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L'INTITULE DU MEMOIRE

HUMAN CAPITAL, TECHNOLOGY FRONTIER AND ECONOMIC GROWTH IN SUB-SAHARAN AFRICA

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DEDICATIONS

To my beloved mother (Doreen Chishe Kalonga), with profound love and gratitude, I dedicate this research work to you. Your unwavering support, boundless love, and countless sacrifices have been my guiding light and my greatest strength. Your encouragement has been my anchor through every challenge and your faith in me has been my inspiration to persevere. Thank you for always believing in me and for being my greatest champion. This accomplishment is as much yours as it is mine.

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LIST OF ABBREVIATION

AUDA: African Union Development Agency

FEM: Fixed Effects Model

FDI: Foreign Direct Investment

FGLS: Feasible Generalized Least Squares

FT: Technology Frontier

GDP: Gross Domestic Product

H: Human Capital Index

ICT: Information and Communication Technology

IDA: International Development Association

IMF: International Monetary Fund

Kc: Stock of Physical Capital

NICs: Newly Industrialised Countries

ODA: Official Development Assistance

OECD: Organisation for Economic Co-operation and Development

PWT: Penn World Table

R&D: Research and Development

REM: Random Effects Model

RGDPC: Real Gross Domestic Product per capita

SSA: Sub-Saharan Africa

SSCs: Sub-Sahara Countries

TFP: Total Factor Productivity

UNESCO: United Nations Educational, Scientific and Cultural Organization

GENERAL INTRODUCTION

BACKGROUND

Human capital is a crucial factor in economic growth theories because it not only directly boosts productivity but also enhances the ability to adopt and utilize advanced technologies developed at both national and international scales. Indeed, human capital is highlighted in the literature, such as developed by Nelson and Phelps (1966), Lucas (1988), and Romer and Weil (1992), as well as in the work of Aghion et al. (2005). Specifically, Romer (1989) and Galor and Weil (2000) suggest that economic growth is strongly linked to the amount of human capital. Meanwhile, the models of Nelson and Phelps (1966) and Aghion et al. (2005) argue that economic growth is mainly influenced by the interaction between the level of education, measured as the average years of schooling of the working-age population, and the distance to the technology frontier.[1]

In addition, Sub-Saharan African (SSA) countries are grappling with complex challenges such as escalating poverty, widening income inequality, and increasing unemployment. These issues compel the governments of these countries to seek ways to bolster economic growth. One pathway to accelerate economic growth is through enhancing workforce productivity, which allows developing economies to bridge the gap with more advanced economies. Developing economies can learn from how producers in developed countries typically utilize advanced technologies and skilled labour forces, leading to increased output.

Unfortunately, SSA countries often struggle with limited access to advanced technologies and a shortage of skilled labour forces, as noted by Gozgor and Can (2017). In contrast, developed countries use high technology and human capital more effectively in their production processes, resulting in higher output levels. To emulate this success, SSA economies need to integrate better technological systems and more skilled human capital into their production strategies. For doing so, they can enhance their economic growth, which in turn enables further investment in infrastructure and welfare programs, potentially reducing poverty, unemployment, and income inequality.

Furthermore, consumers and producers play crucial roles in driving economic growth through effective demand and supply generation. When market forces are strong, they encourage producers to increase output by adopting better technologies and employing more skilled labour

[1] Orlando Gomes (2002): “investment in humans, technological diffusion and economic growth” https://www.researchgate.net/publication/228458303

forces. Therefore, this study aims to empirically explore whether the distance to technology frontiers contribute to economic growth in SSA countries, particularly through channels influenced by varying levels of human capital. The research also examines how the interaction between technology and human capital patterns affects the economic growth in the considered countries.

PURPOSE OF THE STUDY

The purpose of this thesis is to investigate the impact of human capital and the distance to the technological frontier on economic growth of SSA, focusing on a dataset spanning from 1990 to 2019 across 16 SSA countries. This study aims to understand how improvements in educational attainment and the adoption of new technologies influence productivity and economic expansion in the studied countries. By analysing historical data, the study seeks to identify patterns and relationships that could inform policy decisions aimed at fostering growth and development. This research is particularly relevant given the dynamic changes in global technology and the pressing need for SSA countries to harness these innovations for sustainable economic progress.

The contribution of this study lies in its comprehensive analysis of the interplay between human capital and distance to technology frontier within the context of SSA's unique economic challenges and opportunities. By examining data over nearly three decades, this research provides insights into the long-term effects of education and technology on growth. Additionally, the present study will contribute to the existing literature by updating empirical evidence on the effectiveness of human capital development and technological integration in driving economic growth. The findings could offer valuable guidance for policymakers and stakeholders in formulating strategies that effectively leverage education and technology to enhance the economic outcomes in Sub-Saharan Africa.

PROBLEM STATEMENT

The role of human capital and technological advancements in influencing economic growth has garnered considerable attention in economic research. In Sub-Saharan Africa, a region characterized by diverse economic conditions and varying degrees of technological adoption, the interplay between these factors presents a unique landscape for investigation.

Despite substantial natural resources and global strides in technology, many countries within this region continue to face significant challenges, including low GDP growth rates, poor health outcomes, and inadequate educational systems. These challenges underscore the necessity of exploring how human capital defined through the education and health of the populace and the adoption of technologies can propel economic development.

Furthermore, the varying impact of these factors across different nations within SSCs suggests a complex relationship influenced by political, social, and economic contexts. Therefore, this study seeks to dissect the dynamics between human capital, technology, and economic growth in SSCs, aiming to identify actionable insights that could sustain economic development. The central question guiding this research is: **How do human capital and the distance to the technology frontier influence economic growth in Sub-Saharan African countries?**

In addition, this central question is then accompanied by the following secondary questions:

- What are the main difficulties that SSA countries encounter in developing their workforce to meet the needs of quickly evolving technologies?
- Which technologies have had the most significant impact on economic growth in SSA and how has human capital supported their adoption?
- What are the main challenges faced in the development of human capital and how can they be addressed?

RESEARCH HYPOTHESES

H1: Human Capital has a positive impact on the economic growth in the SSA countries.

H2: The distance to the technology Frontier has a negative impact on the economic growth in the SSA countries.

H3: Stock of physical capital per capita has a positive impact on the economic growth in the SSA countries.

METHODOLOGY

Our study employs a methodology that incorporates documentary research, descriptive analysis, and panel data econometric modelling. This approach enables us to investigate and validate all the proposed hypotheses thoroughly.

The documentary research component of our study involves examining various written materials including articles, books, theses, and numerous academic databases. We utilize a theoretical framework to explore and dissect different economic growth theories and the variables influencing economic growth as viewed through each theoretical lens. Additionally, we incorporate empirical research to pinpoint how human capital and the distance to the technology frontier impact economic growth in Sub-Saharan countries. Therefore, we were able to formulate hypotheses with our selected variables.

The descriptive analysis in our study allowed us to depict and illustrate the economic conditions of the countries through graphs and patterns. This enabled us to analyse the progression of human capital and the distance to the technology frontier in the Sub-Saharan region and select studied countries, providing a comprehensive overview to enhance our understanding of their economic performance. We examined data from a panel of sixteen countries over the period from 1990 to 2019.

In the empirical segment of our research, we employed panel data econometric analysis. This portion involved identifying the data for our panel modelling, which adheres to a quantitative approach. We utilized secondary data sourced from the Penn World Table(PWT). Panel data modelling techniques were instrumental in determining the appropriate model for our analysis. Subsequently, data processing was conducted using Stata 17 software.

STRUCTURE OF THE STUDY

Chapter 1 of our research investigates the theoretical and empirical literature concerning human capital, distance to technology frontiers, and economic growth. It starts with a detailed examination of core theories that connect human capital including aspects like education, skills, and health to economic outcomes. The review extensively covers empirical research to illustrate the real-world effects of human capital and the distance to technological frontier within different African settings. This examination not only clarifies the theoretical connections among these key factors but also meticulously evaluates the diverse methodologies and outcomes from prior studies, pinpointing existing trends and identifying gaps that this research seeks to explore. Through this review, the chapter prepares the groundwork for subsequent research, emphasizing the crucial role of human capital and technology in driving economic growth throughout African countries.

Chapter 2 provides an in-depth overview of human capital and the distance to the technology frontiers in SSA countries, with a specific focus on the sources of human capital and the development of distance to the technology frontiers. This chapter begins by defining human capital in the context of SSCs, discussing how educational systems, healthcare quality, and vocational training programs serve as primary sources of human capital. The section on the distance to the technology frontiers explores how these countries have embraced and integrated new technologies, assessing the role of foreign direct investment (FDI), and private sector initiatives in fostering technological advancements. This part of the thesis also compares the distance to the technology frontiers of some selected countries in SSA with that of the USA, it also highlights both successes and challenges faced by the region in harnessing technology for economic growth.

Chapter 3 details the methodology and econometric analysis used in the study. This section describes the data sources and used variables. Additionally, it outlines the econometric models that are applied to analyse the relationship between the studies variables, and also shows the empirical finding and their interpretation. This chapter is essential for understanding the analytical framework and tools that support the study’s conclusions.

Chapter 1. Human Capital, Technology Frontier and Economic Growth: Theoretic and Empirical Literature Review

Introduction

Human capital, the knowledge and skills of a workforce, and its proximity to the technological frontier, the most advanced production methods, are well established drivers of economic growth according to economic theory. Empirical studies support this, showing how a skilled population can both adopt existing technologies and contribute to innovation, propelling economic progress. However, the specific ways human capital interacts with the technology frontier to influence growth remain a subject of ongoing research, particularly in the context of developing economies.

1: Theoretical Literature Review

Any country that aspires to an innovation- and technology- driven economy must first look to the quality of its human capital, which absorbs and produces technological advances. Improving this fundamental component of the economy has broad positive effects, but as the Organisation for Economic Cooperation and Development (OECD) notes, beginning in the late 1990s there was recognition that high- income economies, "are more strongly dependent on the production, distribution and use of knowledge than ever before."[2] A large diffusion of skills and knowledge in the economy is the starting point for modern economic competitiveness and critical for achieving sustainable and inclusive growth. This common- sense assertion is backed by years of economic studies.

A recent article found a "positive relationship, statistically significant between GDP per capita and innovative capacity of human capital (evidenced by the number of patents) and qualification of employees as expected according to economic theory." An International Monetary Fund (IMF) study indicated that although the macroeconomic impact of patents is understudied, average growth rates are correlated with patents, primarily through their impact on research and development (R&D).

All this points to the clear value of a well- developed base of human capital. The key input and determinant of human capital development, particularly in economies looking to move toward upper middle income status, is access to quality education. Education can equip a national workforce with the skills, knowledge, and creativity to compete in the knowledge- based global economy. One Stanford researcher noted that "without improving school quality, developing

[2] "The Knowledge Based Economy," Organization for Economic Cooperation and Development (OECD), 1996, https:// www . oecd . Org / sti / sci - tech / 1913021. pdf.

countries will find it difficult to improve their long run economic performance."[3] Basic literacy and numeracy are starting points, but specialized skills, training, and educational institutions are needed to take full advantage of opportunities in the knowledge economy.

Robert Solow's ground-breaking research in the 1950s (Solow, 1957) employed "growth accounting"[4] a method to decompose growth into its constituent factors. His analysis, using data from 1909 to 1949, revealed a surprising outcome: a vast majority (87.5%) of per capital economic growth remained unexplained by traditional factors like increased physical capital (machinery, factories), labour force size, or working hours. This unexplained portion, termed the "residual," sparked a crucial shift in focus. The substantial size of the residual throughout the 20th century pointed to a missing piece in the growth puzzle. Since physical capital accumulation couldn't fully account for growth, something else was driving progress. This "something else" was identified as knowledge creation and the enhancement of the workforce through education and training, ultimately leading to a rise in human capital. Solow's work thus highlighted the critical role of human capital, previously hidden within the residual, and emphasized its historical importance in understanding economic growth

1.1: Human Capital Theory:

Pioneered by economists like Theodore Schultz and Gary Becker, human capital theory posits that investments in education, training, and health enhance an individual's skills and knowledge, making them more productive in the labour market. This increased productivity translates to higher economic output at the national level. The theory further suggests that a skilled workforce is better equipped to adopt and adapt existing technologies, accelerating economic growth by closing the gap with the leading technological frontier (Lucas, 1988; Mankiw et al., 1992).

1.2: Endogenous Growth Theory:

This theory challenges the neoclassical view of diminishing returns to capital by emphasizing the role of innovation and knowledge creation in promoting long-term economic growth. Economists like Romer (1990a) and Aghion and Howitt (1992) argue that a highly educated workforce fosters innovation by generating new ideas and technological advancements. This

[3] Eric A. Hanushek, "Economic Growth in Developing Countries: The Role of Human Capital," Economics of Education Review 37 (2013): 204, https:// hanushek . stanford . edu / sites / default / files / publications / Hanushek% 202013%20EER%2037. pdf.

[4] Solow, R. M. (1957). Technical Change and the Aggregate Production Function. The Review of Economics and Statistics, volume39 (3), page 312-320.

continuous process of innovation pushes the technological frontier forward, leading to sustained economic growth.

1.3: Knowledge Spillover Theory:

Developed by Arrow (1962) and Romer (1986), this theory highlights the importance of knowledge spillovers, where knowledge and skills can spread from one individual or firm to others. A well-educated population creates a rich pool of knowledge that can be readily adopted and adapted by others within the economy. This facilitates faster diffusion of technology and innovation, accelerating economic growth across the entire economy.

1.4: Technology Gap Theory:

This theory, explored by researchers like Nelson and Phelps (1966), emphasizes the concept of "catching up."[5] Countries further from the technological frontier have the potential to grow faster by adopting and adapting existing technologies developed by leaders. A skilled workforce plays a crucial role in this process, allowing countries to efficiently utilize and integrate these advancements into their economies.

1.5: Human Capital and Innovations (Romer, 1990) or Schumpeterian Growth Theory:

Romer (1990, as cited in Izushi and Huggins, 2004) notes that research and development is carried out by educated workers and concludes that a greater stock of human capital will lead to higher economic growth by its innovation-promoting effects. A portion of human capital is used in the production of final goods (similar to the Lucas model) but the remainder is employed in R&D activities. The Romer model, however, does not need to rely on externalities in the intertemporal accumulation of human capital (as in the Lucas model) to generate sustained per capita income growth and does not treat human capital as a non-excludable good (as do Benhabib and Spiegel).

Aghion and Howitt (1998) extended the model to include more than one economic sector and to consider technology spillovers across sectors. They also introduced the uncertain nature of innovation in their model. According to them the creation of innovations through research is a stochastic process in which the innovation quantity is expressed as flow probability (Izushi and Huggins, 2004).

Many studies examining economic growth in Sub-Saharan Africa (SSA) countries highlight the importance of technological advancements and human capital, often measured through

[5] Nelson & Phelps (1966) propose that developing countries can grow faster by catching up to the technology of advanced economies, emphasizing the importance of education and R&D for effective technology adoption.

educational attainment. While there's a general agreement that education is linked to economic growth, accurately measuring this link proves challenging.

Kleynhans and Labuschagne (2012) identified four key aspects influencing human capital and education: quantity (number of people educated), quality (effectiveness of education), inequality (distribution of educational opportunities), and institutional differences (variations in education systems across countries). However, they acknowledged the difficulty of measuring education, particularly quality and institutional aspects, and were unable to find a perfect solution for capturing this data.

Hanushek and Kimko (2000) entered the discussion, arguing for a significant relationship between the quality of education and economic growth. Their research found strong positive correlations between economic growth and test scores in math and science, suggesting that the quality of education, not just the number of people educated, plays a crucial role.

The theory that education automatically leads to economic growth isn't universally accepted. Benhabib and Spiegel (1994) conducted a cross-national analysis and found no direct connection between the educational level of a workforce and overall output per worker. They proposed an alternative model where a country's existing stock of human capital (the overall level of education in the population) plays a more significant role in economic growth than simply increasing the number of educated people.

Easterly (2004) further supports this point. He cites Klenow's (1998) work, suggesting that models focusing on innovation and productivity growth provide a better fit for real-world data than those solely focused on accumulating human capital through education. Easterly emphasizes the need for more research on the complex relationship between education and economic development.

The link between education and economic growth is a subject of ongoing debate. While it's generally accepted that education is important, a 2002 World Bank report (Paper 2881) suggests a concerning trend: the return on investment in education seems to be diminishing globally since 1950. This means that despite an increase in average schooling years over the past twelve years, the economic benefits haven't grown proportionately. However, the report also highlights a potential silver lining for Sub-Saharan Africa. The Study Group on Measuring Learning Outcomes (2013) found that the average Kenyan citizen in 2010 had spent more years in school than the average French citizen in 1985. Despite this, Kenya's GDP per capita in 2010 was only 7% of France's GDP per capita in 1985. This raises serious concerns about the efficiency of education systems in Africa, suggesting that children might not be learning effectively despite attending school for longer periods. Education quality rather than education access more strongly correlates with economic growth because the quality of an education is a bigger determinant of potential individual earnings. Education access alone can be a misleading indicator. In Ghana and Kenya, for example, even those that graduate from university have lower levels of literacy than OECD residents who have completed secondary school.[6] Translating access into quality education requires institutional changes, but the addition of technological resources can serve as an important impetus and driver of change

The Study Group emphasizes the need for a stronger focus on measuring actual learning outcomes through test scores and knowledge assessments. This would be crucial for ensuring that education investments translate into genuine human capital development - a skilled and knowledgeable workforce - which is essential for economic growth.

Adding to the complexity, Krueger and Lindahl (2000) argue that many studies fail to find a strong correlation between education and growth due to measurement errors. They suggest that when these errors are accounted for, the true impact of education on economic growth becomes clearer. Additionally, they criticize the practice of including the initial stock of human capital (existing education levels) in economic models, believing it can lead to misleading results.

A study by Fredderke and Simkins (2012) on economic growth in South Africa highlights the crucial role of human capital in technological advancement. Their research suggests that South Africa's technological progress follows the Lucas/Schumpeter model, where investments in human capital drive innovation. However, the education system faces challenges in producing a skilled workforce in these critical areas. The study emphasizes the relevance of endogenous growth theories, which posit that growth originates within the economy itself. Their findings indicate a stronger correlation between economic growth and investments in human capital compared to investments in physical capital (Fredderke and Simkins, 2012; Easterly, 2004). This aligns with the arguments made by Easterly (2004).

By adopting existing technologies from advanced economies, developing countries can "leapfrog" ahead and avoid the need to reinvent the wheel (Gerschenkron, 1962). Research supports this notion, with studies by Coe et al. (1997) showing a positive link between a

[6] Lee Crawfurd, "Literacy of Adults in Developing Countries: New Data from a Skills Survey," Center for Global Development, August 16, 2016, https:// www . cgdev . org / blog / literacy - adults - developing - countries - new - data - skills - survey .

developing country's Total Factor Productivity (TFP) and the amount of R&D spilling over from developed nations.

Savvides and Zachariadis (2005) add another layer, suggesting that even countries closer to the technological frontier can experience a significant boost in TFP through knowledge diffusion from leaders in the field. These findings highlight the importance of prioritizing investments in research and development, as well as education, to fuel growth in developing countries. This notion is supported by empirical studies. Coe, Helpman, and Hoffmaister (1997) found a positive correlation between a developing country's Total Factor Productivity (TFP) and the amount of research and development (R&D) spilling over from developed nations. TFP is a measure of a country's efficiency in producing goods and services. Spill overs refer to the unintended benefits, like knowledge diffusion, that accrue to countries not directly involved in R&D activities.

Savvides and Zachariadis (2005) further refine this argument. They suggest that even countries closer to the frontier can experience a significant boost in TFP through knowledge diffusion from leaders in the field. This highlights the importance of not just acquiring existing technologies but also having the capacity to adapt and improve upon them.

There's a concept called "absorptive capacity"[7] which suggests that developing countries can actually benefit more from being technologically behind. This advantage exists if they can effectively adopt technologies pioneered by leading countries (Abromovitz, 1986). While countries differ in their ability to embrace new advancements, investing in research and development (R&D) along with education can generally boost their capability to absorb foreign technologies. Hobday (2003) even highlights that successful newly industrialized countries (NICs) all shared a focus on extensive training and R&D programs – this allowed them to adapt technologies developed elsewhere. This capacity is influenced by factors like:

- **Investment in R&D and Education:** Studies by Hobday (2003) show that successful NICs prioritized extensive training and R&D programs. This allowed them to adapt imported technologies to their specific contexts. Similarly, Nelson and Phelps (1966) and others (Abromovitz, 1986; Cohen & Levinthal, 1989; Benhabib & Spiegel, 1994, 2005; Engelbrecht, 1997) highlight the role of a highly educated workforce in facilitating the assimilation of foreign technology.

[7] Abramovitz, Moses. 1986. "Catching-Up, Forging Ahead, and Falling Behind." The Journal of Economic History 46 (2): 385-406.

- **Local Innovation:** Effective technology transfer is often hindered by the complexity of new technologies and their embeddedness in physical capital (Verspagen, 1991; Fagerberg, 1994). To overcome this, developing countries need to invest in local R&D. This allows them to adapt technologies to their specific needs and conditions (Aghion & Howitt, 2005; Howitt, 2005). Basic skills are necessary but are not sufficient to propel a country to innovation- and technology- led economic growth. To equip their workforce to succeed amidst the rapid economic change now known as the "fourth industrial revolution"[8] characterized by

  breakthroughs in information technology, artificial intelligence, robotics, energy, and other technologies. Developing countries will need to shift the goals and incentives in their education systems or alternative training programs if the education systems are not up to scratch.

According to Kneller and Stevens (2006), investments in R&D and education have a dual effect. They directly contribute to the production of new knowledge and indirectly enhance a country's ability to absorb new technology. This highlights the crucial role of these investments in enabling developing countries to move up the development ladder and eventually catch up with the technological leaders.

New technologies are often intricate and come bundled with physical equipment, creating a tight link between leading and developing countries. To effectively adopt these advancements, developing countries need to invest in local R&D. This allows them to adapt technologies from leaders to their specific needs (Verspagen, 1991; Fagerberg, 1994; Aghion & Howitt, 2005; Howitt, 2005). An educated workforce also plays a crucial role in absorbing foreign technology (Nelson & Phelps, 1966; Abromovitz, 1986; Cohen & Levinthal, 1989; Benhabib & Spiegel, 1994, 2005; Engelbrecht, 1997). These investments are essential for developing nations to upgrade their technology, progress on the development ladder, and eventually catch up with the leaders. In essence, R&D and education have a double benefit: they directly generate new knowledge and indirectly improve a country's ability to absorb foreign technologies (Kneller & Stevens, 2006).

While the benefits of technological catch-up are clear, there are challenges to consider. The increasing complexity of modern technologies can make adaptation more difficult for

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[8] Kalus Schwab, "The Fourth Industrial Revolution: What It Means, How to Respond," World Economic Forum, January 14, 2016, https:// www. weforum . org / agenda / 2016 / 01 / the - fourth - industrial - revolution - what - it - means - and - how - to - respond /.

developing countries (Archibugi & Lundvall, 2001). Additionally, intellectual property rights can restrict access to certain technologies, hindering the catch-up process (Mowery & Rosenberg, 1999). Furthermore, simply acquiring technology is not enough. Developing countries need to foster an innovation ecosystem that encourages local innovation and entrepreneurship. This includes creating a supportive policy environment, investing in infrastructure, and promoting collaboration between academia, industry, and government (Freeman, 1987; Lundvall, 1988).

In the standard neoclassical growth model, a higher rate of population growth reduces the steady-state value of capital per worker and thereby lowers the SteadyState value of per capita income. The decrease in per capita income implies that the economy grows in the transition (for a given value) at a slower rate. The rate of population growth is exogenous in this model, and the effect on the steady-state level of capital per worker involves the flow of new capital that has to be provided to accompany the flow of new workers.

Richer theories, such as the one by Becker, Murphy, and Tamura (1990), include the resources expended on children and allow fertility to be a choice variable of families. A key result is that a larger stock of human capital per person raises the wage rate and, therefore, the time cost of raising children. (The assumption is that the productivity in the sector that raises children does not rise as fast as that in the sectors that produce goods and new human capital.) A higher stock of human capital motivates families to choose a lower fertility rate and to raise the investment in human capital for each child (that is, to substitute quality for quantity in children). These responses of population growth and human capital investment tend to raise the growth rate of output. The model, therefore, provides another channel through which a larger stock of human capital results in a higher subsequent rate of economic growth (Barro).

Lucas assumes that individuals invest in human capital by spending part of their time acquiring skills, instead of a fraction of their income, like in Mankiw/Romer/Weil (1992). Besides, Lucas ignores depreciation of human capital. More importantly, and contrary to Mankiw/Romer/Weil, in the Lucas model, there are two sectors of production: one for consumption goods and physical capital, and another for human capital. The only input in the production of human capital is

human capital meaning education “relies heavily on educated people as an input”. Above all, the Lucas model is characterized by self-sustained growth, which is driven by the accumulation of human capital. If, for some reason, the equilibrium value (the time spent acquiring skills) were to rise, this would lead to a permanent increase of growth. Therefore, additional skill acquisition has a rate effect in the Lucas model, as opposed to the augmented Solow model, where (permanently) higher human capital accumulation only causes a level effect (Schuett, 2003:12).

Although the existence of spill overs from human capital is not a necessary condition for sustained growth in this model (what is actually responsible is the fact that there are constant returns to human capital production), the question of whether or not there are externalities to the average level of skills in the workforce is clearly of significance.

One example of positive human capital externalities may be social benefits such as crime reduction. Lucas himself offers an alternative explanation and presents some general observations that support the existence of positive externalities. He points out that in the arts and sciences (the “creative professions”), the interaction between colleagues has significant benefits and will often prove stimulating for their intellectual output. Moreover, he argues “economic life is creative in much the same way.” According to Lucas, there are two facts that can be interpreted as primarily supportive of this view: immigration and the existence of cities. First, if there were no externalities to human capital, it would offer the highest returns in countries where it was in scarce supply. Thus, one would expect to observe migration of skilled workers from rich to poor countries, instead of the observed flows in the opposite direction. Second, without external effects, there is no reason for cities to exist: capital and labour could just as well move to the countryside, where the rental price of land is much lower.

2: Empirical Literature Review

Numerous studies and research have been carried out concerning this phenomenon of economic growth about human capital and technology frontier. It has raised the interest of many researchers to understand this phenomenon profoundly, especially when there is still this "club convergence phenomenon" Aghion et al. (1998) where other countries seem to be catching up to the growth rates of other developed countries yet some, specifically the ones in Africa seems to diverge from their growth. To understand this, we have decided to look at the previous studies undertaken on some of the variables to synthesize and present the findings of some of these studies.

An empirical study undertaken by (Aghion et al., 2009; Vandenbussche et al., 2006), Literature evidenced that different educational levels of human capital affect Total Factor Productivity (TFP) growth. A high level of intellectual (skilled) human capital is required for innovation, and a low level of education (unskilled) is fitted for imitation. The impact of the technological frontier is negatively related to TFP growth. This theory follows the hypothesis of the advantages of backwardness proposed by Gerschenkron (1962), which summarizes that a country with less technology frontier enhances the TFP growth due to lower effective innovation cost, which allows a faster catch-up to the technology frontier. Therefore, the impact of human capital with higher education (skilled) and technological frontier enhances the TFP growth as innovation is a skill-intensive activity.

On the other hand, unskilled or low-level education human capital decreases TFP growth with the technology frontier because imitation needs mostly physical and less educated human capital (Vandenbussche et al., 2006). Additionally, they argue that the interaction between human capital with tertiary (high) education and the technological frontier is positive. In contrast, human capital with primary

(low) education and the technological frontier is negative. The low levels of education following the innovation in the frontier country is why the interaction effect adversely affects the TFP growth. Suppose the country is near the technological frontier. In that case, the imitation effect becomes more prominent as the effective imitation costs are less. They also added that the impact of primary and secondary education levels is insignificant. In contrast, tertiary education positively and significantly affected TFP growth because of the power of innovation.

Barro, 1991, 1996; Caselli, Esquivel, & Lefort, 1996; Levine & Renelt, 1992; Mankiw et al., 1992; Sachs & Warner, 1997 argue that human capital including health has a positive effect on economic growth. However, it is only recently that empirical growth studies have started to explore the effect of health on economic growth at an accelerated pace. Knowles and Owen (1995, 1997), Bhargava et al. (2001), Barro (1991, 1996), Barro and Lee (1994), and Barro and Sala-I-Martin (1995), measuring health stock as life expectancy, find that health human capital has a positive and significant impact on economic growth.

Fogel finds that about a third of the increase in income over the last two centuries can be attributed to improvements in health and nutrition. Mayer (2001a, 2001b), using a Grangertype causality test, concludes that health, measured as the probability of adult survival by gender and age group, causes economic growth. He finds that the growth impact is higher for improvements in female health than in male health. Improvements in adult health are associated with 0.8–1.5% increase in annual income. Weil (2001), using average height and life expectancy to measure health, finds that health explains about 17% of the cross-country variation in income.

Gallup and Sachs (2000) find that the prevalence of malaria decreases the growth rate of income and that a 10% reduction in malaria incidence is associated with a 0.3 percentage point increase in the growth rate of per capita income. Over (1992) and Ainsworth and Over (1994) conclude that the HIV/AIDS epidemic reduces the growth rate of per capita income by about 0.33 percentage points in African countries. This happens through decreased labour, human capital, as well as savings. All these studies postulate a linear relationship between the stock of health human capital and economic growth. Sachs and Warner (1997) find that the stock of health human capital influences the rate of economic growth in a quadratic way and that health human capital increases economic growth at a decreasing rate.

A study by Barro (1991) over a sample of 98 countries for a period of 1960-1985, found that human capital has a significant positive effect on economic growth. Similarly, a study by Mankiw et al. (1992) found that investment in human capital, particularly education, has a positive effect on economic growth. Another study by Gylfason and Zoega (2002) found that education and training are positively associated with economic growth.

In a recent contribution, Barro and Lee (2015) conduct a growth accounting exercise in a sample of 83 advanced and developing countries (for every decade) between the 1961-2010 period. They found that human capital grew annually by 0.6% and explained a bit more than one-fifth of the world's per-worker GDP growth. The average annual growth rate of the latter amounted to 2.6%. The contribution of human capital is found to be slightly larger among advanced economies (it explains approximately one-fourth of their average annual growth rate) and somewhat smaller for the developing world (approximately one-fifth). Jorgenson, Ho, and Samuels (2016) show that, between 1947 and 2010, only 0.24 percentage points of the US' average annual growth rate of 3.23% can be attributed to improvements in human capital. C. I. Jones (2016) provides similar estimates.

Kleynhans and Labuschagne (2012), Fredderke and Sinkins (2012), and Oketch (2006) presented correlations between human capital and economic growth, although troublesome to find. They all let education account for human capital and investigated this correlation in Africa. Mincer (1981) agreed with this as well, but pointed out a causality problem; maybe economic growth made it possible for more people to access education and not vice versa. This causality problem usually dissolved with a lag function; where the regression correlated GDP per capita growth with human capital lagged 5 or 10 years back in time (e.g. Oketch, 2006; Diasa and Tebaldib, 2011).

Another study was carried out by Altăr, Necula, and Bobeică (2008), they modeled the economic growth with a particular focus on the role of human capital in the following way: they simulate possible growth paths assuming that the economy behaves according to the hypothesis of the Uzawa-Lucas model. By calibrating the model to the economy, they were able to forecast the evolution of the GDP and the proportion of human capital that will be used in the production of goods and services. Although the population growth rate is considered to be zero, the average real GDP growth rate is around 6% due to human capital accumulation, which improves the quality of labour.

Other studies were also taken to understand whether the impact of human capital on economic growth differs by sex. The most common method used was to introduce two separate explanatory variables for human capital (male and female) and to test for a significantly differential effect on economic growth. All contributions in this area, however, maintain the linearity assumption between different types of human capital and growth. A series of papers, by Barro and Lee 1994; Barro 1997, 2001; Barro and Sala-i-Martin 2004 find a significantly different growth effect for male and female education at the post-primary level measured by mean years of secondary plus tertiary schooling. More importantly, the general conclusion from these studies is that the impact of post-primary male education on growth is positive and significant whereas that for female education is negative and meaningful.

One possible explanation for these findings, according to Barro (2001), is that "many countries follow discriminatory practices that prevent the efficient exploitation of well-educated females in the formal labour market". When it comes to education at the primary level, the results are ambiguous. Male schooling at the primary level is generally an insignificant determinant of growth; on the other hand, a significant contribution to female education at the primary level depends on whether fertility is held constant or not; (Savvides and Stengos, 2009:135-136.)

Conclusion

The theoretical and empirical literature paint a complex picture of the interplay between human capital, the technology frontier, and economic growth. Human capital, encompassing education, skills, and innovation capabilities, is widely recognized as a crucial driver of economic progress. It allows individuals to adopt and adapt existing technologies, generate new knowledge, and push the boundaries of the technological frontier.

However, the specific mechanisms through which human capital fosters growth remain a subject of ongoing debate. While some models highlight the importance of a highly educated workforce, others emphasize the need for a broader range of skills, including technical and vocational expertise. Additionally, the literature suggests that the impact of human capital on growth can be conditional on other factors, such as the quality of institutions and the openness of an economy to technological advancements. The technology frontier, representing the leading edge of technological innovation, also plays a critical role in economic growth. New technologies can increase productivity, create new industries, and drive economic expansion. However, simply having access to advanced technologies is not sufficient. The ability to effectively adopt, adapt, and further develop these technologies depends heavily on the existing human capital stock.The empirical literature provides mixed evidence on the precise relationship between human capital, technology, and growth. While some studies find a strong positive correlation, others report more nuanced findings. This suggests that the impact of human capital and technology on growth may vary across countries and over time.

Chapter 2: An Overview on Human Capital and the Distance to the Technology Frontier in Sub Saharan Countries

Introduction

This chapter will provide an overview of the current status of human capital in Sub-Saharan Africa, examining educational systems, workforce skills, and health metrics as foundational components of human capital. It will also assess the extent of technology adoption in these countries, exploring sectors such as mobile connectivity, internet usage, and digital entrepreneurship. The interrelation between human capital and technology will be scrutinized to understand how technological empowerment can lead to significant improvements in productivity and economic outcomes.

Additionally, the challenges inherent in maximizing the potential of human capital through technology in Sub-Saharan Africa, such as infrastructural deficits, political instability, and educational gaps, will be discussed. This exploration aims to not only highlight the current state but also to suggest pathways toward enhanced integration of technology in human capital development.

Through a synthesis of theoretical frameworks, empirical research, and case studies, this chapter sets the stage for a deeper investigation into how Sub-Saharan coutries can navigate their unique constraints and opportunities at the intersection of technology and human capital development. The objective is to contribute to a nuanced understanding of how these critical resources can be effectively leveraged to foster sustainable development in the region.

1: Geographical Overview of the Region

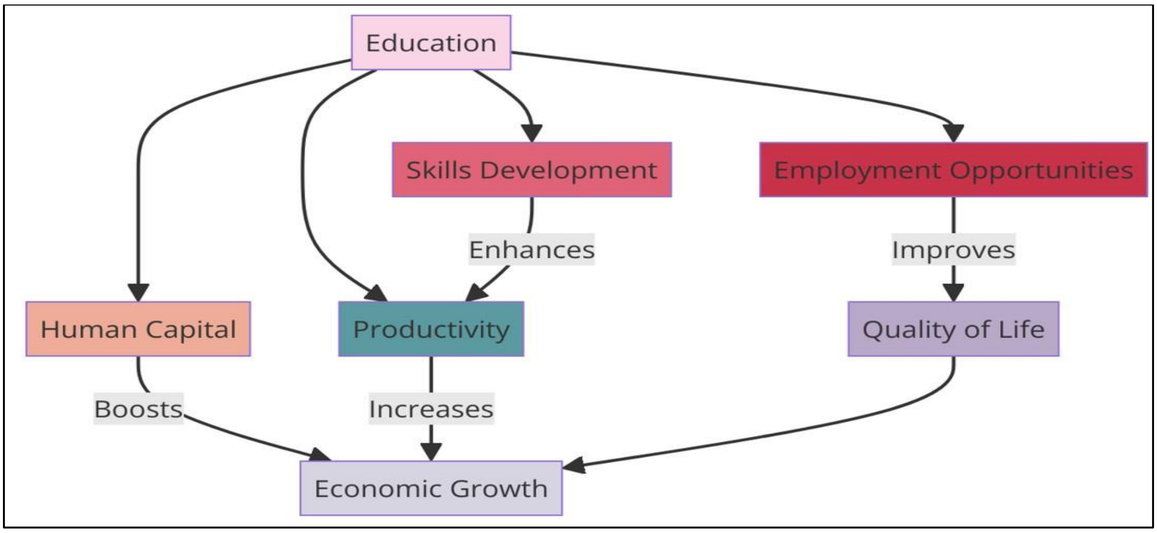
Sub-Saharan Africa refers to the region of the African continent situated south of the Sahara Desert. It encompasses a vast diversity of landscapes, including savannas, rainforests, wetlands, and vast grasslands. The region stretches from the Senegalese Atlantic coast to the horn of Africa in the east, and down to the southern tip of Africa. As of the most recent estimates in 2023, the population of Sub-Saharan Africa is approximately 1.1 billion people. This number is expected to rise rapidly, making it one of the fastest-growing regions in the world in terms of population. Sub-Saharan Africa consists of 46 countries. This includes all African countries that are fully or partially located south of the Sahara Desert.

1.1: Sources of human capital

Human capital, which encompasses the attributes of a population that can be leveraged for economic and social advancement, is fundamentally derived from several critical sources. In Sub-Saharan Africa, these sources are both unique and complex due to the region's socio-economic diversity and historical context. Human capital in SSCs is derived from various sources, each contributing to the development and enhancement of the skills, knowledge, and health of the population. Here’s a breakdown of some of the primary sources of human capital in the region:

(a)Education: Although the human capital theory links education with the acquisition of human skills, knowledge and competencies that leads human capital creation which translates to economic growth in any economy there might be gaps on the implications and application of the theory that remains an explanandum. The human capital theory approach presumes that education increases the productivity and efficiency of workers by increasing the level of cognitive stock of economically productive human capability. Education facilitates economic growth through human capital creation that subsequently enhance the marginal productivity of labour, advance use of technology, technological innovations, earning and savings which all collectively leads to increased productivity (Marginson, 2019). The human capital theory assumes that education creates equal opportunities for development of human potential which contributes to economic growth.

Figure 1: Education impact on economic growth

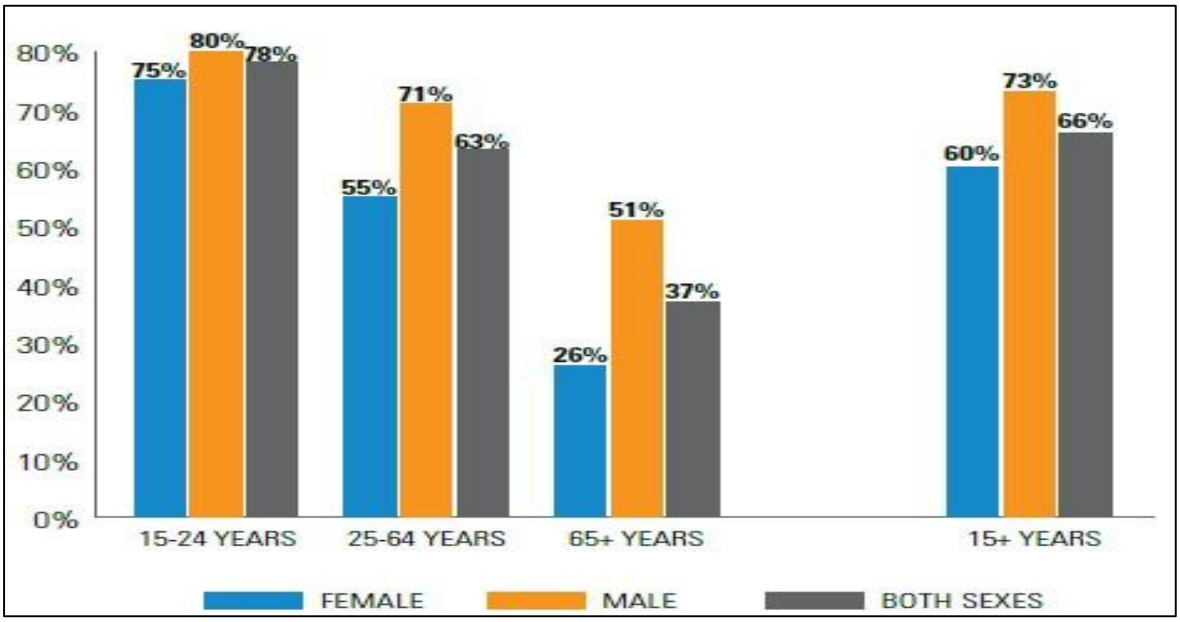


Source: built by authors

Education as demonstrated in the above figure increases the skills development and productivity of the workforce, which is crucial for economic development. Higher levels of education among workers lead to greater efficiency and innovation within industries. Studies have shown that investments in education correlate strongly with economic growth, as a more educated workforce can adapt better to new technologies and processes.

Increasing efforts towards achieving universal quality basic education is an important way of building resilience in populations and actively transforming what could be a demographic burden into a valuable demographic dividend by building citizenship and creating a qualified and employable workforce that can match the needs of the labour market for particular skills and competencies. Education is recognized as a critical development priority by the Africa Union, while the Kigali Statement of Outcomes sets out equitable and inclusive access to education for all, education for sustainable development and global citizenship, and youth and adult literacies, skills and competencies among the regional priorities for sub-Saharan countries, as they move toward the Education 2030 goals. African countries have committed themselves to the goal of ensuring that human capital is fully developed through universal access to early childhood development and basic education, and sustained investments in higher education, science, technology, research and innovation.

Figure 2: literacy rate by age group and gender in SSA (2018)



Source: UNSECO institute for statistics

Despite significant progress in literacy on the region, a large portion of the African population remains illiterate. In 2018, about one in three people aged between 25 and 64, and one in five young people aged between 15 and 24, were illiterate as shown above.Yet these young people can become an engine of economic growth and development, if they are given the skills and competencies they need. The transformative power of education is well established. The knowledge and skills provided by quality education helps to develop human capital, increasing not only the productivity and employability of individuals, but also improving the overall development of the countries in which they live. Equally critical is the effect of education in many areas of human development: from better health and women's empowerment, to civic engagement and social cohesion.

Education helps bridge the gender gap. Educating girls and women leads to numerous social benefits, including delayed marriage, reduced fertility rates, and improved family health. Women with education are more likely to participate in political processes and decision-making, promoting gender equality.

Human capital theory thus provides a rationale and justification for nation's policy goals on investment in education aimed at promoting economic growth through human capital. Marginson (2019) explicates that human capital theory education driven policy goals are based on the assumption that, ensuring equality of opportunity to all available productive talent would become educated consequently optimising the economics of education. Various global bodies such as the United Nations Educational, Scientific and Cultural Organisation (UNESCO), Organisation for Economic Cooperation and Development (OECD) have advocated for the human capital approach. Nonetheless, Marginson (2019) argued that despite the prominence and dominance of human capital approach in public policy there might be wide a gap between what is the envisaged application and implications in theory and the real world and societies.

(b)**Remittances**: International remittances are cross-border financial or in kind non reciprocal transfers by migrants to families/relatives/friends in country of origin. According to the IMF, remittances consist of the following components: a) compensation of employees, that is income earned by temporary migrant workers, staying abroad for less than one year in the host country recorded under "income sub-category of current account"; b) workers' remittances, that is the income of workers staying abroad for one year or more, employed by embassies, international organisations, and foreign companies shown under the heading of "current transfers"; c) personal transfers in cash or in kind made by residents to individuals in other countries reported under "capital transfer" (Ghosh, 2006; Plaza and Ratha,2017). Though the flow of remittances is closely linked to migration, this is not the only source of it. On the other hand, not all migrants and not always (permanently) do remit. These factors show that human capital development in Sub-Saharan countries is a multifaceted issue that requires coordinated efforts across education, health, economic policy, and social programs to achieve significant improvements.

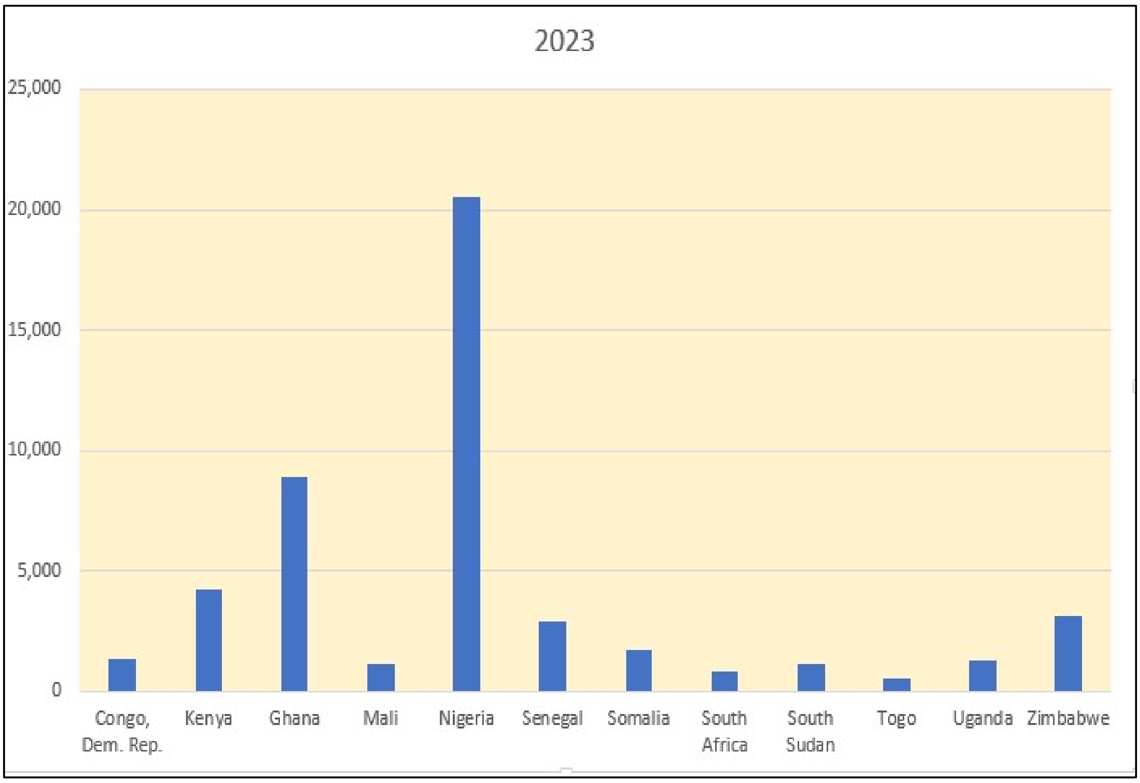
During the last half-century, till the outbreak of the COVID pandemic, remittances at global level have increased dynamically and significantly: from USD 1.9 billion in 1970 to USD 37.0 billion in 1980, to USD 68.4 billion in 1990, to USD 121.6 billion in 2000, to USD 418.7 billion in 2010 and to USD 714.2 billion in 2019 (World Bank). The growth was extremely high after the turn of the century: between 2000 and 2019 remittances increased almost sixfold, and overpassed ODA (Official Development Assistance) flow by 4.6 times, meaning that aid is less capable of financing development than remittances.

The World Bank's 2021 report, "Recovery. COVID-19 Crisis Through a Migration Lens," noted that global remittances were expected to drop to USD 719 billion in 2020 due to the pandemic's impact, which included unemployment, lockdowns, travel restrictions, and diminished migration flows. Furthermore, the international migration stock shrank by 2 million people that year. However, with improving global economic conditions, remittances were projected to rebound, reaching USD 773 billion in 2021 and USD 802 billion in 2022. Despite ongoing challenges from the COVID-19 crisis and uncertainties stemming from the conflict in Ukraine, the outlook remained positive, with global remittances anticipated to climb to USD 842 billion by 2023.This is further explored in the 2022 report, "A war in a pandemic. Implications of the Ukraine crisis war and COVID-19 on global governance of migration and remittance flows.

Top recipients of remittance in SSA in 2023

In 2023, Sub-Saharan countries witnessed significant remittance flows, with certain countries standing out due to their large diaspora communities and effective remittance-receiving policies. Nigeria, Kenya, Ghana, Senegal, and Zimbabwe emerged as the top receivers in the region. Effective remittance-receiving policies also likely played a role in attracting these flows. By streamlining the process and reducing fees, these countries made it easier and cheaper for migrants to send money back, ensuring more resources reached families and communities. This financial injection has a significant impact on poverty reduction, investment in education and healthcare, and overall economic development in the region.

Figure 3: Remittance inflows in SSCs(US$ million)



Source: built by authors using data from the World Bank

The top-performing countries in terms of remittances in the SSA region in 2023 were as follows, Nigeria maintained its position as the leading recipient of remittances in the region, reflecting a robust diaspora network and its significant population abroad. Countries like Kenya and Ghana also showed notable inflows, supported by improving economic conditions in their diaspora communities. Senegal and Zimbabwe followed closely, with remittances being bolstered by their respective government policies aimed at enhancing financial inclusion and attracting more inflows through formal channels.

On the other hand, smaller economies such as Togo and Mali also recorded increases, although their total volumes remain relatively small compared to the larger economies in the region. Overall, the performance of remittances in SSA in 2023 reflects broader global economic trends, including the recovery in employment rates in the countries where the diaspora resides, and fluctuating exchange rates which affect the value of money sent home.

(c) Health: Health improvements are directly linked to human capital development. Lower child mortality rates and better health services contribute to a healthier workforce capable of sustained economic activities and productivity. Initiatives such as increasing access to healthcare and reducing the prevalence of diseases are integral to building human capital in the region.

Increasing government expenditure on healthcare and education is essential for achieving inclusive growth, particularly in sub-Saharan Africa. There exists a positive relationship between economic growth and health outcomes, as demonstrated by Erdogan et al. (2013). Improved health indicators, such as increased life expectancy and reduced infant mortality rates, are associated with economic prosperity, highlighting the importance of accessible and high-quality healthcare in fostering socioeconomic development.

Here's an overview of how health impacts economic growth, particularly focusing on Sub-Saharan Africa:

- **Productivity Increase:** Healthier individuals tend to be more productive. In SSA, where diseases such as malaria and HIV/AIDS have historically reduced life expectancy and labor productivity, improvements in health have shown to boost worker efficiency and economic output. The economic benefits of healthier populations in SSA are further amplified by

  the potential for increased life expectancy and the resulting longer working lives, which contribute to greater lifetime earnings and economic output. When workers stay healthy, they can contribute more effectively and for extended periods, reducing the turnover costs for businesses and stabilizing the workforce. Moreover, a healthier workforce attracts foreign direct investment, as companies seek stable and reliable environments in which to operate. Thus, by focusing on improving health, nations in SSA can not only boost their current economic output but also lay a foundation for sustained economic growth and development.

- **Education Enhancement:** Health directly impacts educational outcomes by increasing school attendance and cognitive abilities. Healthier children are more likely to attend school and perform well, which is vital in SSA where educational attainment levels need to rise to stimulate economic development. The ripple effects of enhanced educational outcomes are significant for economic development in SSA. As educational attainment levels rise, the workforce becomes increasingly skilled and capable of handling more complex tasks and responsibilities. This improvement in the quality of human capital is essential for driving innovation and adapting to global economic demands. Higher education levels also correlate with greater employment opportunities, higher earnings, and improved socioeconomic status, contributing to a cycle of prosperity that can lift communities out of poverty and catalyse broader economic growth across the region. By investing in both health and education, SSA can accelerate its development trajectory and realize more robust and sustainable economic progress.

- **Labour Force Participation**: Good health increases the size of the labor force by reducing disease-related absenteeism and delaying the age of retirement. In SSA, where the informal sector is large, healthier individuals can contribute more effectively and for longer periods. In SSA, where a large portion of the workforce is employed in the informal sector, the benefits of good health are even more pronounced. Individuals working in the informal sector often do not have the safety nets provided by formal employment, such as paid sick leave or health insurance. As a result, their economic stability is heavily dependent on their ability to work. Healthier individuals in this sector are able to work more regularly and for longer periods, thus enhancing their economic contribution and stability. This sustained labor force participation is crucial for not only personal economic stability but also for the broader economic development of the region, as it leads to increased income generation and consumption.
- **Demographic Dividend**: Improved health services can lead to lower mortality and fertility rates, which eventually results in a larger proportion of working-age population. SSA countries can harness this demographic dividend if they have a healthy population that can contribute to the economy. For SSA countries to harness this

  demographic dividend effectively, it is essential that the working-age population is not only large

  but also healthy and skilled. A healthy population can contribute more efficiently to the economy, with fewer resources diverted to dealing with health issues and more focused on productivity and innovation. Moreover, investing in education and skill development concurrent with health improvements ensures that the workforce is equipped to meet the demands of increasingly complex job markets.
- **Reduced Health Cost:** Investment in health can reduce the economic burden of disease. For SSA, this means lower spending on healthcare and more funds available for other economic activities, like infrastructure and education. For SSA, reallocating resources saved from reduced health costs into other vital sectors such as infrastructure

and education could catalyse broader economic growth. Infrastructure development, such as better roads and improved electricity supply, can enhance productivity and attract foreign investment. Simultaneously, investing in education ensures a more skilled workforce, ready to engage with modern technologies and industries, thereby driving economic progress. This comprehensive approach to investing health savings not only creates a healthier population but also lays the groundwork for a more robust and diversified economy.

- **Economic Resilience:** Healthy populations are better equipped to withstand and recover from economic shocks. In SSA, resilience is particularly important due to the region's vulnerability to economic fluctuations and environmental crises. In SSA, where many countries face frequent environmental crises such as droughts, floods, or disease outbreaks, a robust and healthy workforce is indispensable. These health challenges can significantly strain economic systems, reduce agricultural outputs, and hinder the overall capacity of economies to grow. By investing in healthcare infrastructure and preventive measures, countries in SSA can enhance their population's health, thereby strengthening economic resilience. This not only aids in quicker recovery following disruptions but also supports sustained economic growth by ensuring that the workforce remains productive and capable of supporting both local and broader economic activities

(d) Learning by doing: The concept of "learning by doing," as discussed by economists Paul Romer (1986) and Robert Lucas (1988), is a pivotal mechanism in the development of human capital, particularly in the context of Sub-Saharan Africa. According to Romer's endogenous growth theory and Lucas's emphasis on human capital, learning by doing represents a process where individuals acquire skills and knowledge through the very act of performing tasks. This form of learning is inherently practical and context-specific, allowing workers to improve their efficiency and productivity directly through their work experiences.

In SSA, where formal educational opportunities may be limited and the landscape of employment is diverse, learning by doing can be a crucial driver of economic development. It helps in building a workforce that is more adaptable and skilled, tailored to the needs of local economies. For instance, in agricultural or artisan sectors, where much of the work is learned through hands-on experience, this method of skill accumulation is particularly valuable. It not only enhances individual capabilities but also contributes to the collective knowledge base of communities, potentially leading to innovation and improved practices over time.

Moreover, the implementation of policies that encourage investment in technology and infrastructure can amplify the benefits of learning by doing. By providing more opportunities for workers to engage with new tools and processes, governments can foster an environment where practical skills are continuously developed. This approach aligns with Romer's and Lucas's theories, suggesting that sustained economic growth in SSA can be achieved by harnessing the potential of its human capital through continuous learning and adaptation in the workforce.

2: The Distance to the Technology Frontier in Sub Saharan Countries

The "technology frontier" concept refers to the most advanced level of available technology at which the latest methods, practices, and applications are developed and utilized. It represents cutting-edge technological progress and is often seen as a benchmark for measuring a country's or region's technological capabilities relative to the global leaders. In economic terms, being at or near the technology frontier means a country or region can maximize productivity and efficiency, driving economic growth and competitiveness. For countries far from this frontier, the main focus is often on catching up through technological adoption and adaptation rather than innovation.

Countries at the technology frontier are typically those that not only adopt new technologies but also contribute to generating significant innovations. This involves substantial investment in research and development (R&D), a strong educational system that promotes scientific and technological skills, and a business environment that supports innovation and entrepreneurship. Being at the technology frontier can lead to a sustained competitive advantage, allowing countries or regions to produce goods and services more efficiently and of higher quality than their competitors. This is crucial in today's global economy where technological prowess can influence economic status and development trajectories.

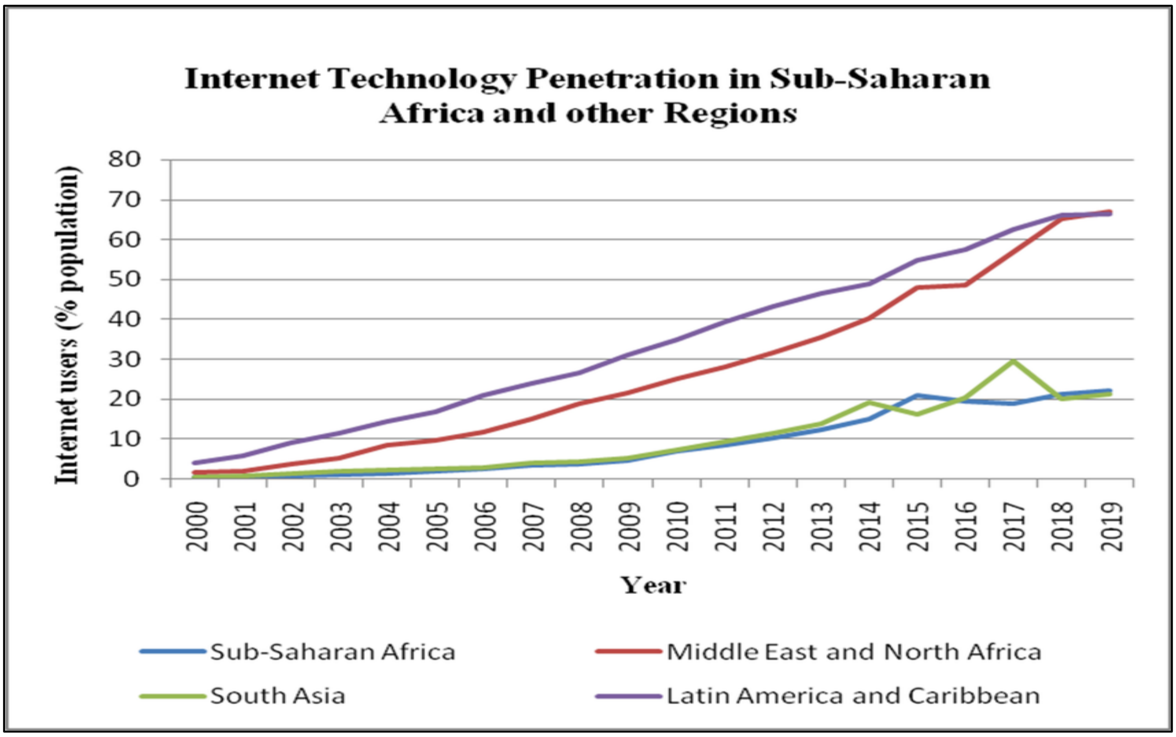
In comparison to the rest of the world, SSA is far behind in its pace with technological innovation and development. Myriad reasons could be attributed to this to name a few, high influence of political patronization, corruption, and the lack of a proper legislative system to ensure the market system and governance of institutions are properly functional without interference according to Jackson and Jabbie, 2019; Jackson, 2018; Jackson, 2016. Governments across the SSA region must endeavor to pull resources and make research and development a priority for the national agenda if they are to keep pace with the rest of the world. With the astronomical cost of production factors in the developed economies, it is now time for economies in the Sub-Sahara Africa region to take advantage of their resource wealth capacity to induce scope for technology transfer that will ultimately impact the developmental landscape of in region. As already mentioned, the situation in the SSA region is dire in terms of the need to foster innovation, there is evidence to attest that global economic growth is on the downturn - with high uncertainty, there is a need to ensure innovation is set at the center of developmental agenda to capacitate the necessary engines that will make the region more attractive to technology transfer. Such transfer of technology is based on the fact that the cost of production in the developed economies is astronomically high compared to that in the SSA region.

Despite the obstacles, there are significant initiatives underway that aim to bridge this gap. Mobile technology, for example, has seen expansive growth in Sub-Saharan Africa and is a major contributor to economic activity. For every 10% increase in the mobile consumer base, there is a notable increase in GDP, showcasing how pivotal technology is to economic growth in the region. Additionally, the Fourth Industrial Revolution (4IR) presents opportunities for Sub-Saharan Africa to leapfrog traditional phases of development, especially in areas like mobile banking, agricultural technology, and digital health services.

Despite these advancements, the overall technology adoption in Sub-Saharan countries still lags behind global standards, particularly compared to the rest of the world. Efforts to improve this situation include enhancing educational systems to boost tech skills, increasing government and private investment in tech infrastructure, and fostering policies that support technological innovation.

Enhancing educational systems is crucial, this includes integrating technology into the curriculum, providing teacher training on digital tools and ensuring students have access to the necessary resources to develop technology skills from an early age. Increasing government and private investment in technology infrastructure is essential. This involves expanding internet connectivity, especially in rural areas and ensuring reliable electricity supply. Public-private partnership can be instrumental in developing and maintaining this infrastructure. Furthermore, providing incentives for tech companies to operate and invest in the region can stimulate economic growth and technological advancement.

Figure 4: **Internet Technology penetration in SSA in comparison to other Regions of the world.**



Source of data: World Bank open database (2020)

2.1: Indicators of the Technology Frontier in Sub-Saharan Countries

The indicators of the technology frontier in Sub-Saharan countries are broadly categorized into several key areas that reflect the region's capacity for technological adoption, innovation, and development. These indicators provide insight into how technology is utilized and the progress made toward integrating more advanced technologies. Here are some of the main indicators evidenced in the region.

(a) Digital Infrastructure Expansion: Sub-Saharan Africa has seen significant investments in expanding digital infrastructure. This has been reflected in the increasing accessibility to digital services, such as internet connectivity and mobile communications which are crucial for economic development, innovation, and social inclusion. Furthermore, The World Bank andother development partners and sector stakeholders are supporting the region in achieving its digital transformation within the International Development Association (IDA), technology is a cross-cutting theme covering three areas of work: Closing the digital connectivity gap, investing in safe and open digital public infrastructure (DPI), and Helping countries access and use digital services, particularly in the context of the jobs and economic transformation agenda.

A range of World Bank projects have contributed to a 115% increase in the number of internet users in Sub-Saharan Africa, from 19% in 2016 to 36% in 202. Over 160 million

Africans gained broadband internet access between 2019 and 2022. 191 million additional individuals made or received a digital payment between 2014 and 2021. 1,700 kilometers (km) of fiber optic cable deployed in Mauritania between 2021 and 2022. 4.7 million people in Uganda benefited from a regional program that aimed to lower prices for international capacity and extend the geographic reach of broadband networks. Since 2014, 4.3 million people in Malawi have benefited from increased access to affordable, high-quality internet services.

The World Bank's flagship Digital Economy for Africa (DE4A) initiative supports the ambition of ensuring that every individual, business, and government in Africa is digitally enabled by 2030. Under the DE4A initiative, the World Bank has delivered 70 digitalization projects in Africa since 2019, aiming to build the foundation for a vibrant, safe, resilient, and inclusive digital economy totaling $9 billion across 37 countries in the region. Increased accessibility of broadband services, accompanied by enhanced affordability and service quality, leads to higher inclusion. Digital inclusion in turn has a positive impact on creating jobs and reducing poverty. In 2023, a World Bank flagship report found that in Nigeria and Tanzania, extreme poverty declined by about 7% after three or more years of exposure to Internet coverage while labor force participation and wage employment increased by up to 8%.

(b) The start-up ecosystem and venture capital (VC) activity: These are strong indicators of the technological frontier in Sub-Saharan Africa, highlighting regions and sectors where innovation is thriving and attracting investment that is to say;

- **Innovation Hubs** in countries like Nigeria, Kenya, South Africa, and Egypt are leading in start-up activity and VC funding. These nations have become significant hubs for technological innovation and entrepreneurship in the continent, receiving a substantial portion of Africa's total VC investments. Funding secured from innovation hubs by Nigeria, Egypt, South Africa, and Kenya has continually increased over the years: from a 79.4% share in 2018 to 87.5% in 2019 and then 89.2% in 2020. In 2021, The Seventh Edition of Disrupt Africa's African Tech Start-ups Funding Report revealed that start-ups in the Big Four raised a combined $1.9 billion about 92.1% of the overall total investments raised in Africa for that year. The latest figures are, in fact, part of a years-long trend of the big-four dominance in Africa's start-up scene.
- **Growth of Venture Capital**: Venture capital investment in Africa has been increasing, reflecting confidence in the region's technological and entrepreneurial potential. In 2022, Africa attracted $5.2 billion across 786 deals, despite the global economic

downturn affecting other regions more significantly. Deal making was concentrated in the financial sector, which assumed 31% of the deal volume and 42% of the deal value. The 2022 median deal size across all investment stages was US$2.0 million, a 43% increase from the 2021 full-year median of US$1.4 million. In 2022, 15 super-sized deals in companies raising both venture capital and venture debt took place with a combined value of US$2.2 billion. Startups raising their first round of venture financing only accounted for 37% of VC deal volume. The path to parity gained momentum and startups with a gender diverse founding team raised a cumulative total of close to US$950 million.

(c) Investment in Research and Development (R&D): R&D investment serves as a multifaceted indicator of a region's technological capabilities and its potential for future innovation and economic expansion. It signifies a proactive approach to embracing and developing new technologies that can lead to sustainable growth and development in Sub-Saharan Africa. Through new technologies and innovations, investment in R&D in Sub-Saharan Africa has been central to sectors such as agriculture, healthcare, and digital technologies. For instance, projects like the African Agricultural Technology Foundation focus on R&D to improve agricultural practices through technology, which is essential for a region where a large portion of the economy depends on agriculture.

African governments, policymakers, and regional economic communities during the Second Africa-wide Science, Technology, and Innovation High-Level Conference organized by AATF in collaboration with the African Union Development Agency-NEPAD(AUDA-NEPAD) and the Government of Rwanda in April were urged to enhance strong political will to further integrate Science Technology and Innovation (STI) in Africa for sustainable economic growth and agricultural transformation. It was revealed that if the continent is to address the socio-economic challenges facing the majority of the Sub-Saharan Africa (SSA) countries, there is an urgent need for African governments to increase funding for STI to transform agricultural development in Africa.

(d) Technology-Driven Economic Contributions: The economic impact of technology is evident in its contribution to GDP. For instance, the mobile economy contributed significantly to the GDP of Sub-Saharan Africa by enabling growth in mobile and digital transactions. As a result of extensive networks of undersea Internet cables, physical Internet infrastructure is much more expensive in landlocked regions than in coastal ones. Access for landlocked countries primarily stems from the infrastructure already in place in neighboring countries leading to large disparities in access within sub-Saharan Africa. South Africa, with ample access to international cabling on the ocean bed, has an Internet penetration rate of 50%, while West Africa's 30% is still much higher than the 10% in Central Africa.

(e) Access to capital: This is a crucial indicator of the technology frontier in Sub-Saharan Africa because it has enabled startups and businesses to develop innovative technologies and scale operations, driving economic growth and technological progress in the region. Venture capital funding, in particular, plays a significant role. For example, various Africa-focused venture capital funds such as Sony Innovation Fund, Saviu Ventures, and Chui Ventures have a gender-inclusive focus in their plan to back founders in Africa focused on mass-market products. Its maiden fund bagged $9 million backing from Mastercard, to serve a market that has recently received clamor for local capital. Africa has been actively investing in sectors like fintech, health tech, and entertainment startups across Sub-Saharan Africa. These investments help foster a vibrant startup ecosystem that is necessary for technological advancement and innovation.

3: The Distance to the Technology Frontier of SSA in comparison with that of The United States of America.

In recent years, several countries in Sub-Saharan Africa have been sprinting toward digitization and have had the potential to reach new heights as long as they address shortfalls in physical and human capital, as well as weaknesses and gaps in digital governance and regional trade agreements. Comparing the technology frontier of Sub-Saharan Africa with that of the United States of America (USA) involves looking at several dimensions, including innovation, infrastructure, access to technology, and the general technological landscape. Both regions have unique characteristics and challenges that shape their technological environments. The United States is a global leader in technology and innovation, hosting many of the world's leading tech companies like Google, Apple, and Microsoft. The country's strong R&D ecosystem is supported by a combination of public and private funding, leading to advancements in various fields including artificial intelligence, biotechnology, and aerospace. The presence of world-class universities and research institutions further fuels this innovation.

While the USA leads in technological development and infrastructure, Sub-Saharan Africa is making notable strides in using technology to solve region-specific challenges. The innovation in mobile and financial technologies in Africa offers a compelling example of how different paths to technological advancement can be, tailored to a region's unique needs and contexts.

3.1: Comparison of the chosen countries.

Due to the region's vastness, we have chosen countries to compare with the USA, we have selected twelve countries to study due to their recent efforts made towards technological advancement in the region overall: Lesotho, Zambia, Malawi, Democratic Republic of Congo, Cameroon, Uganda, Kenya, Nigeria, South Africa, Ghana, Tanzania, and Senegal.

Here are comparisons of each country based on its performance.

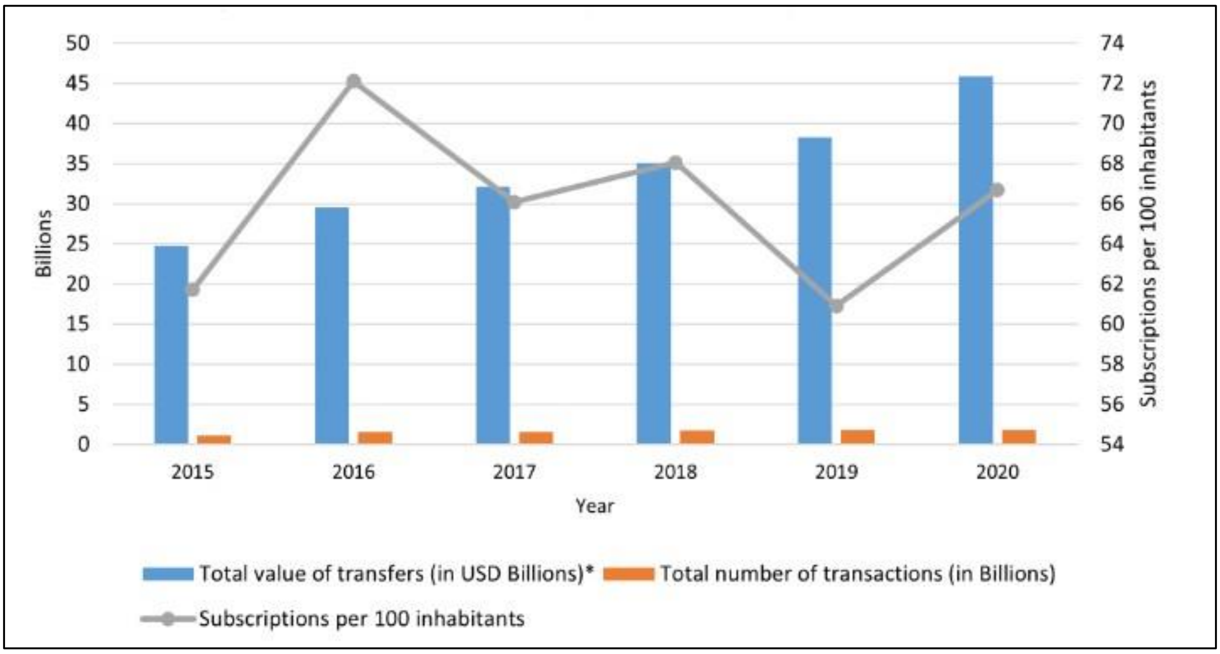
Kenya:

Kenya, located in East Africa, is recognized as one of the leading countries in technology adoption within the Sub-Saharan Africa region. As of early 2023, Kenya's population was approximately 54.56 million, with around 17.86 million internet users, resulting in an internet penetration rate of 32.7%. This reflects considerable access to the internet, though there remains a notable gap in technology advancement compared to countries like the USA, which could be bridged by further developing infrastructure and enhancing affordability measures.

Kenya is globally renowned for its pioneering mobile money platform, M-PESA, launched in 2007 by Safaricom. M-PESA has played a crucial role in financial inclusion, providing a reliable transaction platform for the unbanked and underbanked populations. This innovative service has significantly reduced transaction times and costs, making financial services more accessible to millions of Kenyans. The impact of M-PESA has been transformative, allowing users to perform various financial transactions such as sending and receiving money, paying bills, and accessing loans, all through their mobile phones. This ease of access has been particularly beneficial in rural areas where traditional banking services are scarce.

From 2006 to 2019, the percentage of Kenyan adults excluded from the financial system dropped dramatically from 42% to 11%, highlighting the profound impact of M-PESA on financial inclusion. By 2019, 83% of Kenyans had a financial account, including bank and mobile money accounts, a substantial increase from just 29% in 2006. The widespread adoption of mobile money services is further evidenced by the mobile money penetration rate, which reached 66.68 subscriptions per 100 inhabitants by 2020. This statistic underscores the effectiveness of digital financial solutions in Kenya and the country's success in integrating its population into the formal financial system through innovative technology.

Figure 5:The steady growth trend of Kenyan mobile money between 2015 and 2020



Source: KNBS Economic Survey 2020&2021 (values converted to USD from ksh)

When comparing the technology frontiers of Kenya and the USA, we identify distinct paths in technological development and adoption, each shaped by differing economic, social, and governmental influences. In the USA, technology investment and innovation continue at a high rate, emphasizing cutting-edge trends like artificial intelligence, quantum computing, and edge computing. According to the McKinsey Technology Trends Outlook 2023, significant investments are ongoing in various tech sectors, highlighting a strong belief in their future growth potential. This outlook is particularly robust in fields like cloud computing and bioengineering, which continue to see substantial innovation and expanded applications across industries.

However, by increasing internet coverage and utilization by most Kenyans, the country could enhance awareness and market outreach on various innovations in the technology sector. While the USA is continuing to invest in broadening its technological infrastructure, aiming to improve internet access across urban and rural areas, though challenges remain in achieving equitable access nationwide, Kenya is also making efforts to develop a digital-first economy, focusing on mobile technology, internet accessibility, and government-backed initiatives to foster innovation. In conclusion, each country's approach to technology and innovation reflects its unique economic priorities, societal needs, and government policies.

Nigeria:

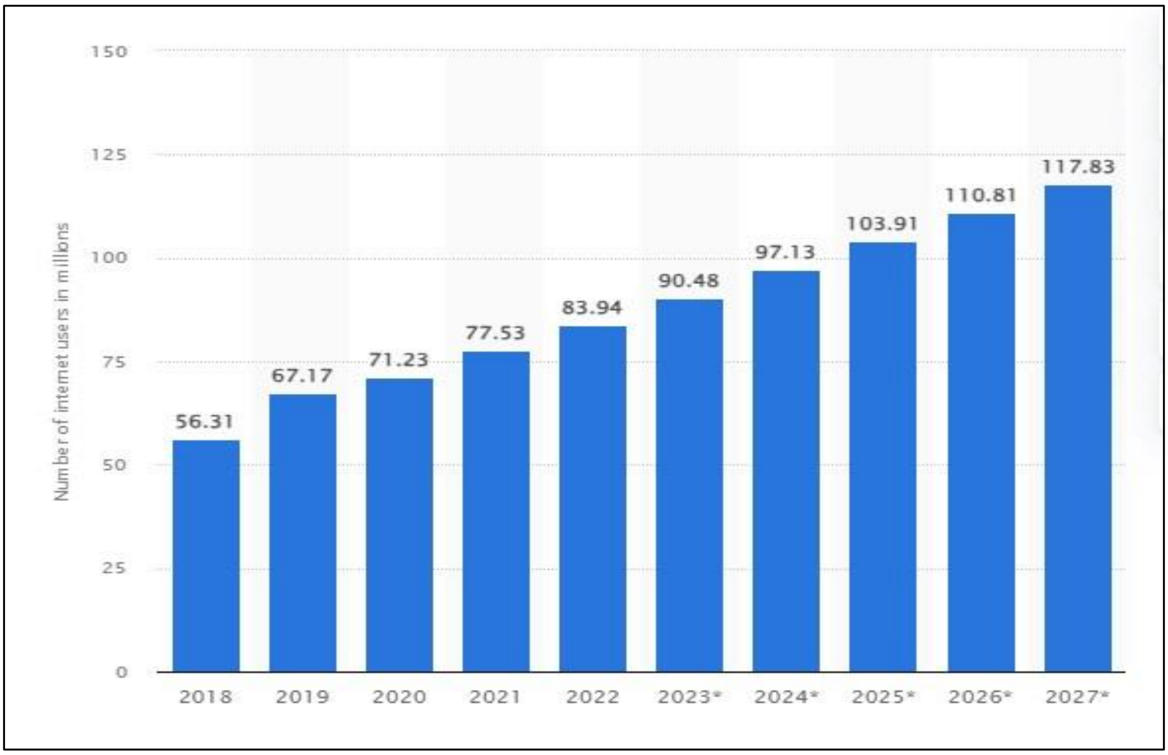
As of early 2022, Nigeria, with a population nearing 220 million and an internet penetration rate of 51%, represented a significant and growing ICT consumer market. This rate translated to approximately 109 million active internet users, showcasing a 4.6% year-on-year growth. The prospects for further expansion are substantial, especially considering the population is projected to reach 377 million by 2050. Speed tests by Ookla indicated that the median mobile connection speed in Nigeria was 17.4 Mbps, and for fixed connections, it was just over 10 Mbps, both figures showing annual increases. Comparatively, the global median speeds were significantly higher, emphasizing the gap in internet quality. Broadband penetration also saw an increase from 39.9% to 45.1% over a year, contributing to a rise in total internet subscriptions from 142 million to 152 million in the same period.

While Nigeria has made notable strides in expanding internet access, the current state of inter net infrastructure reveals significant disparities that hinder equitable participation in the digita l economy. Despite an overall internet penetration rate of 51%, the quality and distribution of this access are uneven, leaving a substantial portion of the population underserved.

A 2022 report by the Alliance for Affordable Internet reveals a stark reality: only 12.1% of Ni gerians had access to reliable, highspeed internet. This means that the vast majority of the pop ulation either has no internet access at all or experiences slow, unreliable connections that limi t their ability to fully engage in online activities. This digital divide is particularly pronounced in rural areas, where only 6.6% of the population enjoys quality internet access compared to 16.4% in urban areas. This geographical disparity stems from a lack of investment in infrastru cture development in rural communities, leaving them behind in the digital revolution.

Furthermore, the report highlights a concerning gender gap in internet access, with men (15.5 %) significantly more likely to have reliable connections than women (7.2%). This disparity r eflects broader societal inequalities that hinder women's access to education.

Figure 6: Number of internet users in Nigeria from 2018 to 2022, with forecasts from 2023 to 2027(in millions)



Source: Statista 2024(https://www.statista.com/aboutus/our-research-commitment/2683/doris-dokua-sasu)

As of 2022, Nigeria boasted nearly 84 million internet users, a number expected to grow to 117 million by 2027, reflecting an increase in internet penetration from 38% to 48% of the population. The country's technology landscape, particularly within the information and communications technology (ICT) sector, plays a pivotal role in the economy, emphasizing mobile telecommunications and internet services. Nigeria holds the distinction of having the largest ICT market in the region, accounting for a significant share of Africa's telecom subscribers and internet users.

In comparison, the USA stands as a global technology leader, with substantial investments in various sectors such as ICT, biotechnology, renewable energy, and aerospace, including cutting-edge fields like artificial intelligence and quantum computing. Home to Silicon Valley, the USA not only fosters innovation through robust economic policies and frameworks but also attracts global tech talent, maintaining a competitive edge in technology. The contrast between Nigeria's developing technology landscape and the USA's advanced technological ecosystem underscores the challenges and potential growth areas for Nigeria, highlighting the need for effective policies and public-private partnerships to bridge the technological gap.

South Africa:

South Africa is emerging as a key player in digital entrepreneurship within the African continent, addressing various sectoral challenges through technology-driven startups in health, transport, and education. The country leads in the sub-Saharan region with 49% of cellular IoT connections and has pioneered commercial 5G deployment, enhancing its connectivity infrastructure primarily in urban areas. However, this progress has also accentuated a digital divide, with rural areas lagging behind in technological access and advancements.

In its quest to close the technological gap with global leaders such as the USA, South Africa is actively participating in events like "Digitizing Africa 2023" to drive digital transformation and economic growth across the region. The emphasis is on expanding digital infrastructure to improve technology accessibility, with digital platforms like YouTube, Instagram, and TikTok seeing substantial user growth, indicating a surge in digital consumer engagement.

Despite the USA's dominance in technological innovation and investment, South Africa is making significant strides in integrating technology into its socio-economic development strategies. This includes efforts highlighted in UNCTAD reports to adopt green technologies and other innovative solutions to tackle environmental challenges and enhance economic resilience. These initiatives show South Africa's proactive approach in leveraging technology not only to catch up with global trends but also to address pressing local and global challenges effectively.

Ghana:

Ghana, a country traditionally known for its rich deposits of gold and cocoa, is increasingly gaining recognition for its emerging tech scene, despite previously being overshadowed by other African giants like Nigeria, South Africa, and Kenya. The tech ecosystem in Ghana is experiencing growth with a rising number of startups in sectors like fintech, agritech, and health tech attracting significant investments. Notable companies like mPharma and Jetstream are raising capital, demonstrating the potential within the local market. Additionally, international tech giants like Twitter and Google are making substantial commitments by setting up operations in Ghana, which has an internet penetration rate of 46.5%, surpassing the African average and neighbouring West African countries but still lagging behind global and Kenyan standards.

The Ghanaian government is actively fostering this growth through initiatives like the Accra Digital Centre and support entities such as the Meltwater Entrepreneurial School of Technology

(MEST) and the Ghana Innovation Hub, which assist startups and encourage innovation. Efforts to integrate digital technologies were particularly noticeable during the pandemic with increased adoption of big data and mobile technologies in health and crisis response sectors. Local companies like KA Technologies are advancing in electronics manufacturing, enhancing Ghana's capabilities in both hardware and software development. However, despite these advances, Ghana faces challenges like limited access to capital and less developed infrastructure compared to the U.S., which boasts a mature and innovative tech ecosystem supported by extensive investments and technical expertise. To bridge the technological gap, Ghana could focus on enhancing investment, education, infrastructure, and policy-making to propel its tech sector forward and align more closely with global technological frontiers.

Uganda:

Uganda's technology landscape in early 2024 shows a steady increase in internet and social media use, with about 17.3% of the population actively using platforms like Facebook, Instagram, and LinkedIn, while mobile connections account for 66.9% of the populace. This highlights mobile technology as the primary gateway to online services. Additionally, Uganda is focusing on enhancing its digital infrastructure, especially in the fintech sector, with organizations like the Financial Technology Services Providers' Association (FITSPA) working to foster a safe and innovative ecosystem. The government is also committed to accelerating digital transformation, as evident from the Digital Transformation Roadmap by the Ministry of ICT, which includes strategies for big data and digital skills enhancement to meet developmental objectives.

In contrast, the United States leads as a global technology innovator, excelling in sectors such as IT, biotechnology, and renewable energy, with a strong influence on global tech standards. The differences in technological advancement between Uganda and the USA can be attributed to disparities in economic resources, infrastructure, and institutional support. For Uganda to advance its tech frontier, it's crucial to improve digital literacy and education, integrate digital skills into school curriculums, and promote digital technology awareness nationwide. Additionally, targeted efforts to bridge the digital divide, such as providing affordable internet access and setting up community tech hubs, are essential for making technology accessible to all Ugandans, thereby enhancing their capacity to leverage emerging technologies for broader economic and social benefits.

Tanzania:

As of early 2024, Tanzania's technology penetration rate reached 31.9%, with about 21.82 million internet users, demonstrating a consistent growth in connectivity primarily driven by mobile internet. This widespread mobile connectivity has significantly boosted social media usage, with platforms like Facebook and Instagram becoming particularly popular. The expansion of internet access has also played a pivotal role in enhancing the business landscape, enabling Tanzanian companies to utilize digital platforms for marketing, customer engagement, and e-commerce, though a digital divide persists with rural areas lagging behind urban centers in internet accessibility.

Tanzania is integrating technology into its national development strategy with a focus on sustainable development and agriculture, emphasizing climate-resilient technologies. Efforts include adopting improved agricultural technologies like drip irrigation and renewable energy sources such as mini-hydropower and rooftop solar to address climate challenges. The business sector is also seeing a surge in technology adoption, with increasing projects and tenders in ICT, telecommunications, and security systems, indicating a robust environment for technology providers and startups driven by both local innovation and international collaboration.

Comparatively, Tanzania and the USA exhibit distinct technology landscapes reflecting their developmental priorities and economic conditions. Tanzania's technology efforts are aimed at addressing immediate socio-economic and environmental needs through sustainable and agricultural advancements. Meanwhile, the USA is advancing in high-tech areas like edge computing, expected to significantly grow by 2024, with applications in smart cities and healthcare. This showcases the USA's focus on cutting-edge research and innovation, contrasting Tanzania's emphasis on foundational and sustainable technologies. These differences underscore the unique ways each country leverages technology to meet their respective challenges and future goals.

Zambia:

At the end of 2022, Zambia reported a technology penetration rate of 56.8%, with active internet subscriptions reaching approximately 11.1 million, marking a 6.73% increase from the previous year. However, this rate still indicates that a considerable portion of the population lacks regular internet access, underscoring both ongoing challenges and growth opportunities within Zambia's digital landscape.

Zambia is actively working to enhance its technological infrastructure, exemplified by significant governmental initiatives such as the nationwide establishment of community Digital Transformation Centers, which utilize Zambia Postal Services facilities to offer free internet and digital literacy programs. Further bolstering its tech sector, Zambia plans to inaugurate a smartphone factory by June 2024 to make smartphones more affordable and increase digital inclusivity. These initiatives are part of a broader strategy to use technology as a lever for economic, environmental, and social advancement.

In comparison, the technology strategies of Zambia and the USA are shaped by their distinct developmental stages and needs. Zambia focuses on foundational infrastructure and socio-economic resilience, while the USA pushes boundaries in high-tech innovation and global technological leadership. Zambia's practical approach targets inclusive growth and sustainability, aiming to close the technology gap through enhanced infrastructure, improved educational policies, and strengthened international cooperation. Meanwhile, the USA continues to innovate and define new technological paradigms, maintaining its position at the forefront of global technology.

Cameroon:

In Cameroon, about 14 million people from its 25 million population lack internet access, highlighting significant challenges in telecommunication infrastructure despite ongoing efforts. The country is working to expand its national fiber network and introduce 5G technology, with MTN Cameroon taking a lead role. However, the telecommunications sector has seen a steep investment decline of 78% from 2016 to 2019, indicating a pressing need for renewed investment to bridge the existing digital divide and fully leverage digital transformation opportunities.

Compared to the USA, where Silicon Valley epitomizes the zenith of global tech innovation, Cameroon's technology sector is still developing. Cameroon is nurturing a growing startup ecosystem in fintech, Agri-tech, and e-commerce, supported by a young, entrepreneurial demographic. In contrast, the USA excels in high-tech areas like artificial intelligence, biotechnology, and quantum computing, backed by a strong network of universities, research institutions, and venture capital. For Cameroon to close this technological gap, it is essential to improve infrastructure, foster international tech partnerships, support innovation-friendly policies, and enhance STEM education to cultivate a skilled workforce for future tech advancements.

Lesotho:

Lesotho has been advancing its technological infrastructure, reporting a 47% internet penetration rate with about 1.1 million internet subscribers as of early 2022. The country also shows significant mobile connectivity, with 2.56 million cellular connections suggesting high mobile usage, possibly due to multiple SIM card ownership. Social media is also gaining traction, with approximately 532,000 users, and the introduction of 5G technology by Econet aims to enhance modern applications and infrastructure. However, challenges like the high cost of 5G-compatible devices could hinder the widespread adoption of this advanced technology

Comparatively, Lesotho's technology strategy focuses on enhancing infrastructure to provide basic digital services and improve connectivity, a foundational step for its socio-economic development. In contrast, the USA is concentrated on spearheading innovation and developing cutting-edge technologies that dictate global trends and open new markets. This distinction underscores the global digital divide, suggesting that Lesotho could further its technological progress by forming international partnerships, investing in technology education, and fostering policies that encourage technology transfer and innovation.

Democratic Republic of Congo (DRC):

As of early 2024, the Democratic Republic of the Congo (DRC) reports an internet penetration rate of about 27.2% with 28.31 million users, which is significantly lower than the global average, indicating limited digital access for most of the population. Mobile technology, with a penetration rate of 44%, remains the primary internet access method due to the scarcity of fixed-line infrastructure. The expansion of telecommunications is challenged by geographical and economic factors, impeding the provision of fast and reliable internet services across the region.

The technological disparity between the DRC and the United States is pronounced, with the DRC focusing on basic digital access and infrastructure development, while the USA leads in high-tech innovation and the application of advanced technologies in various sectors. To reduce this technological gap, the DRC would benefit from enhanced infrastructure investments, policies promoting technology education and digital literacy, and international collaborations that support technology transfer and development, thereby accelerating its progress towards a more sophisticated technological landscape.

Malawi:

In 2024, Malawi shows a growing engagement with technology, with internet users reaching approximately 5.04 million, or 24.4% of its population, reflecting a notable increase from the previous year's 20.2% penetration. The country boasts around 11.81 million active mobile connections, accounting for 57.2% of the population, which is crucial for internet access due to the limited fixed broadband infrastructure. Meanwhile, social media usage is also expanding, though it remains relatively modest at about 3.8% of the population.This rise in digital access in Malawi is driven by government and stakeholder efforts to enhance digitalization, which aims to improve access to information, education, and economic opportunities. Despite these efforts, a significant portion of the population remains offline, underscoring the persistent challenges in closing the digital divide. The goal is to enhance overall digital engagement and address the infrastructural shortcomings that hinder wider internet accessibility.

Comparatively, the technology landscape in Malawi and the USA highlights stark differences in development levels. The USA, with its nearly universal internet penetration and advanced technological infrastructure, leads in high-tech innovations including AI, quantum computing, and biotechnology. Malawi, on the other hand, is focused on foundational digital access and mobile connectivity to mitigate infrastructural deficits. To narrow this technological gap, Malawi could benefit from increased investment in digital infrastructure, improved technology education policies, and international partnerships to foster technology transfer and innovation.

Senegal:

Senegal is making significant strides in technology with an impressive technology penetration rate of around 89.63% in 2024, thanks to initiatives like the Diamidino Digital Technologies Park. This park enhances Senegal's digital economy through advanced telecommunications infrastructure, including submarine cables and terrestrial fiber deployments. It supports a high mobile phone penetration rate of 98%. These efforts align with the broader Emerging Senegal Plan aimed at transforming the country into a digital innovation and economic hub. This plan focuses on increasing digital access and leveraging technology across various economic sectors.

In contrast, while Senegal is advancing in digital infrastructure and connectivity, it is still in the nascent stages compared to the USA's mature and deeply integrated technological landscape. The USA continues to lead in high-tech innovation, setting a benchmark that Senegal aims to reach with ongoing investments and strategic planning. Both countries value technology's role in economic and societal development, though they are at different stages of technological integration

Conclusion

In conclusion, this chapter has critically examined the dynamic interplay between human capital and the technology frontier in Sub-Saharan African countries. Throughout our analysis, we have identified both challenges and opportunities that shape the trajectory of technological advancement in the region. Our findings underscore the pivotal role that human capital education, skills, and health plays in enabling these nations to leapfrog into modern technologies and enhance their positions on the global technology frontier.

Our study highlighted that despite the existing hurdles such as limited infrastructure, low levels of education, and inadequate healthcare systems, there are emerging signs of significant progress. Initiatives aimed at improving educational outcomes and health standards have shown promising results, directly contributing to a more skilled and productive workforce capable of driving technological innovation and adoption. Moreover, the rise of mobile technology and the internet has catalysed new avenues for economic and social development, making technology an increasingly integral part of everyday life and business operations across the region.

In light of this, the path forward should be strategically oriented towards creating synergies between human capital development and technological empowerment. By doing so, Sub-Saharan countries can unlock a new era of economic growth and development, making significant strides towards achieving their long-term development goals and enhancing their competitive edge in the global economy. This thesis contributes to the understanding of these complex dynamics and offers a foundation for future research and policy formulation aimed at integrating technology and human capital development in SSCs.

Chapter 3: Methodology and Econometric Analysis

Introduction

In this final chapter, we embark on a detailed exploration of the methodology and econometric analysis that underpin our study. This chapter is designed to meticulously outline the procedures and techniques employed in gathering and analysing data, ensuring that our findings are robust and empirically sound. We will delve into the specific econometric models used, discussing their relevance and applicability to addressing our research questions. The chapter will also cover the data collection process, the rationale behind the selection of variables, and the methodological choices made to ensure the integrity of the analysis. By providing a comprehensive overview of these methodologies, this chapter aims to offer clarity and insight into how our conclusions are drawn, setting the stage for a thorough understanding of the economic implications highlighted by our study.

1: Methodology

1.1: Research Design

To address our inquiry into the impacts of human capital and the distance to the technology frontier on the economic growth in SSCs, our research employs a deductive methodological approach, entailing the evaluation of existing theories and hypotheses. Beginning with overarching theories or hypotheses, we employ data to ascertain whether these suppositions are substantiated or invalidated. We selected this method because we have formulated hypotheses regarding the interrelation between specific factors and economic growth. Through the collection and analysis of data, we intend to draw conclusions grounded in logical reasoning and empirical evidence concerning the principal determinants of economic growth in Sub-Saharan countries. Our study adopts a quantitative research methodology.

In this research, we adopt a hybrid methodology that combines case study and panel data econometric modelling to explore the relationship between human capital, the distance to the technology frontier and stock of physical capital and economic growth in SSCs. The case study methodology allows for an in-depth examination of selected countries within the region, enabling us to delve deeply into the unique contexts and intricate dynamics that underpin their economic development. This involves utilizing a variety of data sources to ensure a rich, multifaceted understanding of each country's specific circumstances and challenges.

Simultaneously, the panel data econometric modelling of our methodology focuses on the collection and analysis of data over the studied periods. This approach is crucial for observing trends and changes in economic growth, as well as for identifying the long-term impacts of various studied variables. By integrating these two approaches, we aim to leverage the strengths of both to provide a comprehensive analysis to the role playing human capital and the distance to the technology frontier in SSCs' economic growth. This dual approach enhances the robustness of our findings, offering valuable insights that are both contextually rich and temporally deep, thereby contributing significantly to our understanding of economic development in SSCs.

For our study, we utilized secondary data, which consists of information previously collected and published by other researchers or institutions. This approach allows us to leverage existing data for a comprehensive analysis. Our study employs panel data modelling, which combines cross-sectional and time series datasets, enabling us to examine the same variables across multiple entities over different time periods. This methodology is particularly beneficial as it helps address unobserved heterogeneity, such as omitted variable bias, thereby enhancing the reliability of our results.

Panel data analysis provides distinct advantages by integrating the strengths of both time series and cross-sectional analysis, offering deeper and more nuanced insights than could be obtained through either method alone. To conduct our regression analysis, we employ Stata 17 software.

1.2: Panel Data Modelling

In this research, we utilize panel data analysis, a method well-suited for empirical studies that integrate both time series and cross-sectional observations. Our dataset adheres to this format; it comprises panel data from Sub-Saharan countries (cross-section) tracked over a specific time period (time series). This analytical approach enables us to investigate how human capital and the distance to the technology frontier impact economic growth across these countries over the period 1999-2019. This methodology is crucial for gaining a deeper understanding of the dynamics at playing and ensuring the accuracy of our findings.

1.3: Why Panel Data?

Panel data, which combines time series and cross-sectional data, offers several distinct advantages in research and analysis:

- **Controlling for Unobserved Heterogeneity:** Panel data allows researchers to control for individual heterogeneity—traits or characteristics that vary across entities (like countries, firms, or individuals) but are constant over time. This feature is particularly valuable because it helps to account for unobserved variables that can influence the dependent variable, thereby reducing omitted variable bias

- **More Informative Data:** The richness of panel data, due to its multidimensional nature (across time and entities), provides more variability, less collinearity among variables, more degrees of freedom, and more efficiency in the data. This enhances the robustness of statistical results.
- **Detecting and Measuring Change**: With panel data, it's possible to analyse changes at the individual level, not just at an aggregate level. Researchers can examine how changes in policy or economic conditions affect specific entities over time, offering a clearer view of cause-and-effect relationships.
- **Increased Variation**: Panel data inherently includes more variation and less multicollinearity (i.e., fewer problems with independent variables that are too closely linked), enhancing the precision of estimates.
- **Study of Complex Interactions**: The structure of panel data makes it feasible to explore more complex behavioral models, including those involving interactions between variables that vary both across entities and over time.

In this section, we delve into the methodology of our study, utilizing panel analysis which combines observing multiple individual units (cross-sectional data) over consecutive time periods (time series). Essentially, the same cross-section is measured across different times.

The foundational equation for our panel data model is outlined as:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \varepsilon_{it} \quad \text{………………… (1)}$$

where Y_{it} denotes the dependent variable, i is the individual unit observed over time t, β_0 is a constant for all observations, β_1 represents the coefficients of the independent variables X_{it}, and ε_{it} encapsulates the error term, which includes both random variation and unobserved factors.

It is important to note that the error term:

$$\varepsilon_{it} = \mu_{it} + v_{it} \quad \text{………………………… (2)}$$

with μ_{it} indicating individual-specific effects that may be observable or unobservable, and v_{it} representing random errors.

This section provides a detailed description of the methodology used in our analysis. Initially, we introduce the sample data and clearly define the variables, ensuring consistency across each country and over different time periods. We then conduct a descriptive analysis to examine the distribution of the variables, presenting summary statistics that include the number of observations, means, standard deviations, and the range of values (maximum and minimum).

In the next step, we move on to model specification. Here, we construct our mathematical model, incorporating the variables in logarithmic form to facilitate our estimations. To address the inherent challenges of panel data analysis, such as unobserved heterogeneity, we apply two primary models: The Fixed Effects model and the Random Effects model, as suggested by Studenmund (2016). These models help us effectively handle variations that are not directly observed within the data.

(a) Fixed Effects Model (FEM)

This approach is also referred to as the Within Estimator, Covariance Model, or Least Squares Dummy Variable Model. It involves estimating equations for panel data by incorporating dummy variables. This technique ensures that the coefficients estimated from the model remain unbiased by accounting for omitted variables that do not change over time. This method was also employed in our study because it operates under the assumption that the time-invariant characteristics of the individuals are perfectly collinear with the dummy variables. By taking the average over time for each individual, which is generally inconsistent under the null hypothesis $H0$: Cov (Ui, Xit) =0, it effectively addresses the issue of multicollinearity. Mathematically, a fixed effect model can be expressed as:

$$y_{it} = \alpha_i + \beta x_{it} + \varepsilon_{it} \dots\dots\dots\dots\dots\dots \text{(3)}$$

where:

- γ_{it} is the dependent variable observed for entity i at time t.
- α_i is the unobserved individual-specific effect (fixed effect)
- x_{it} represents the independent (explanatory) variables that may vary over time and across entities.
- β is the coefficient of the independent variables.
- ε_{it} is the error term, assumed to be iid (independently and identically distributed.

(b) Random Effects Model (REM)

This model operates under the assumption that the fixed effects U_t are not correlated with the regressors X_{it} according to the null hypothesis H_0 : Cov(U_t|X_{it}) = 0 it is alternatively known as the Random Intercept or Partial Pooling Mode which accounts for variations both within and between individual units. The general form of the linear equation is structured as follows:

$$y_i = \beta_0 + \beta_1 x_{it} + \gamma_i + \varepsilon_{it} \text{ ……………….. } (4)$$

In the random effects model, the distinction from the fixed effect equation lies in the term γ_i which represents the individual-specific random effect. This effect accounts for unobserved heterogeneity, presumed to be random and not correlated with the explanatory variables. Additionally, ε_{it} is the error term, corresponding to random errors unique to each observation.

The Hausman specification test, established in 1978, is employed to decide the most appropriate model between fixed effects and random effects. The test operates under the null hypothesis that the random effects model provides consistent estimations, denoted by $E(U_{it}|X_{it})$ = 0. If the p-value from this test is greater than 0.05, we accept the null hypothesis, indicating a preference for the random effects model. On the other hand, if the p-value is below 0.05, we reject the null hypothesis in favour of the alternative, suggesting that the fixed effects model is preferable.

Following the selection of a model, various validation tests are conducted to ensure its robustness. These tests include the Wooldridge test for autocorrelation in errors, examining the linear relationships among variables, and tests for multicollinearity to detect strong dependencies between regressors. The Modified Wald test is also used to check for group-wise heteroskedasticity. If the null hypotheses of these tests are accepted (p-value > significance levels at thresholds of 1%, 5%, and 10%), it validates the model's appropriateness for analytical and forecasting purposes.

Should the null hypotheses be rejected, it signals issues such as heteroskedasticity, autocorrelation, and multicollinearity within the model. These problems can result in biased and inefficient estimates, unreliable standard errors, and incorrect statistical conclusions. To mitigate these issues, the Feasible Generalized Least Squares (FGLS) method is recommended for re-estimating the model, ensuring robust and dependable outcomes.

2: Econometric analysis

2.1: Presentation of Data

We used panel data, also known as longitudinal or cross-sectional time-series data, in our research. This type of data tracks multiple variables over different time periods for the same entities, like individuals or businesses (Longhi and Baltagi 2013). We selected this approach due to its considerable advantages for statistical analysis across numerous fields, making it an effective tool for capturing dynamics that might be obscured in cross-sectional or time-series data alone. Panel data offers several key benefits to researchers: It controls for Individual Heterogeneity by accounting for unique, individual variations that may not be directly observable but could distort the results if overlooked. It enables the examination of dynamic changes and the adjustment for time-varying confounding factors, allowing researchers to investigate how internal shifts within entities correlate with changes in other variables, such as economic growth and employment rates. Additionally, by integrating elements of both cross-sectional and time-series data and providing more data points, panel data analysis often yields more precise and efficient statistical estimates.

2.2: The Studied Sub-Saharan African Countries.

We conducted a study of sixteen SSCs over the 1990 -2019(i.e.30 years) using balanced panel data. Due to the availability of data, we chose 16 countries to work with. By analysing a more extensive set of countries, our study aims to deliver a nuanced understanding of the factors influencing economic growth and technological progress across SSCs.

Table 1: The Studied Countries

Zambia	Gabon	Ethiopia	Malawi
Lesotho	Senegal	Kenya	Cameroon
Zimbabwe	South Africa	Ghana	Mali
Uganda	D.R. of the Congo	Nigeria	U.R. of Tanzania

Source: Elaborated by authors

2.3: The studied variables

We selected variables based on their relevance to our research question and the availability of data. The variables chosen were Real GDP (RGDP) per capita, human capital (H), stock of physical capital per capita (Kc), and the distance to the Technology Frontier (FT), measured as the share of human capital in the considered country with respect to the human capital of USA. To mitigate issues with heteroskedasticity, all these variables are presented in natural logarithmic form. Furthermore, Real GDP per capita at constant prices (RGDP) was designated as the dependent variable in our analysis. All studied variables are annually findings (1990-2019) and extracted from Penn World Table (PWT 10.0).

Table 2: A summary of studied variables, including their descriptions, expected outcomes (signs), and sources

Variable	Description	Expected results(sign)	Source
H	Human capital index based on years of schooling and returns to education.	+	PWT 10.0
Kc	Stock of physical capital at constant 2017 national prices (in mil 2017 US$)	+	PWT 10.0
FT	Distance to the Technology Frontier	-	Calculated by the authors
RGDP	Real GDP at constant 2017 national prices	Dependant variable	PWT 10.0

Source: Elaborated by authors

2.4: Description of the studied variables

a) Dependent Variable

- Real GDP per capita is a measure of a country's economic output that accounts for its number of people. Specifically, it is the Gross Domestic Product (GDP) adjusted for inflation (to reflect real, not nominal, values) divided by the total population. This metric gives an average economic output per person, which is useful for comparing the standard of living across different countries or time periods. It is calculated as:

$$\boldsymbol{real\ GDP\ per\ capita} = \frac{\boldsymbol{real\ GDP}}{\boldsymbol{total\ population}} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

Where;

Real GDP is the value of all goods and services produced in a country, adjusted for Inflation.

Total Population is the total number of people living in the country.

b) Independent Variables:

- **Human Capital Index(H):** This encompasses the skills, knowledge, and competencies individuals gain through education, training, and experience, which lead to enhanced productivity and innovation. It is an economic concept that emphasizes the role of human factors in economic development, beyond just physical means of production like land and capital. In our research, human capital is quantified using the average number of years of schooling as an educational proxy.

  Healthier and better-educated individuals tend to be more creative and innovative. This connection is supported by the theoretical contributions of Gary.S. Becker (1964) and Lucas, R. E. (1988) who demonstrate how human capital contributes to technological advancement, thereby boosting labour productivity and facilitating the adoption of new ideas and technologies. Furthermore, these scholars and their works are foundational in the field of economics, particularly in understanding how human capital influences productivity, innovation, and ultimately, economic growth. Their theories suggest that investments in human capital not only benefit individual workers but also lead to broader economic benefits for society.

- **Stock of Physical Capital (Kc):** The stock of physical capital encompasses the total value of tangible assets such as infrastructure, machinery, buildings, and equipment that are integral to the production process. The stock of physical capital is a crucial component of a nation's productive capacity and is often accumulated through investment over time. Paul Romer's endogenous growth theory acknowledged the importance of physical capital while focusing on innovation and human capital. This illustrates that a robust stock of physical capital enhances productivity, facilitates technological advancements, reduces production costs, and attracts further investment, thereby driving sustained economic growth.

- **Technology Frontier (FT):** The distance to the Technology Frontier represents the highest level of technological advancements accessible within a specific industry or an overall economy at any given time. It symbolizes the pinnacle of technological progress, showcasing the most advanced knowledge and capabilities that have been achieved. Entities at this frontier whether industries, companies, or countries are at the cutting edge of technology, employing the latest and most sophisticated innovations. This advanced positioning facilitates enhanced innovation and productivity, as these entities can leverage state-of-the-art technologies to optimize processes, create new products, and gain competitive advantages.

The distance to the technology frontier is often measured by comparing the level of technological advancement in each country to that of the United States, which is widely considered the global benchmark for technological progress. This comparison underscores the United States' advanced technological infrastructure, significant investments in research and development, and a robust ecosystem that fosters technological innovation. By using the United States as a reference point, the distance to the frontier highlights how far other countries need to go to reach the forefront of technological advancements.

(c)Descriptive statistics of the data

Table 3*:* Data description

Variable		Mean	Std. dev.	Min	Max	Observations
lrgdpc	overall	7.776876	.8437009	6.00495	9.903353	N = 480
	between		.826832	6.812827	9.699391	n = 16
	within		.2637616	6.775576	8.565193	T = 30
lkc	overall	8.732501	1.127199	6.721766	11.27564	N = 480
	between		1.135165	7.0754	11.02816	n = 16
	within		.2449329	8.011788	9.904264	T = 30
lh	overall	.5684725	.234465	.0676587	1.068153	N = 480
	between		.2166175	.1781164	.8321666	n = 16
	within		.1043626	.3112684	.8579193	T = 30
ft1	overall	.5001429	.1102325	.3110465	.776	N = 480
	between		.1041055	.3305107	.6388075	n = 16
	within		.044378	.3845885	.6419699	T = 30

Source: Elaborated by authors using stata 17.

The table above presents a summary of the statistical descriptions (mean, minimum, maximum, and standard deviation) of the variables utilized in this study across sixteen SSCs over the period 1990-2019, and expect the variable of TF, RGDP, H and Kc are expressed in logarithm. Each variable has 480 observations, indicating that the panel is balanced. This means that there are no missing data points for any country over the period studied.

(d) **Model Specification**

Our research aims to understand the impact of human capital and the distance to the technology frontier on economic growth (measured by real GDP per capita) in SSCs. Based on the literature review, we identified four potentially significant variables: human capital index(h), stock of physical capital(kc) and technology frontier(ft). These variables are included in our initial model, which follows a general linear form:

$$RGDP = f(H,\ KC,\ FT) \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

We utilize a panel data econometric modelling approach, using a balanced macro panel that consists of data from sixteen countries observed over a 30 year period, from 1990-2019. The panel is considered balanced as there are no missing observations. It is classified as macro because the number of cross-sectional units, N is greater than 7, specifically N=16 countries. The time dimension T extends from a minimum of 20 years to, in this case, 30 years, further affirming the balance of the panel. As previously noted, the variables are transformed using logarithms (logarithm = Log = l), making the regression model linear in logs. The linear regression equation to be estimated is presented as follows:

$$Log\ rgdp_{it} = \beta_0 + \beta_1 logh_{it} + \beta_2 logkc_{it} + \beta_3 ft_{it} + \varepsilon_{it} \ \ldots\ldots\ldots\ldots \text{(7)}$$

Where:

i: indicates the country

t: indicates the period from 1990 to 2019

β_i: i=0……3 represents the parameters to be estimated

ε_{it} : This is an error term that represents both unobserved factors and random

The model links three explanatory variables (H, KC, FT), with real gross domestic product per capita(RGDPC) serving as the dependent variable, representing economic growth for each country i over time t. This setup outlines the general framework for the model, and the most suitable model will be selected from the two options after conducting the estimations.

2.5: Interpretation of results

Table 4: Interpretation of results

Dependent variable lrgdpc						
Model	FIXED EFFECTS MODEL			RANDOM EFFECTS MODEL		
Independent Variables	Coefficients	std.err.	P-value	Coefficients	std.err.	P-value
lKC	.6422718	.028899	0.000	.6419943	.0267268	0.000
lH	2.867421	.2534085	0.000	2.851048	.2474816	0.000
FT	-4.889018	.5751582	0.000	-4.86411	.5610932	0.000
C	2.983394	.3285049	0.000	2.982667	.3123242	0.000
No. Obs	480			480		
No. Groups	16			16		
R-squared	0.7511 (within)			0.8560 (overall)		
	F(3.461)=463.67			Wald chi(3) = 1490.05		
	Prob > F = 0.0000			Prob > chi2 = 0.0000		

Source: Elaborated by authors using results prepared by stata 17.

The dataset contains 480 observations, indicating a balanced panel with no missing data. The McFadden R-squared values for both models are close to 1 (within = 0.75, overall = 0.85), demonstrating their suitability for estimations. The table 4 layout includes an initial column listing the independent variables, models, total observations, number of groups, and R-squared values. The subsequent two larger columns present the estimated coefficients, standard errors, and p-values, highlighting the significance of each independent variable at a 1% significance level for each model respectively.

The fixed effects and random effects models have constant coefficients of 2.933 and 2.926, respectively. For both models, the coefficients of the physical capital per capita (kc) are positive (0.642 for fixed effects and 0.641 for random effects) and statistically significant, with p-values below 0.01. This indicates that stock of physical capital per capita **(**kc) significantly and positively influences economic growth at the 1% significance level.

In both models, the coefficients for Human capital index(h) are positive, recorded at 2.86 and 2.85, respectively. These coefficients are statistically significant, with p-values less than 0.01, indicating significance at the 1% level. This demonstrates that the variable representing Human capital index has a significant positive effect on economic growth.

The distance to the Technology Frontier(FT) coefficients in both models are negative, at -4.88 and -4.86 respectively, and their p-values are below 0.01, indicating statistical significance at the 1% level. This suggests that the distance to the Technology Frontier has a negative important effect on economic growth.

Based on the analysis of the estimated coefficients from both models, all the coefficients related to the explanatory variables are statistically significant and align with the expected directions, consistent with the theoretical and empirical literature discussed earlier. Notably, the coefficient for technology frontier is negative.

Both models provided well-estimated results for this study; however, only one can be chosen as the most suitable for interpreting the findings. To determine the best model for estimating the results of this study, a Hausman test was conducted. This test helps to decide between fixed effects and random effects models by examining the consistency of the estimators.

Hausman Specification test (1978)

Table 5: Hausman fixed.

	coefficients		(b-B) Difference	Sqrt(diag(V_b-V_B)) Std. err.
	(b) fixed	(B) random		
lKC	.6422718	.6419943	.0002775	.0109921
lH	2.867421	2.851048	.0163734	.0544858
FT	-4.889018	-4.86411	-.0249076	.1264173
chi2(3)	= (b-B) [(V_b-V_B) (-1)](b-B)= 5.87			
Prob > chi2	=0.1183			

Source: Elaborated by authors using results prepared by Stata17.

The Hausman test evaluates two hypotheses to select the appropriate model for our panel data analysis. The null hypothesis (H_0) posits that the random effects model is suitable if the p-value is greater than 0.05. Conversely, the alternative hypothesis (H_1) asserts that the fixed effects model should be adopted if the p-value is less than 0.05. In this instance, the Hausman test yielded a value of 5.87, with a probability of 0.1183, which is greater than the 5% significance threshold. Consequently, the null hypothesis is accepted, confirming the random effects model as the more appropriate choice. This model effectively captures the relationship between lRGDPC and the selected independent variables for the countries included in the study, offering a more accurate depiction of the impact of these variables on economic performance.

Various diagnostic tests were conducted on the random effects model to ensure there were no issues with error auto-correlation, multicollinearity, or heteroskedasticity. These tests help verify that the model is robust and the results are reliable.

We performed the Wooldridge test to detect autocorrelation in our panel data, and the findings revealed a p-value of 0.0006. This result is significantly lower than the critical value of 0.01 at the 1% significance level, leading us to reject the null hypothesis. Consequently, we confirm the presence of autocorrelation among the error terms. This autocorrelation complicates the analysis as it may obscure the true relationships between the independent variables and the dependent variable, lRGDPC. Addressing this issue is crucial for improving the accuracy of our model and ensuring reliable interpretations of how these independent factors influence economic output.

Furthermore, the results from Friedman's test of cross-sectional independence show that the probability is 0.0012 which is less than 0.01 at a 1% significance level, leading us to reject the null hypothesis. Therefore, we confirm the presence of autocorrelation among the individuals.

According to the results of our validation tests, they indicate that the current model fails to accurately estimate the impact of independent variables on lRGDPC. To address these technical issues, it is necessary to re-estimate the regression equation using a more sophisticated method known as Feasible Generalized Least Squares (FGLS).

By employing the FGLS taking into account the serial correlation and cross section correlation, we aim to enhance the reliability and validity of our model, ensuring that our estimates more accurately reflect the true effects of the independent variables. The revised results, following the implementation of FGLS, are presented in the table below, illustrating the improvements in model performance and statistical robustness.

Table 6: Results of estimation of FGLS Model

Dependent variable lRGDPC			
Independent variables	Coefficients	Std.err.	P-value
lKC	.6567765	.0139152	0.000
lH	1.14379	.1622019	0.000
FT	-1.813889	.3032579	0.000
C	2.382753	.1465205	0.000
No. Obs	480		
No. Groups	16		
Time periods	30		
Wald chi2(3)	=4343.53		
Prob>chi2	=0.000		

Source: Elaborated by authors using results prepared by Stata17.

According to the table above, the estimated coefficients represent the elasticities of various independent variables. Specifically, the coefficients for lKC (0.656) and lH (1.143) demonstrate a positive influence on lRGDPC, with their respective p-values standing at 0.000, which is below the threshold of 0.01, thus indicating statistical significance at the 1% level. Conversely, the coefficient for FT is negative (-1.813), and its p-value is also 0.000, falling well below the 0.01 mark, confirming its significance at the 1% level. This suggests that the variable FT adversely affects lRGDPC.

A one-unit increase in the value of lKC leads to a 0.656% rise in lRGDPC. Similarly, a one-unit increase in lH results in a 1.143% increase in lRGDPC. Conversely, a one-unit increase in FT corresponds to a 1.813-unit decrease in lRGDPC.

The results above demonstrate that specific variables such as the human capital index (based on years of schooling) and stock of physical capital per capita have a positive influence on Real Gross Domestic Product per capita thereby they are main sources of economic growth. On the other hand, the distance to the Technology Frontier is shown to negatively impact economic growth. In the context of the SSA countries, technology isn’t yet fully developed hence it does not significantly contribute to the economic growth.

The study's outcomes reveal that the human capital index plays a crucial role in driving economic growth within a country. With extended education, individuals acquire essential knowledge and skills that foster innovation and enhance work efficiency and productivity. This finding supports Barro's [1991] assertion that the quality of education significantly contributes to sustainable economic development. Furthermore, the Endogenous growth theories posit that investment in education boosts research and development activities, leading to innovation and economic advancement. The correlation between educational attainment and economic output underscores the importance of prioritizing educational policies to stimulate long-term economic growth (R Barro 1991).

According to the results of the study, stock of physical capital per capita brings about a positive impact on economic growth According to the results of our study, the stock of physical capital per capita has a significant and positive impact on economic growth in the analysed SSCs. Physical capital, which includes infrastructure, machinery, and equipment, enhances the productivity of both labour and other inputs. When the per capita stock of physical capital increases, it enables more efficient production processes and higher output levels.

Lastly, the distance to Technology Frontier impacts economic growth negatively confirming hypothesis H2 of the negative sign. Adopting cutting-edge technologies often requires substantial upfront investment. Countries in the SSA lack sufficient initial capital and struggle to keep up with technological advancements, resulting in slower growth. Furthermore, the benefits of technological advancements are often unevenly distributed, with higher-skilled workers and those in tech-related industries reaping the most rewards.

Conclusion

The objective of this chapter was to identify the impact of human capital, stock of physical capital and the distance to the technology frontier on the economic growth in SSCs using econometric methods. The study focused on sixteen (16) countries over 30 years from 1990 - 2019. Data sourced from the PWT were analyzed using panel data econometric modelling.

The study's findings indicate that human capital and stock of physical capital significantly and positively impact the economic growth in SSCs. Additionally, the distance to the technology frontier is significant but negatively impacts economic growth in the studied countries.

According to the study, countries should increase spending on the education sector to ensure a larger percentage of children can access free education to reduce dropout rates, invest in research into the best curriculum, and emphasize practical skills over theoretical work to enhance the quality of graduates produced in each country. Additionally, invest in R&D to foster innovation and the development of new technologies, and improve job matching services to connect workers with suitable employment opportunities. This is to improve and maintain the performance of Human capital of the region's economic growth.

SSC ought to foster a Culture of Adaptability and Innovation, this is to encourage a cultural shift towards adaptability, continuous learning, and innovation. Raise public awareness about the benefits and challenges of technological advancements to build a supportive environment for change. Furthermore, the governments of the SSC should promote Inclusive Growth to ensure equitable access to new technologies and the opportunities they create for all regions and demographics and enhance digital literacy across all segments of the population to reduce the digital divide. This is to close the technology gap between the SSC and other developed regions.

GENERAL CONCLUSION

GENERAL CONCLUSION

The connection between human capital and economic growth has been the subject of extensive empirical research for several decades. While it is broadly accepted that a higher level of skilled human capital benefits the economy and society as a whole, there remains no definitive agreement on its precise effect on growth.

This study is underpinned by a theoretical model that forecasts that the closer a country is to the technological frontier, the greater the impact of skilled human capital on economic growth. The synergy between human capital and proximity to the technology frontier intensifies when considering the skilled segment of the workforce. On the other hand, for countries that are distant from the technological frontier, the growth-enhancing effect of unskilled human capital is more pronounced. Countries near the technology frontier tend to allocate their resources increasingly towards innovation activities, necessitating a higher number of skilled workers to reach or push the technology frontier further. Conversely, countries farther from the frontier need to focus their resources on imitating or adopting technologies developed elsewhere.

The main objective of this study was to determine the impact of the distance to the technology frontier and human capital on economic growth and how these factors can be better implemented by policymakers in different SSCs.

Initially, a review of existing empirical studies on this topic was conducted, followed by a study on the performance of human capital and the distance to the technology frontier in different SSCs in comparison with the USA. Additionally, an econometric study was performed using a sample of sixteen countries from the SSA, covering the period from 1990 - 2019, depending on data availability.

Based on the empirical, and theoretical studies and the availability of data, we used four variables in the course of our study. Human capital index based on years of schooling and returns to education, stock of physical capital per capita at constant 2017 national prices, and the distance to Technology Frontier as our independent variables and RGDPC as our dependent variable.

The panel data econometric modelling was chosen to thoroughly examine the impact of these variables and their variance over time, utilizing both Fixed Effects and Random Effects models. Subsequently, a more Advanced model (FGLS) was employed for more robust and valid results. Out of the three independent variables, Human capital index and Stock of physical capital were found to be significant and positively influenced the rate of economic growth whereas the distance to the Technology frontier was found to have a negative effect on the economic growth rate among the studied countries.

According to the study, the negative impact of the distance to the technology frontier on the economic growth of SSCs are caused by several reasons such:

- **Technological Gap**: Countries in the SSA that are further from the technology frontier often lack access to the most advanced technologies. This gap means that these countries are using older, less efficient technologies, which can limit productivity and economic growth.
- **Adoption and Diffusion**: Majority of the countries in SSA are far from the technology frontier which implies a slower rate of technology adoption and diffusion. Advanced technologies take longer to be introduced and assimilated in these countries, leading to slower improvements in productivity and economic growth.
- **Human Capital**: The ability to adopt and utilize advanced technologies often requires a well-educated and skilled workforce. Countries further from the technology frontier may have lower levels of human capital, which hampers their ability to effectively implement new technologies.

However, countries that prioritize education, vocational training, and continuous learning are better positioned to leverage technological advancements for sustained economic growth for example The Big Four countries in the region such as Ghana, Nigeria, Kenya, and South Africa. Advancements at the distance of the technology frontier in these countries hold immense potential for driving economic growth by enhancing productivity, fostering innovation, and creating new industries.

From the chosen countries, Human capital has undergone significant evolution over the past few decades, marked by the progress through it varies widely across countries. Efforts to improve education, health, and workforce skills have been central to this development, driven by both government initiatives and international support. In countries such as Rwanda, Kenya, Ghana, Ethiopia, and Nigeria where free education for school-going citizens and free health facilities have been notably implemented in the past few decades.

However, despite the development of these two factors in the region contributing to economic growth, there is still a need to invest in them and improve their performance in the region. Below are several recommendations. These suggestions aim to further enhance human capital, stock of physical capital and the distance to the technology frontier development in SSCs and support sustainable economic growth:

- Governments of the SSCs should increase investment in education and allocate more resources to improve educational infrastructure, teacher training, and access to quality education at all levels. Emphasis should be placed on STEM education to prepare the workforce for future technological advancements. Furthermore, they should establish continuous learning and vocational training programs to ensure the workforce remains adaptable to changing market demands. This will help bridge the skill gap and reduce unemployment rates.
- Investment in Research and Development (R&D) should be done in all the SSCs to spur innovation, technological advancement, and skills development to enhance labor productivity to get rid of the negative impact of the technology frontier in the region.
- Increase Public Investment in Infrastructure such as invest in building and maintaining roads, railways, ports, and airports to improve connectivity and reduce transportation costs. Expand electricity generation and distribution networks to ensure reliable and affordable power supply.

Limitations of our study.

Limited existing literature on our research topic made it difficult to build a solid theoretical foundation or compare findings with previous studies. In addition, we had a challenge in obtaining data for some variables from some less developed SSCs.

The findings of this study reveal that advancing towards the technology frontier and investing in skilled human capital are pivotal for driving sustainable economic growth in SSA. While significant progress has been made, the study highlights the need for continued investments in education, healthcare, and innovation to enhance productivity and competitiveness. By addressing these critical areas and fostering an environment that supports technological advancement and human capital development, SSA countries can unlock their full economic potential and achieve long-term prosperity.

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APPENDICES

Validation tests (Tests de robustesse du modèle retenu)

Appendix 1

```
Wooldridge test for autocorrelation in panel data
H0: no first order autocorrelation
    F(  1,      15) =    100.927
           Prob > F =      0.0000
```

Appendix 2

Correlation matrix of residuals:

	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12
r1	1.0000											
r2	0.3443	1.0000										
r3	0.6345	0.6824	1.0000									
r4	-0.1290	0.5054	0.3450	1.0000								
r5	-0.8497	0.0750	-0.2777	0.4504	1.0000							
r6	-0.1929	0.4375	0.6020	0.6062	0.4581	1.0000						
r7	-0.6341	-0.2080	-0.0706	0.4031	0.5843	0.6315	1.0000					
r8	-0.9231	-0.5049	-0.6471	0.0135	0.7129	0.1124	0.6281	1.0000				
r9	-0.6966	0.1352	0.0684	0.5352	0.8296	0.8164	0.7811	0.5883	1.0000			
r10	0.9141	0.4593	0.8448	0.0309	-0.6898	0.1792	-0.3928	-0.8728	-0.3995	1.0000		
r11	0.7498	-0.0352	0.0458	-0.3547	-0.7877	-0.7045	-0.6861	-0.6515	-0.9225	0.4598	1.0000	
r12	0.7900	0.6621	0.6288	0.1262	-0.5112	-0.0184	-0.5906	-0.9364	-0.4316	0.7755	0.5092	1.0000
r13	0.6088	-0.1670	0.5133	-0.1010	-0.5697	0.1363	0.0390	-0.4351	-0.2337	0.6672	0.3718	0.2518
r14	0.1495	-0.1932	0.1486	-0.0872	-0.1621	0.0288	0.1148	0.1942	-0.0633	0.0989	0.1110	-0.3626
r15	-0.5057	-0.6554	-0.3177	-0.0962	0.2652	0.1782	0.6952	0.7258	0.3737	-0.3916	-0.4118	-0.8212
r16	-0.9066	-0.4998	-0.5760	0.1354	0.6921	0.2297	0.8023	0.9431	0.6627	-0.8197	-0.6752	-0.8933

	c13	c14	c15	c16
r13	1.0000			
r14	0.4536	1.0000		
r15	0.1998	0.4936	1.0000	
r16	-0.3281	0.1175	0.7621	1.0000

Friedman's test of cross sectional independence =   37.242, Pr = 0.0012

Average absolute value of the off-diagonal elements =   0.456

LIST OF ILLUSTRATIONS

ABSTRACT

This study investigates the impact of human capital and the distance to the technological frontier on economic growth in Sub-Saharan Africa (SSA). Human capital, encompassing education and health, is pivotal for enhancing productivity and adopting advanced technologies. The study examines a dataset spanning from 1990 to 2019 across 16 SSA countries, analysing how educational attainment and technological adoption influence productivity and economic expansion. The research employs documentary research, descriptive analysis, and panel data econometric modelling to validate the proposed hypotheses.

Key findings suggest that human capital positively and significantly impacts economic growth, while the distance to the technology frontier is significant but has a negative impact. The study contributes to the literature by providing empirical evidence on the effectiveness of human capital development and technological integration in driving economic growth in SSA. These insights can guide policymakers in formulating strategies to leverage education and technology for sustainable economic progress.

Résumé

Cette étude examine l'impact du capital humain et de la distance à la frontière technologique sur la croissance économique en Afrique subsaharienne (ASS). Le capital humain, englobant l'éducation et la santé, est essentiel pour améliorer la productivité et adopter des technologies avancées. L'étude analyse un ensemble de données couvrant la période de 1990 à 2019 dans 16 pays de l'ASS, en examinant comment le niveau d'éducation et l'adoption des technologies influencent la productivité et l'expansion économique. La recherche utilise des recherches documentaires, des analyses descriptives et une modélisation économétrique des données de panel pour valider les hypothèses proposées.

Les principales conclusions suggèrent que le capital humain a un impact positif et significatif sur la croissance économique, tandis que la distance à la frontière technologique est significative mais a un impact négatif. L'étude contribue à la littérature en fournissant des preuves empiriques sur l'efficacité du développement du capital humain et de l'intégration technologique dans la stimulation de la croissance économique en ASS. Ces perspectives peuvent guider les décideurs politiques dans la formulation de stratégies visant à exploiter l'éducation et la technologie pour un progrès économique durable.