.339727e-01 6.682247e-01
13      2008 6.703068e-03 1.995619e-02 7.369544e-01
14      2009 -1.306660e-01 3.609119e-02 2.941019e-04
15      2010 -7.278045e-02 3.361391e-02 3.037322e-02
16      2011 -4.424338e-02 5.093531e-02 3.850555e-01
17      2012 -1.201060e-01 3.824443e-02 1.686696e-03
18      2013 -9.375737e-02 3.434037e-02 6.328862e-03
19      2014 -9.869556e-02 3.358299e-02 3.294268e-03
20      2015 -2.306938e-01 3.648888e-02 2.576934e-10
21      2016 -1.681412e-01 2.955630e-02 1.279031e-08
22      2017 -9.069409e-02 4.084919e-02 2.640399e-02
23      2018 -4.933349e-02 3.376625e-02 1.440073e-01
24      2019 -1.314676e-01 2.300833e-02 1.104067e-08
25      2020 -1.659080e-01 3.704111e-02 7.498518e-06
26      2021 -6.454761e-02 5.118448e-02 2.072808e-01
27      2022 -9.481031e-02 4.823896e-02 4.936447e-02
28      2023 -1.315785e-01 4.628254e-02 4.469955e-03
> print(m_2b)
      term coefficient  std_error  p_value

```

```

1 lag(log_GDPcap, 1) 8.419915e-01 0.1079033053 6.035477e-15
2 Broadband_penetration 4.493102e-02 0.0294471525 1.270550e-01
3 EGov 1.737153e-01 0.2510428441 4.889533e-01
4 BB_EGov -5.730270e-02 0.0361970410 1.134039e-01
5 FDI_stock -1.406324e-04 0.0005011084 7.789845e-01
6 Government_effectiveness 5.761553e-02 0.0494748558 2.442046e-01
7 Trade_Openness 5.371468e-04 0.0006533899 4.110244e-01
8 log_GCF 3.408594e-02 0.0266625093 2.011006e-01
9 Education -2.707946e-04 0.0007952458 7.334674e-01
10 Inflation_rate -4.616914e-05 0.0002973814 8.766224e-01
11 Population_growth -3.921901e-02 0.0278049874 1.583913e-01
12 (Intercept) 5.566963e-01 0.4611726403 2.273812e-01
13 2008 9.145251e-03 0.0205252654 6.559146e-01
14 2009 -1.089306e-01 0.0361394484 2.576802e-03
15 2010 -6.099394e-02 0.0340582788 7.331422e-02
16 2011 -2.745578e-02 0.0363257708 4.497565e-01
17 2012 -1.165934e-01 0.0363180543 1.325768e-03
18 2013 -8.267558e-02 0.0331772394 1.270487e-02
19 2014 -6.990044e-02 0.0381898717 6.719916e-02
20 2015 -2.003854e-01 0.0440890388 5.493127e-06
21 2016 -1.541979e-01 0.0299603152 2.650552e-07
22 2017 -6.039819e-02 0.0451061106 1.805627e-01
23 2018 -5.730373e-02 0.0350081858 1.016583e-01
24 2019 -1.359227e-01 0.0296053725 4.408092e-06
25 2020 -1.912181e-01 0.0470345276 4.793281e-05
26 2021 -7.560475e-02 0.0452920513 9.506351e-02
27 2022 -1.196526e-01 0.0401432984 2.876495e-03
28 2023 -1.416200e-01 0.0501240612 4.722326e-03
> print(m_2c)

```

```

      term coefficient std_error p_value
1 lag(log_GDPcap, 1) 8.788191e-01 0.0660187098 1.980141e-40
2 Broadband_penetration 1.881940e-02 0.0180191958 2.962965e-01
3 Government_effectiveness 7.493888e-02 0.0527601252 1.555001e-01
4 BB_Gov -1.550287e-02 0.0166435315 3.516130e-01
5 FDI_stock -1.361153e-05 0.0004701022 9.769009e-01
6 EGov -1.222134e-02 0.1873185360 9.479800e-01
7 Trade_Openness 2.330460e-04 0.0005279707 6.589239e-01
8 log_GCF 2.967697e-02 0.0214169551 1.658458e-01
9 Education -3.240622e-05 0.0007134125 9.637692e-01
10 Inflation_rate -7.756231e-05 0.0002978656 7.945602e-01
11 Population_growth -3.513609e-02 0.0218712652 1.081651e-01

```

```

12      (Intercept) 4.361954e-01 0.3759496727 2.459472e-01
13      2008 9.855943e-03 0.0193472348 6.104551e-01
14      2009 -1.045282e-01 0.0360240684 3.712367e-03
15      2010 -5.774832e-02 0.0373773638 1.223443e-01
16      2011 -2.742470e-02 0.0352031418 4.359554e-01
17      2012 -1.059502e-01 0.0346254437 2.214159e-03
18      2013 -7.579497e-02 0.0317328338 1.691572e-02
19      2014 -7.365394e-02 0.0337006798 2.884981e-02
20      2015 -1.979427e-01 0.0382322171 2.250243e-07
21      2016 -1.473789e-01 0.0291119927 4.138330e-07
22      2017 -6.949935e-02 0.0395836937 7.912991e-02
23      2018 -4.178389e-02 0.0348833531 2.309881e-01
24      2019 -1.250047e-01 0.0299587500 3.011952e-05
25      2020 -1.698409e-01 0.0421179961 5.518640e-05
26      2021 -6.820417e-02 0.0384488645 7.608087e-02
27      2022 -1.105815e-01 0.0332464770 8.806689e-04
28      2023 -1.429760e-01 0.0470393908 2.369749e-03

```

```

> print(diags)
  model  ar2_p sargan_p
1 Full 0.2680869 0.9355594
2 2a 0.4952360 0.2371453
3 2b 0.6663408 0.1033146
4 2c 0.5375828 0.2028960
> # AR(1) and AR(2) for all models
> ar_tests <- data.frame(
+   model = c("Full", "2a", "2b", "2c"),
+   ar1_p = c(
+     mtest(model2_full, order=1, robust=TRUE)$p.value,
+     mtest(model2a, order=1, robust=TRUE)$p.value,
+     mtest(model2b, order=1, robust=TRUE)$p.value,
+     mtest(model2c, order=1, robust=TRUE)$p.value
+   ),
+   ar2_p = c(
+     mtest(model2_full, order=2, robust=TRUE)$p.value,
+     mtest(model2a, order=2, robust=TRUE)$p.value,
+     mtest(model2b, order=2, robust=TRUE)$p.value,
+     mtest(model2c, order=2, robust=TRUE)$p.value
+   ),
+   sargan_p = c(
+     sargan(model2_full)$p.value,
+     sargan(model2a)$p.value,

```

```

+   sargan(model2b)$p.value,
+   sargan(model2c)$p.value
+ ),
+ obs = c(
+   nobs(model2_full),
+   nobs(model2a),
+   nobs(model2b),
+   nobs(model2c)
+ )
+)
> print(ar_tests)
  model    ar1_p    ar2_p  sargan_p obs
1 Full 0.112056836 0.2680869 0.9355594 940
2  2a 0.006120707 0.4952360 0.2371453 940
3  2b 0.007148454 0.6663408 0.1033146 940
4  2c 0.009551724 0.5375828 0.2028960 940
>

```

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