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DIGITAL DIVIDE NELL’AFRICA SUBSAHARIANA: UN PANEL DI ANALISI SULLA DIFFUSIONE DI INTERNET

DIGITAL DIVIDE IN SUB-SAHARAN AFRICA: A PANEL ANALYSIS OF INTERNET DIFFUSION

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ABSTRACT

The objective of this study is to investigate the sources of the differences of digital technologies diffusion in Sub-Saharan Africa. Based on previous literature and economic theory, we selected relevant macroeconomic variables as the determinants of Internet diffusion. Our dependent variable is the number of Internet users as a percentage of population and the independent variables are GDP per capita, urbanization, mobile cellular and fixed broadband subscriptions. The study examines a panel data for 41 SSA countries over the period 2006-2016. We applied dynamic panel estimation using a data from the World Bank and International Telecommunication Union. The two-step GMM estimation result shows income, mobile subscriptions, lagged Internet users and urbanization exerted a positive effect on internet diffusion. The result implies that SSA countries need to invest on telecommunication and technology infrastructure to bolster digital technologies diffusion. Moreover, to reduce the magnitude of digital divide, countries should promote affordable digital services.

Keywords: Digital divide, Internet diffusion, Sub-Saharan Africa

RIASSUNTO

L'obiettivo di questo studio è di indagare le fonti delle differenze di diffusione delle tecnologie digitali nell Africa subsahariana. Dalla letteratura e teoria economica, abiamo selezionato variabili macroeconomiche rilevanti come determinanti della difusione di Internet. La nostra variable dipendente è la percentuale di utenti di internet e le variabili indipendenti sono il PIL pro capite, l'urbanizzazione, gli abbonamenti a banda larga mobile e fissa. Lo studio esamina un pannello di dati per 41 paesi dell'Africa subsahariana nel periodo 2006-2016. Una stima dinamica è stata applicata utilizzando i dati della Banca Mondiale e dell'Unione Internazionale delle Telecomunicazioni. Il risultato della stima MGM (Metodo generalizzato dei momenti) in due fasi mostra che reddito, abbonamenti mobili, utenti di internet e urbanizzazione hanno esercitato un effetto positivo sulla diffusione di Internet. Il risultato implica che i paesi dell'Africa subsahariana devono investire sulle telecomunicazioni e sulle infrastrutture tecnologiche per rafforzare la diffusione delle tecnologie digitale. Inoltre, per ridurre il divario digitale, questi paesi dovrebbero promuovere servizi digitali accessibili.

Parole chiave: digital divide, Diffusione di Internet, Africa subsahariana

AKNOLEGNMENT

The past two years have been both interesting and challenging. The thesis was started when the Coronavirus pandemic reached critical level here in Italy and around Europe. As a result, the pace of the work did not progress as planned. To complete the thesis, I am extremely thankful for my advisor Alessandro Sterlacchini. I was receiving feedbacks at a time I could not imagined. That is special to me since the lockdowns affected the physical contact and could have disrupted the thesis if not for the diligent digital mentoring. Apart from the thesis, the coursework was a new experience for me as an interdisciplinary master's program. I have a special place for economics professors in the vibrant faculty, "Giorgio Fua". I also do not want to take for granted the opportunity I got to study with international students. My enrolment was possible with the financial assistance from Università Politecnica delle Marche. I am very grateful for the FLOR scholarship program of the university.

DEDICATION

To Zola and Dag

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LIST OF ACRONYMS

GDP: Gross Domestic Product

ICT: Information and Communication Technology

ITU: International Telecommunication Union

OECD: Organization for Economic Cooperation and Development

SSA: Sub-Saharan Africa

UN: United Nations

UNCTAD: United Nations Conference on Trade and Development

UNIDO: United Nations Industrial Development Organization

RD: Research and Development

WDI: World Development Indicators

WEF: World Economic Forum

WB: World Bank

3D: 3-Dimensional Printing

CHAPTER ONE

INTRODUCTION

As they are fast becoming an essential tool for economic activity, digital technologies became a vital engine of economic performance. While the use of digital technology is expected to transmit information easily and less costly, rapid diffusion (especially due to price decreases) has raised the issue of the so-called "digital divide". Digital divide refers to unequal diffusion and use of digital technologies among individuals, group or countries which creates leaders and followers of a digital society. The term first appeared in the mid-1990 's in United States and represents a crucial research issue in the field of economics of innovation. Investment in digital technologies in developed countries helped to improve productivity, job quality and to reduce significant transaction costs. In Sub-Saharan Africa (SSA), the wider development impact of most digital technologies is still low since access to the mass population is a challenge.

The data on Internet diffusion reveal, at a given time, there is a significant difference among countries. Developed countries have a well-established infrastructure and hence high level of Internet diffusion. On the other hand, most of the population in developing countries is not connected to digital technologies. When we say technology diffusion, we refer to the definition to the process in which technologies are adopted to use across individuals. In that regard, diffusion and penetration of Internet are used alternatively in the thesis.

The impact of digital divide has been evident during the current Covid-19 pandemic when lockdowns and social distancing are the main mechanisms to control the virus. Most economic activities turned out to be held online following full and partial lockdown rules around the world. For instance, education has continued partially to be delivered for students at home through Google hangouts, Alibaba's DingTalk, Google classroom, Zoom meeting and Microsoft teams in emerging and developed countries unlike in most developing countries where schools and universities have been completely shut down due to lack of online services. Despite the alarming digital divide problem, the contribution of digital technologies in the fight against Covid-19 is far from negligible. Countries with wider Internet access and safer Internet servers tend to have better governance and infrastructure to cope with the pandemics. Moreover, it is showed that digital technologies help to flatten the curve by helping to provide timely and trustworthy information, connecting workers and students to their offices and schools, and improving diagnosis and monitoring of the infectious disease. Therefore, Internet has been found to be the answer for many lockdown problems and the global use has spiked to unprecedented level. Following these trends, researchers urged developing countries to consider digital inclusion and warned that coronavirus could further worsen the digital divide.

Digital technologies adoption by firms, people and governments have spread rapidly in much of the world although the more sophisticated technologies like e-commerce, inventory management, enterprise network and secured servers are much lower in developing countries. The digital technology revolution in developing countries result in a lot of benefit in different sectors. Agriculture is one of the sectors taking benefit from digital transformation. Digital technologies helped farmers to enhance on-farm productivity by improving agricultural extension services in SSA, south Asia, and Latin America. In that regard, extension agents use a combination of voice, text, videos, and Internet to reduce transaction costs and increase interactions with farmers. Moreover, digital technologies improved agricultural supply management especially in deep rural areas with limited transportation infrastructure.

Despite many individual success stories in many sectors of the economy, there has been limited evidence of aggregate improvements in important economic outcomes. Therefore, digital dividend, the broader development benefits from using digital technologies, have lagged. One of the reasons for that is since half of the world population is offline. Moreover, the digital divide inside countries is high as between countries. The convergence between low-income and high-income countries is also very slow and widening in some digital technologies.

In Africa, digital divide has many dimensions. Adoption rate differences within countries, between lower and higher income groups, rural and urban, and among demographic groups (age and gender) are still considerable. Moreover, the digital divide in Africa is associated with the access to the technologies unlike other developed regions where the major problem is digital skills which comes after it.

As witnessed by a very large number of publications, the subject matter is studied extensively in developed countries. Despite the growing number of studies in recent times, the concept of digital divide is still not clear according to some sources. Given the fact that basic digital technologies are used as infrastructure for advanced ones, studying the dynamics of the diffusion process is germane for discussions and policy implications.

This thesis provides some attempts to fill three gaps is the literature. First, most cross-country studies are either at global level or categorize countries as low and high- income to study Internet diffusion. In this regard, our focus is limited to SSA countries with similar economic conditions. Secondly, to circumvent data problems, previous studies focus on a panel of very short periods. Despite the data problem for important variables in our sample, our study has relatively longer period covering the most important stage of Internet diffusion. Finally, from the econometric point of view the study addresses endogeneity, one of the major problems in technology diffusion model. To solve the problem, we adopted robust two-step dynamic panel approach incorporating the lag of the dependent variable into the regression equation. We use a panel data for 41 SSA countries over the period 2006-2016 to shed light on the main factors governing the Internet diffusion and obtain implications for the digital divide.

The major objective of the study is therefore to investigate the pattern of digital divide across sub-Saharan African countries by focusing on the Internet diffusion. Specifically, first, we investigate the determinants of Internet penetration rate difference across SSA countries. Secondly, we carry out a comparative analysis of the selected Africa countries by looking at their recent trends.

The dissertation is organized as follow; the second chapter reviews the theoretical and empirical literature about the economics of digital technologies. The third chapter covers the recent trends of digital technologies and policy implications at global level and using selected SSA countries. The fourth chapter consists of methodology of the study and econometric results. The final chapter provides summary and conclusion.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews the existing theoretical and empirical literature. The first section presents the basic economic theory related to technology diffusion, ICT, and development. In that regard, we give considerable attention to economic growth and technology adoption in low-income countries, particularly in Sub-Saharan Africa (SSA). The second section analyse the most important empirical contributions on the topic.

2.1. The economic analysis of digital technologies

Digitalization is defined as “the diffusion of digital technologies, services, products, and skills within and across countries” (UNCTAD, 2019). It is associated with the increased use of artificial intelligence, information and telecommunication technologies, big data analytics, three-dimensional printing (3D) and cloud computing, among others. The core aspects of the digital technologies are computers, telecommunication devices, Internet, and telecom networks. They also include products and services that rely on digital platforms and payment services. The wider component of the sector incorporates e-commerce, finance, media, tourism, and transportation which is usually called “digitalized economy” (UNCTAD, 2019). A related concept, ICT is the use of electronic and communication equipment to collect, store, process and send data electronically

(Cirera et al., 2016). ICT is an umbrella term that includes any communication device or application, encompassing: radio, television, cellular phones, computer and network, hardware and software, satellite systems and so on, as well as the various services and applications associated with them, such as video conferencing and distance learning.

Internet, as one of the components of ICT, is a means of connecting a computer to any other computer, or computer to any electronic device, or any other electronic devices interconnected to each other via dedicated routers and servers to share information, audio, video and other output. Internet can also be defined as a world-wide computer network that can be accessed via computer, mobile telephone, and digital TV, among others. The Internet is today's largest network that supports many new advanced services and a key to progress in communications and in the exchange of information, knowledge, technologies and goods and services (Shiferaw, 2015).

The effect of technological change on economic growth and development is the centre of economic theory in different models. The two dominant models of economic growth are neoclassical growth model (NGM) and endogenous growth model (EGM). According to the neoclassical model, long-run economic growth is determined by exogenous factors such as technological change (Solow, 1956; Popa, 2014). The Solow model does not explain the long-term growth but only the possibility to avoid stagnation of production per capita. The pessimism is based on the decreasing marginal productivity of capital. The inability of neoclassical growth model to explain the long-run growth led to the development of endogenous growth model.

Endogenous growth model "emphasized that growth is the endogenous outcome economic system, not the result of forces imping from outside" (Romer, 1994 p. 3-4). The model posit that long-run growth is determined by the accumulation of knowledge (Romer, 1986). It also eliminates the assumption of decreasing marginal productivity of both physical capital and human capital. In this mode, innovation is an increasing return to scale activity.

Sachs (2000) categorized the countries growth experience in the following ways, related to the underlying geography, economic policy, and resource endowment of a country:

- endogenous growth: if, in 1995, the country inventors registered 10 US patents per million inhabitants;
- catching-up growth: if the country exports of manufactures in the machinery and transport sectors accounted for at least five percent of GNP in 1995;
- resource-based growth: if the country commodity exports were greater than or equal to 10 percent of GNP in 1995;

- Malthusian decline: it the country had a total fertility rate greater than or equal to 4.0 in 1995;
- economic isolation: if the country is land-locked and not classified in one of the preceding categories.

According to this classification, most of SSA countries are under resource-based growth and Malthusian decline categories. Even if one country (Mauritius) is included in the catching-up growth category, no country from SSA was under endogenous growth category. 16 SSA countries experienced resource-based growth where per capita income changes primarily with resource. Whereas 18 SSA countries were experiencing Malthusian decline.

Table 2. 1: SSA countries classification according to growth mechanism

Catching-up	Resource-based growth		Malthusian decline	
Mauritius	Angola	Mozambique	Benin	Lesotho
	Cameroon	Nigeria	Botswana	Liberia
	Congo	Sierra Leone	Burkina Faso	Mali
	Gambia	Tanzania	Central Africa Republic	Namibia
	Ghana	Togo	Chad	Niger
	Guinea	Uganda	Congo, DR	Rwanda
	Guinea Bissau	Zimbabwe	Eritrea	Somalia
	Kenya		Ethiopia	Sudan
	Mauritania		Gabon	Zambia

Source: Sachs (2000)

The world economic forum identified five ways ICT can impact the economy: direct job creation, contribution to GDP growth, creating new services, workforce transformation, and innovation (WEF, 2013). Even if technology is the engine of growth, Santacru (2015) showed that barriers to technology adoption resulted in the persistence of income difference across countries. In his multicounty dynamic general equilibrium model using data for innovation, GDP per capita and bilateral trade for 30 countries, the author categorized countries growth as "disembodied" and “embodied” growth. He defined “embodied” growth as countries accumulate domestic innovation by investing in research and development (RD) and adopt foreign technologies through intermediate products they import. He captured Disembodied growth, on the other hand, by an exogenous total factor productivity (TFP) shock. Furthermore, he defined the two sources of embodied growth as (i) domestic innovation, which is mainly driven by an increase in the number of domestic innovations, and (ii) international technology diffusion, which is mainly driven by the increase in the number of adopted foreign innovations. Based on these classifications, his results showed that the contribution of embodied growth is 52 percent in emerging countries. On the other hand, in the most innovative OECD countries, the contribution of embodied growth is 64 percent. From these results, emerging economies achieved 75 percent of “embodied” growth through technology adoption. In developed countries (OECD), on the other hand, domestic innovation explains 75 percent of growth (Santacru, 2015).

2.2. Empirical literature in SSA

The empirical analysis focuses on the characteristics of digital divide and its determinant considering the implication on economic growth and policy in SSA. Relevant studies from developed and developing economies are also included for methodological advantages and comparative analysis.

Chinn and Fairlie (2007) studied global digital divide based on a cross-country analysis of computer and Internet penetration. The study is based on a panel of 161 countries at the early stage of ICT diffusion in most developing countries (1.68% computer and 1.31% Internet penetration rates per 100 in SSA) between 1999-2001. The result on computer penetration shows that income per capita and education (average years of schooling) are significant variables. The impact of telephone line density is also reported to be very high implying the multidimensional complementarities between computers and telephone lines. The demographic variables youth dependency ratio also showed positive and significant relationship with computer use. Regulatory quality is also found to be highly significant implying market-friendly environment and countries with a better governance (rule of law) bolster computer penetration. However, the electricity consumption (significant with threshold effects) and trade openness are insignificant. The determinants of internet penetration are comparable to the computer ones. Electric power consumption, income per capita, youth dependency ratio, trade openness, and regulatory quality are significant. The average years of schooling, telephone density, and monthly telephone subscription charges, on the other hand, did not show up as a significant variable. Furthermore, the regional decomposition result shows that the regional computer penetration difference (with reference to US penetration rate) is largely explained by income. More than 50 percent of the computer penetration difference between SSA and US is reported to be explained by income. Telephone lines, Age distribution, urbanization and electric consumption also showed considerable importance for the regional disparity as well. However, the impact of trade in goods (as a percentage of GDP) and monthly subscription cost are reported to have a very limited role for the regional difference between SSA and US. The regional difference on internet is also showed largely explained by income (68 percent of SSA and US of internet penetration gap).

Buys et al. (2009) investigated the sources of digital divide in SSA. Although there is an extensive government monopoly in the sector, the study finds out that countries with decent market competition have high mobile penetration. The study identified that probability of cell tower location is positively related with potential market size (approximates by population), per capita income, and national competition policy. Improving competition policy through privatization, easing licencing requirements, lifting bars to market entry are some of the mechanisms to generate telecommunication connectivity benefits. The study also confirmed the necessity of government intervention to narrow rural-urban gap by providing different incentives for investments in low-density rural areas.

The study by Wunnava and Leiter (2009) showed the importance of economic, social, and political differences as sources of digital divide across countries. The study used a cross-sectional sample of 100 (including 23 SSA countries) countries to discover the determinants of Internet penetration. The Weighted Least Square

(WLS) estimation result showed that economic strength measured by GDP per capita, telecommunication and technology infrastructure calculated by taking the minimum of the telephone and personal computer (PC) penetration rates per 1000 people, tertiary enrolment, English proficiency and freedom (civil liberties and political rights) were significant and positive variables. A percentage increase in GDP per capita was associated with an estimated increase of 0.49 Internet users per 1000 inhabitants. The impact of infrastructure is however slightly higher than the impact of GDP per capita in which for every additional PC/phone per 1000 people, the number of Internet users per 1000 people were estimated to increase by 0.5 percent. A positive impact is also observed for education in which a percentage increase in tertiary enrolment leads to an estimated 1.4 percent increase of Internet users per 1000 people. Countries with English as official language have an Internet penetration rate estimate to 45 points higher than other countries. The coefficient of freedom index (measured though a Likert scale from 1 to 7) showed the improvement from one scale to another increases the Internet penetration rate by 27 percent per 1000 inhabitants. The impact of income inequality on the other hand is negative and a point rise in Gini index is associated with a 2.5 percent decrease of Internet usage rate. The results are however too aggregate in which low-income and high-income countries are studied together for a precise quantitative estimate. The diffusion pattern of Internet and its association with economic strength is different depending on levels of development. For instance, Andrés et al. (2010) showed that impact of GDP per capita is insignificant in high-income countries. Moreover, even if the cross-sectional nature allowed to incorporate a wider range of countries and variables, the dynamics of the process is ignored in the study.

Andres et al. (2010) studied the adoption and diffusion of Internet in 214 (46 SSA) countries. The study finds out that developing countries adopt Internet at a faster speed than developed countries. The study also confirmed the S-shaped Internet diffusion process which implies lower rate of adoption at initial level, higher in the middle and decreasing at later stage. Moreover, they identified how explanatory variables affect the diffusion process at different income levels. The lagged number of Internet users, for instance, is more important for high income countries than low- and middle-income countries. The market competition is considered to push the diffusion of Internet, but, again, the impact is visible in high-income countries. Its impact is even stronger when it is interacted with the large number of Internet users in previous year. It is also interesting to note that, while GDP per capita is a very important determinant of Internet adoption in low-income countries, it is not significant in high-income countries. The study however ignored other important variables like trade openness and urbanization as a determinant of Internet adoption.

Birba and Diagne (2012) investigated the determinants of Internet adoption in Africa using on a simultaneously collected survey data from 17 Sub-Saharan countries[1]. The study adopted generalized multi-level linear model due to the nested nature of the data (country-strata-household-individuals). The individual level data shows that Internet is more prevalent among men (15%) than women (8). Furthermore, the data shows that the use of Internet decreases with age (14for under 30 and 4% for above 50). Individual level of education is highly related Internet adoption in which 58% of higher-education graduates unlike only 1 percent of primary and people with no formal education. Beyond individual-level characteristics, the socioeconomic situation of the household individuals live also plays an important role in Internet adoption. For instance, the study reported that Internet adoption decreases with household size. The survey furthermore shows that the proportion of Internet users in the group of individuals who have a computer in their household (54%) is much greater than the proportion of Internet users in the group of individuals who do not have a computer in their household (8%). The data on demographic and socioeconomic characteristics shows people living in cities (18%) adopt Internet more than the urban (9%) and rural (3%) counterparts. The percentage of people who adopt Internet also vary with GDP per capita (15% for above USD 1000 and 15% in between USD 245-450). The regression analysis confirmed the above descriptive analysis. The individual level of education, gender, income, and age remained significant. However, household size was insignificant. The impact of macro variables is mixed that Literacy rate, GDP per capita, and the primary completion rate were not significant contrary to most findings (Murthy et al., 2015; Andres et al., 2010). Indeed, macro variables are not negligible considering the significant impact of population density, urbanization, and the proportion of households with an Internet connection at home.

[1] (South Africa, Benin, Botswana, Burkina Faso, Cameroon, Ivory Coast, Ethiopia, Ghana, Kenya, Mozambique, Namibia, Nigeria, Rwanda, Senegal, Tanzania, Uganda, and Zambia)

A micro econometric study by Penard et al. (2015) investigated the determinants of Internet adoption in Africa using a household survey data from Cameroon (Douala, Limbe and Buea cities). The authors categorized the dependent variable as Internet adoption and usage. The result shows probability of Internet adoption is found to be driven by age, education, family abroad, education, computing skills, income, and Internet accessibility. On the other hand, the choice of Internet usage is mainly influenced by gender, age, education, and computer skills. For instance, college students use Internet for information search than entertainment. The result indicates the existence of two level of digital divide (adoption and usage).

Murthy et al. (2015) investigated the long-run factors of Internet diffusion in sub-Saharan Africa. The study used a "panel-cointegration analysis" over 1997-2013 in 30 SSA countries. Using a time series data from International Telecommunication Union and World Bank, the author showed the long-term positive impact exerted by real GDP per capita, urbanization and infrastructure (measured by the number of fixed telephones per 100 inhabitants) on Internet diffusion. However, the diffusion coefficient (lag of Internet users) is not considered in the study which is found to be a strong determinant as Andres et al. (2010) showed in their cross-country study.

As it will be stressed in chapter three, digital technologies adoption pattern is different between rich and poor countries. One of the reasons for this difference is the centrality of infrastructure in low-income countries. Armey and Hosman (2016) studied the significance of electricity as a driver of Internet demand in low-income countries. The study used Gini-coefficient[2] of night light to measure electricity availability for a panel of 40 low-income countries (28 from SSA) between 2000 and 2009. Henderson et al. (2009, 2011) showed the amount of light emanating from earth recorded by weather satellite every night between 8:30 pm and 10:00 pm is related to economic activity and it can be used to as a measure of GDP when a reliable data is not available. The intensity of night light ranges from 0 (no light) to 63 per pixel and are available from US air force. Therefore, the Gini-coefficient of night light measures distribution inequality (Gini-Coefficient approaches to one the more unequal the distribution). Using dynamic panel data analysis method, the study finds out that the increasing distribution (the lower Gini-coefficient) of electricity within a country increase the number of Internet users. More specifically, the author estimated that the decrease in one standard deviation Gini-coefficient of night light improves Internet adoption by 10-11%. The vital role of electricity on internet adoption in low-income countries implies policies that would increase populations access to electricity have a considerable positive effect on ICT diffusion. However, other control variables (GDP per capita, urbanization, trade

[2]A Gini-coefficient is a measure of a distribution equality of a variable, widely used to measure income inequality.

openness, lagged democracy, lagged telephone lines and mobile phones per 100) were not significant.

It is often assumed that technological innovation and adoption favours democratic regimes and threaten the survival of authoritarian regimes (Milner, 2006). Stier (2017) studied the temporal patterns of technology adoption by showing the relationship between regime type and Internet diffusion. The study performed a cross-sectional analysis during the period 1996-2013. The findings showed that, all things being equal, democratic regimes had a temporary superiority in Internet diffusion. However, since 2012, there is not a significant difference between democratic and autocratic regimes.

Doshi and Narwold (2018) studied the penetration of mobile phones in Latin America and the Caribbean. Using the data over 2001-2015, the study result showed that mobile subscriptions were increasing at a decreasing rate. GDP per capita is found to be the most important variable in both Latin America and the Caribbean positively affecting the subscriptions of mobile phones. However, the impact of GDP per capita on the growth rate of mobile phone subscriptions is negative. Population density and urbanization are also important drivers of mobile phone subscriptions.

Haftu (2019) studied ICT and economic growth in SSA for the period of 2006-2015 using a panel data of 40 countries. The study showed the different impact of Internet and mobile phone penetration on GDP per capita. The study employed dynamic panel approach to consider the persistence of GDP per capita over time. According to the estimation, lagged GDP per capita, government consumption, gross capital formation, trade openness, inflation and population growth were relevant variables in explaining the change in GDP per capita. Mobile phone subscription has also a significant impact on income improvement in SSA. "A 10% increase in mobile phone penetration results in a 1.2% change in real GDP per capita." Therefore, improving mobile phone coverage in the region will help to reduce poverty. However, the impact of Internet was insignificant. Lack of local content and the low penetration of Internet could be responsible factors exasperated by lack of ICT skills in SSA. The implication of the study is that governments and stakeholders should design policies to encourage for the expansion of Internet. To bolster the impact of Internet on the economy, countries should design policies that encourage local contents and decrease cost of accessing the technology.

Asongu et al. (2019) studied how inequality inhibit the role of Internet through inclusive education (inequality adjusted). The paper adopted a generalized method of moment (GMM) technique to examine the linkage among the ICT, inequality, and education in Sub-Saharan Africa for the period 2004-2014. Three indicators of inequality are employed, namely: the Gini coefficient, the Atkinson index, and the Palma ratio[3]. Inclusive education is measured by the gender parity of "primary and secondary education" in the study. Adopted ICT indicators are mobile phone penetration, Internet penetration and fixed broadband subscriptions. Firstly, the study establishes a maximum threshold of Gini and Atkinson index of 0.4 and 0.625 respectively for Internet penetration to have a positive influence of inclusive education. Secondly, a Gini coefficient, an Atkinson index of respectively, 0.574 and 0.676 are the thresholds of income inequality that, if exceeded, would make inclusive education not affected by fixed broadband subscriptions. As established from the findings, income inequality inhibits access to information technology. I In other words, while information technology can promote the enrolment of more girls in primary and secondary schools, growing income inequality would negatively affect the enrolment of more girls in these institutions of learning.

Donou-Adonsou (2019) studied the impact of ICT (Internet and mobile phones) change economic growth in countries with different levels of education. The study examined whether telecommunications infrastructure promotes economic growth in countries with better access to education compared to those with less access using

[3] The Atkinson index is useful in determining which end of the distribution contributed most to the observed inequality. The Palma ratio is the ratio of the richest 10% of the population's share of gross national income divided by the poorest 40%'s share (Cobham et al., 2013).

a panel of 45 Sub-Saharan African countries from 1993 to 2015. Using the fixed-effects GMM estimator, the results indicate that in countries with better access to education, the Internet contributes to economic growth, whereas mobile phones do not seem to do so. These results suggest that better access to education is indispensable for the Internet to generate economic value, while it seems to be not relevant for mobile phone usage.

Myovella et al. (2020) studied digitalization and economic growth in SSA by comparing them with OECD countries. The study used a panel dataset from 42 SSA and 33 OECD countries to analyse how digitalization affects the economy with different levels of development. In SSA, the system GMM estimation which includes the lag of the dependent variable (GDP per capita) as a regressor showed that only mobile subscription is a positive and significant variable. Internet and broadband, on the other hand, are negative and insignificant in line with the result of Haftu (2019). In OECD, instead, Internet diffusion is found to be significant and positive unlike mobile and broadband subscriptions. The results of the study showed the significant contribution of digitalization irrespective of their development level. The effect of broadband Internet is minimal in SSA countries. Whereas the impact of mobile is higher in SSA compared to OECD countries. This noticeable difference between SSA and OECD related to digitalization is due to the level of development and use of ICT. In SSA, mobile is used for financial and economic transactions apart from communication benefits. In developed countries like OECD, on the other hand, many activities depend on Internet. Generally, ICT improves GDP per capita to different extent at different stages of development.

One of the channels in which digital technologies affect economic growth is financial inclusion (Sassi and Goaied, 2013). Cheng et al. (2020) explore the effects of financial development and ICT diffusion on economic growth based on panel data covering 72 countries (10 African countries from the 36 low and middle-income countries) from 2000 to 2015. The result shows an unexpected negative effect of financial development on economic growth particularly in high-income countries. The implication of this result is that the malfunctioning of financial markets with an excess of speculative activities, could waste resources and lower investments. For instance, the 2007-2008 global financial crisis is the result of excessive risk taking by banks combined with housing bubble in the US. The diffusion of ICT was found to have a growth effect in high-income countries. On the other hand, the effect in middle and low-income countries is found to be ambiguous. In line with findings of previous studies, mobile diffusion was found to be the only significant ICT variable. The interaction between financial development and ICT diffusion have a positive impact in both group of countries, even if it is significant only in high-income countries, implying that the interaction effects of ICT and finance can reduce the negative effects of financial development.

However, it is significant only in high-income countries. Therefore, reinforcing and upgrading ICT applications in the financial sector can help decrease the unfavourable impact from financial development on an economy.

2.3. Empirical literature in developed and emerging economies

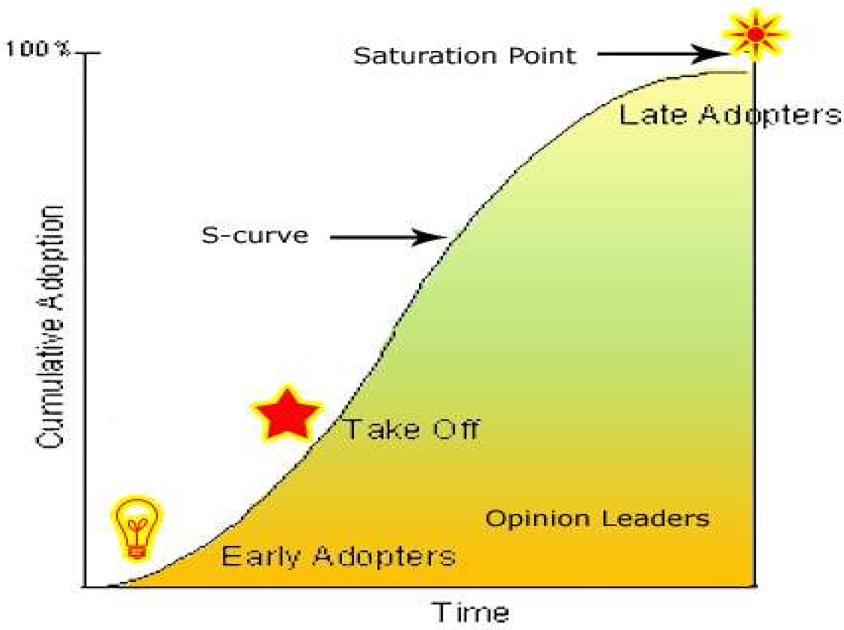
Hargittai (1999) is one of the leading studies on the diffusion of Internet focusing on the OECD area. As recognized in many of works on the topic, economic strength (GDP) does matters in predicting Internet connectivity the study suggests. More recently, however, Andres et al. (2010) investigated the marginal role of income in Internet diffusion among high-income countries. A plausible interpretation of their result is that once the income level is high enough to support the use of Internet, further increments in income will have little impacts on Internet adoption. In contrast to more recent literature (Wunnava and Leiter, 2009), the study showed that English proficiency measured by native English-speaking population has insignificant role in Internet diffusion suggesting that browsing activity requires only familiarity with the language. The impact of telecommunication policy shows that the existence of a monopoly in the telecom sector of a nation seems to have a considerable negative impact on that country's Internet connectivity.

Kiiski and Pohjola (2002) studied the early stage of Internet diffusion across OECD countries. The study investigated the determinants of Internet diffusion by estimating the Gompertz model of technology diffusion with data on Internet hosts per capita for the years 1995–2000. The study showed that GDP per capita and Internet access cost were the most important variables for Internet diffusion in the OECD sample. On the other hand, the result identified that investment on education and competition in telecommunication market were not significant variables in contrast to Hargittai (1999). In the study's refined sample including "industrial and developing countries", investment on education particularly at university level is significant.

Li and Shiu (2012) studied Internet diffusion in China using a panel data on 31 Chinese provinces. The study incorporated variable less important in cross-country studies since the focus of the study is the regional difference within China. Consequently, Income per capita, real cost of local phone call, and number of computers per capita are considered relevant for the study. The study also considered the impact of network effects using the lag of the dependent variable, Internet penetration. The result shows that income, network effects, illiteracy and infrastructure are the main factors for regional digital divide in China.

More recently, Lin and Wu (2013) studied the diffusion of broadband in 34 OECD countries for the period 1997-2009. The overall regression indicates platform competition, lagged broadband penetration and Internet content are the significant factors. The positive significance of platform competition implies broadband penetration increases with an increasing competition of different technologies by lowering prices and expanding innovation. Lagged broadband penetration, on the other hand, indicates the network effect of the diffusion process. Lastly, the significance of content implies the richness of information and services increase the willingness of broadband subscribers. The above analysis considers the diffusion as a single process and is consistent with previous literature.

Figure 2. 1: The S-shaped diffusion curve



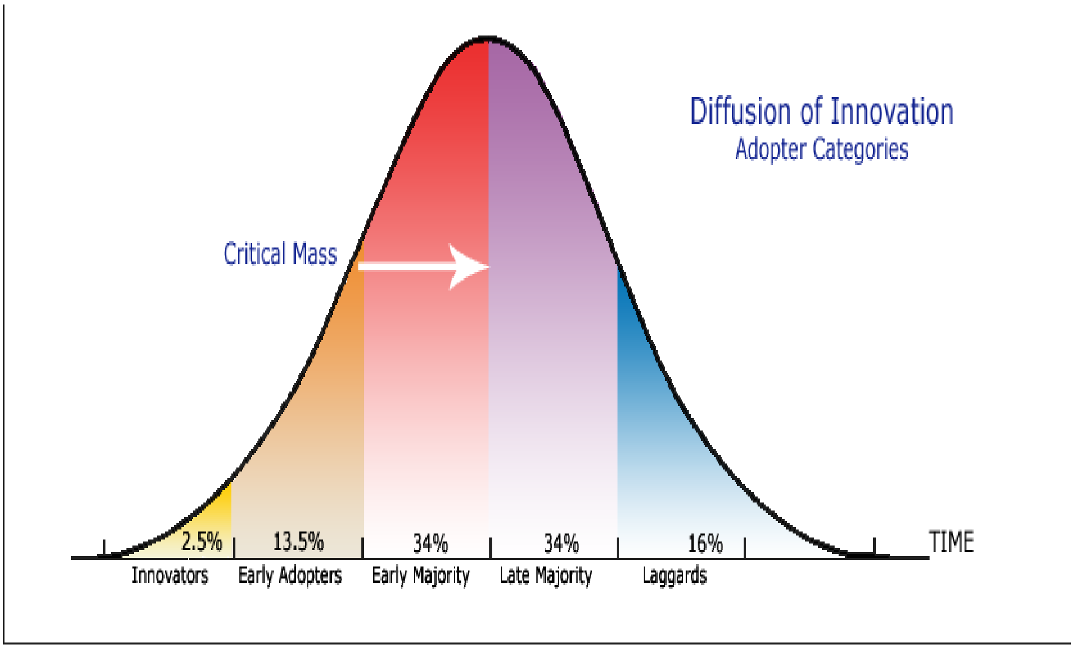
Source: Kaminski, 2011

However, the importance of the determinants is also different at different stages. Following Rogers (2003), the study further categorized the diffusion process in three stages: innovators and early adopters (1997-2001), early majority (2002-2005), late majority and laggards (2006-2009).

Originally, Rogers (2003) categorized stages of innovation diffusion into five categories: innovators (2.5%), early adopters (13.5%), early majority (34%), late majority (34%), and laggards (16%) as shown in figure 2.1 and 2.2. The category is applicable for many situations from individual and groups to countries economic condition. Similarly, category of countries growth experience is performed by Sachs (2000) as shown in Table 2.1. For instance, laggards and innovators have similar characteristics with countries experienced economic isolation and endogenous growth.

For innovators and early adopters, education, and platform competition, and previous broadband penetration are the significant variables. For early majority, the significant variables are income, broadband price, and content, and previous broadband penetration. And for late majority and laggards, income, broadband price, and content, and previous broadband penetration are the significant variables in the OECD countries. The results suggest that governments should follow different strategies at each stage since adopters have different attributes.

Figure 2. 2: Diffusion of innovation adopter categories



Source: Kaminski, 2011

Our theoretical literature survey shows that technological innovations allowed countries to achieve a sustained improvement in per capita income unlike the traditional input (labour and capita). The advent of digital technologies in the economic system also altered the production, distribution, and consumption behaviour of economic agents. African countries source of economic growth is dominated by physical capital and labour. The marginal role of technology shown by total factor productivity for economic growth is largely explained by lack of endogenous technology as Sachs (2000) showed.

The empirical literature survey shows that the focus has shifted from studying the distribution of digital technologies to its economic implication (education, inequality, employment, and financial development). There is no common ground for global studies since institutions and infrastructure have different nature in developing, emerging, and developed countries. For instance, even if the economic strength is underscored in most literature, more recent articles found its negligible role in digital technology diffusion at least in the OECD nations. In fact, it is understandable since it is recognized that there are digital skills divide mostly in technology advanced countries where access is less problematic. Moreover, the role of institutions and telecommunication policy is mixed in the dynamics of digital divide. Some quantitative estimates showed authoritarian regimes managed to have equal if not better digital technology diffusion than democratic ones. There are also individual country success stories difficult to incorporate in regression analysis with monopolistic telecommunication policy.

CHAPTER THREE

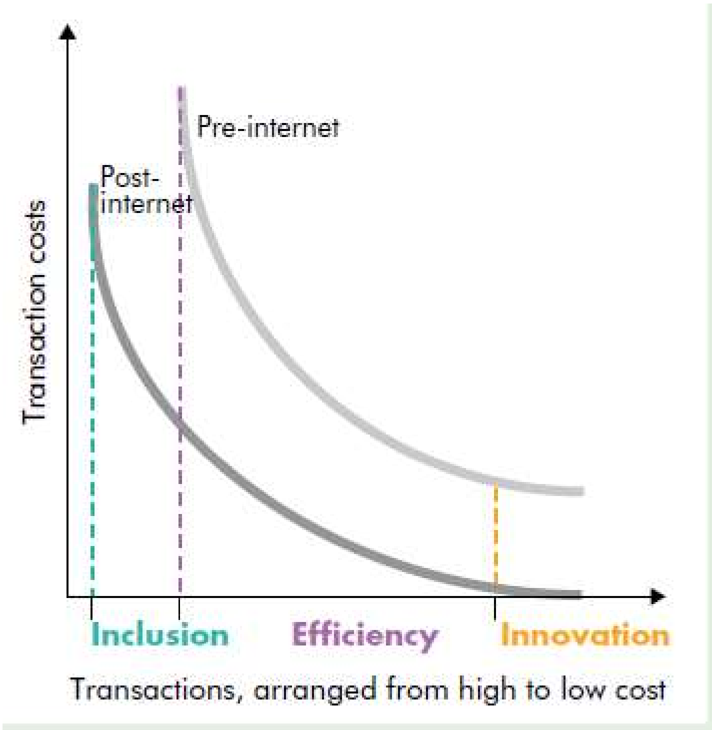
RECENT TRENDS OF DIGITAL TECHNOLOGIES

3.1. Digitalization and it's economic implications

The unequal diffusion of technologies has created leading and following economies. According to United Nations for Industrial Development Organization (UNIDO, 2020), 10 economies account 91% of global patenting in advanced digital technologies which includes artificial intelligence, cloud computing, Internet of things and big data analytics, among others. This substantial "digital divide" is also a common phenomenon in the Information and Communication Technologies. Hence, technology is one of the many factors for exacerbating global inequality and polarizing labour market (UNCTAD, 2019).

Digital technologies contribute to economic growth in both demand and supply side (Myovella et al., 2020). Digital technologies reduced the cost of storage, computation, and transmission of data (Goldfarb and Tucker, 2019). The main channels of development are innovation, efficiency, and inclusion of many services impossible before the advent of the Internet (World Bank, 2016; Kpodar and Andrianaivo, 2011; Sassi and Goaied, 2013). We adopted a simple framework from the World Bank to show how Internet promotes development (Figure 3.1). Before the advent of the Internet, some transactions were impossible, and Internet allows them to be carried out and, hence promotes inclusion. Moreover, Internet lowers the cost of existing transactions as shown in the middle of the Figure. The most dramatic effect of internet is shown on the right—side of the Figure. Once Internet is adopted, in many instances, the marginal transaction cost is zero.

Figure 3. 1: channels through the Internet to promote development

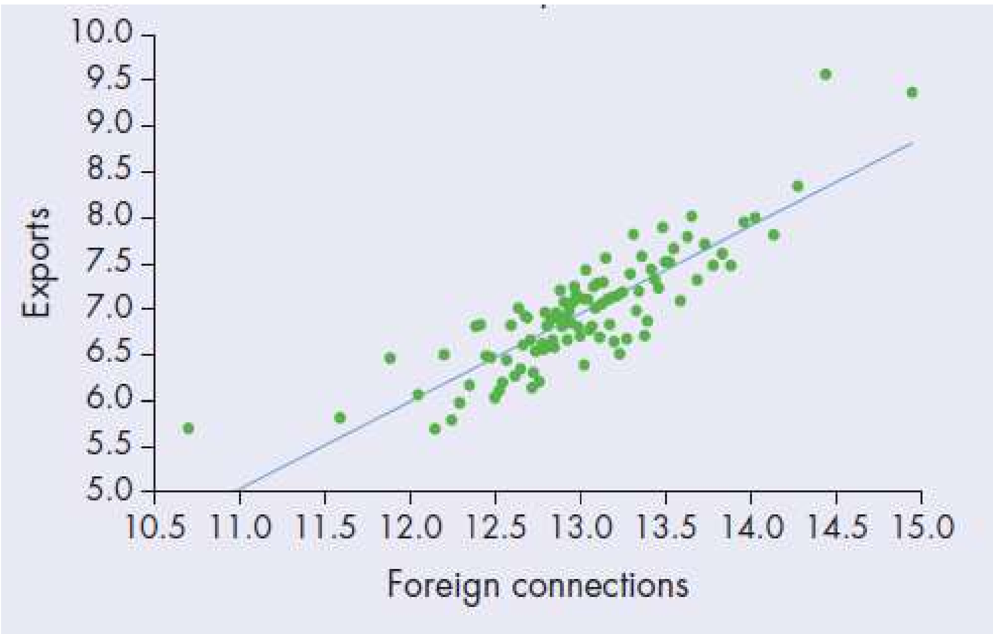


Source: World Bank, 2016

The improvement of communication infrastructure is also found to be one of the most important drivers of international trade (Riker, 2014). For instance, the advent of Internet reduced significant transaction costs for firms, consumers, and governments by enhancing opportunities for global value chain participation

(World Bank, 2016). Figure 3.2 shows the strong correlation between export and number of foreign connections indicated by members of LinkedIn across countries. In addition to the above effects, the increased use of digital technologies has a positive environmental effect by lowering CO2 emissions (Ozcan and Apergis, 2018).

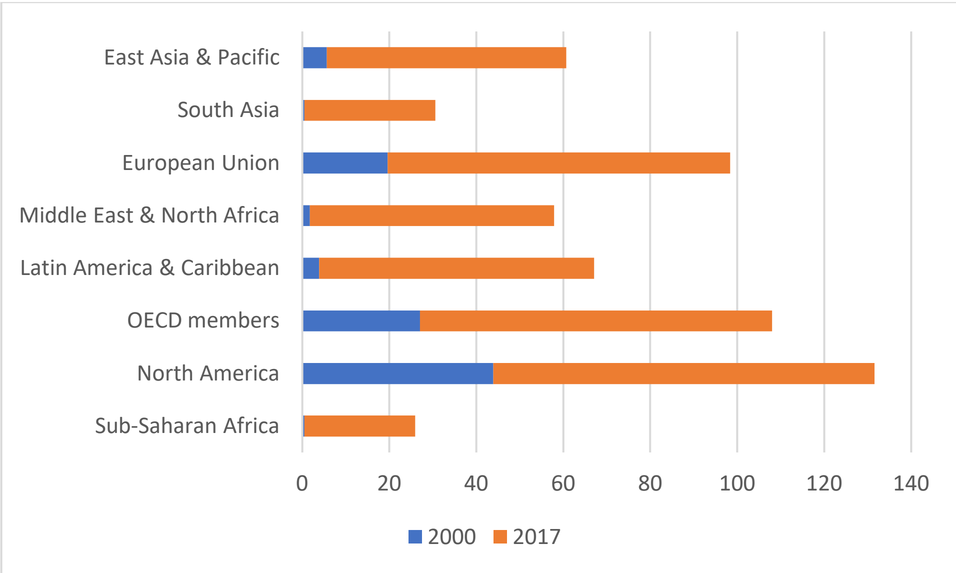
Figure 3. 2: Export and foreign connections



Source: World Bank, 2020

The problem, however, is the divergence among different regions as shown in figure 3.3. In 2017, the most recent year for which data are available, the average number of Internet users in Sub-Saharan Africa (SSA) was 25%. On the other hand, for OECD countries, the figure was 82%.

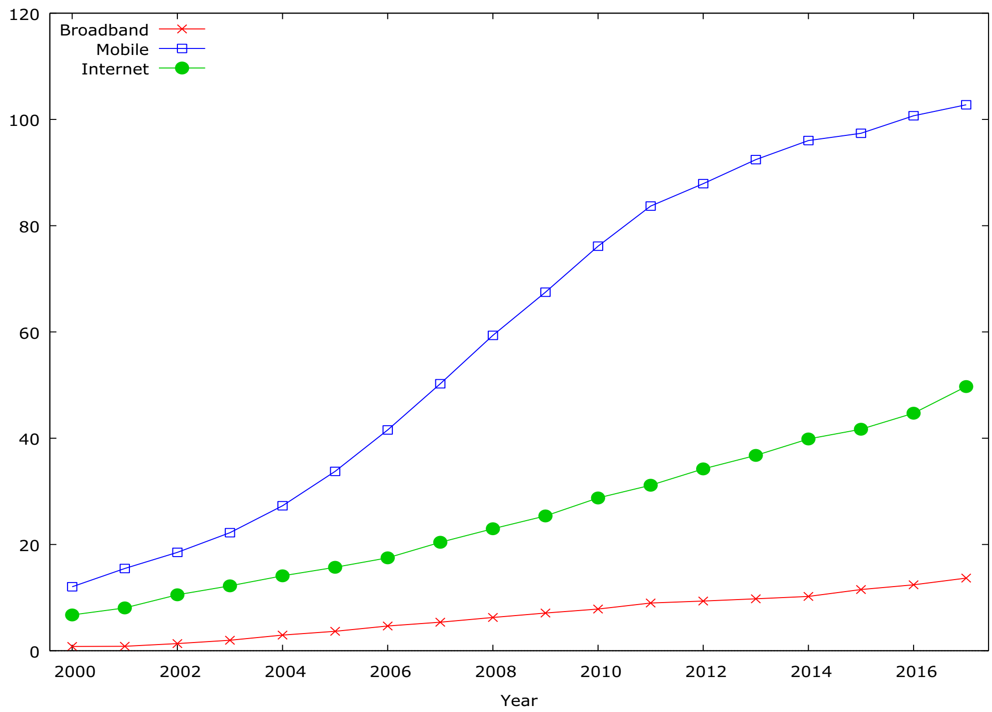
Figure 3. 3: Internet penetration across different regions



Source: World Development Indicators

Figure 3.4 shows that the share of global population using Internet increased from 7% in 2000 to 50% (3.9 billion people) in 2017. The highest penetration is observed in the number of mobile subscriptions which increased from 12% in 2000 to 103% in 2017. On the other hand, broadband subscriptions are low, reaching only 14% of the global population in 2017.

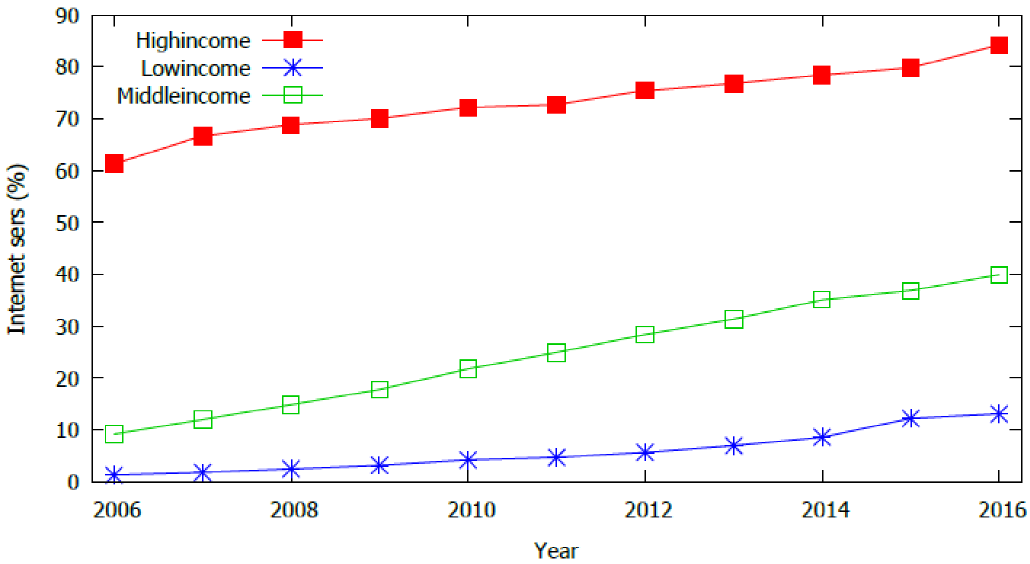
Figure 3. 4: Global mobile, Internet, and broadband user



Source: International Telecommunication Union

As already stressed in the literature survey (Chapter 2), digitalization exerts a diversified impact among countries based on the state of technology and level of economic development. The effect of broadband Internet is minimal for SSA compared to OECD countries, whereas the impact of mobile telecommunications is higher in SSA compared to the OECD counterpart (Myovella et al., 2020). In SSA, unlike phone penetration, Internet did not contribute to income per capita growth which implies further research and policy measures needed to unlock the potential of this technology. During the period 2006-2016, a 10% increase in mobile phone penetration results in a 1.2% growth of real GDP per capita in SSA (Haftu, 2019).

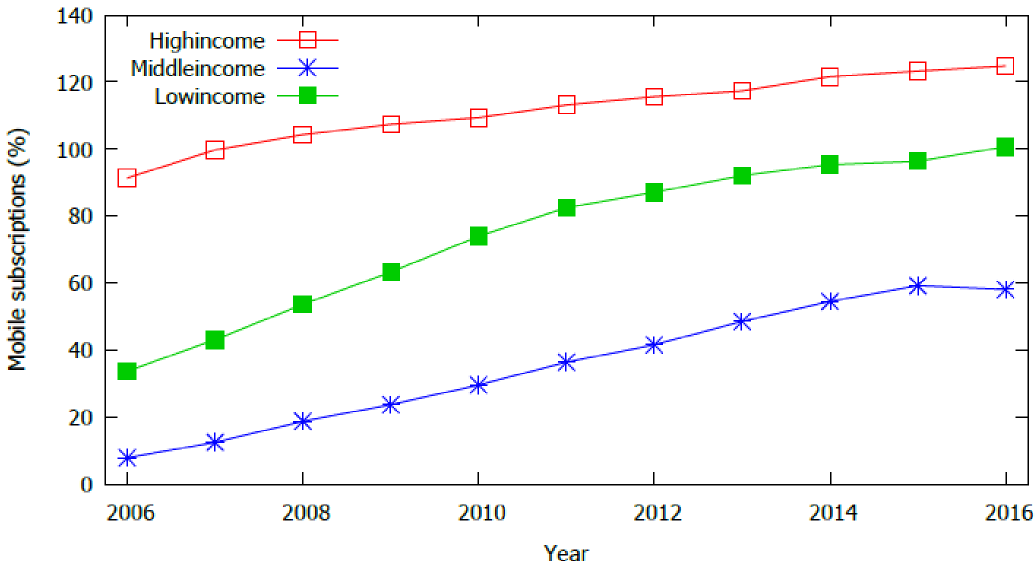
Figure 3. 5: Internet in different income group of countries



Source: International Telecommunication Union

The diffusion pattern of access to technology is characterized by convergence looking at mobile phone diffusion while for Internet diffusion countries tend to diverge (World Bank, 2016). In 2016, the number of mobile cellular subscriptions per 100 inhabitants in low-income countries (58%) was lower than half of that in 1high-income countries (125%) while it was 1% and 48% in 2006 as shown in figure 3.6. The convergence is even strong between high and middle-income countries. On the other hand, for Internet, the trend shows rather divergence as shown in Figure 3.5. The growth of Internet penetration has been also slow particularly in low-income countries.

Figure 3. 6: Mobile diffusion in different income group of countries



Source: International Telecommunication Union

3.2. Economic conditions and digital divide in Sub-Saharan Africa

According to the World Bank, there are 48 countries in SSA (World Bank, 2020). The United Nations classified 33 of them as least developed countries with less than USD 1025 gross national income (GNI) per capita (UN, 2020). From 2006-2016, the compound annual growth rate[4] of SSA's GDP per capita was 1.5%.

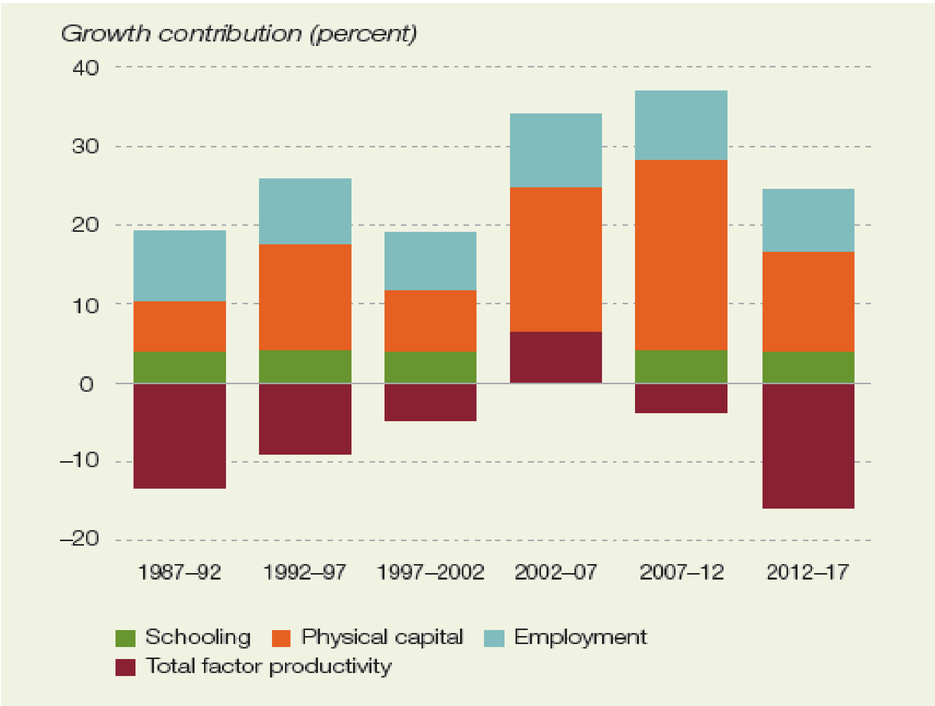
---

[4] Compound annual growth rate is defined as the mean annual growth rate of a variable over a specified period longer than one year. Compound annual growth rate of GDP per capita over the period 2006-2016 is calculated as

$$CAGR = \{\frac{GDPpc2016}{GDPpc2006}\}^{\frac{1}{10}} - 1 * 100$$

Growth accounting estimation[5] shows that, over the past three decades, physical capital growth has been the major source of growth in African countries as figure 3.7 shows. The contribution of employment is like the rises in years of schooling. Total factor productivity (TFP) on the other hand has either negative or zero contribution most of the time (Outlook, 2020).

Figure 3. 7: Sources of economic growth in African countries



Source: Outlook, 2020

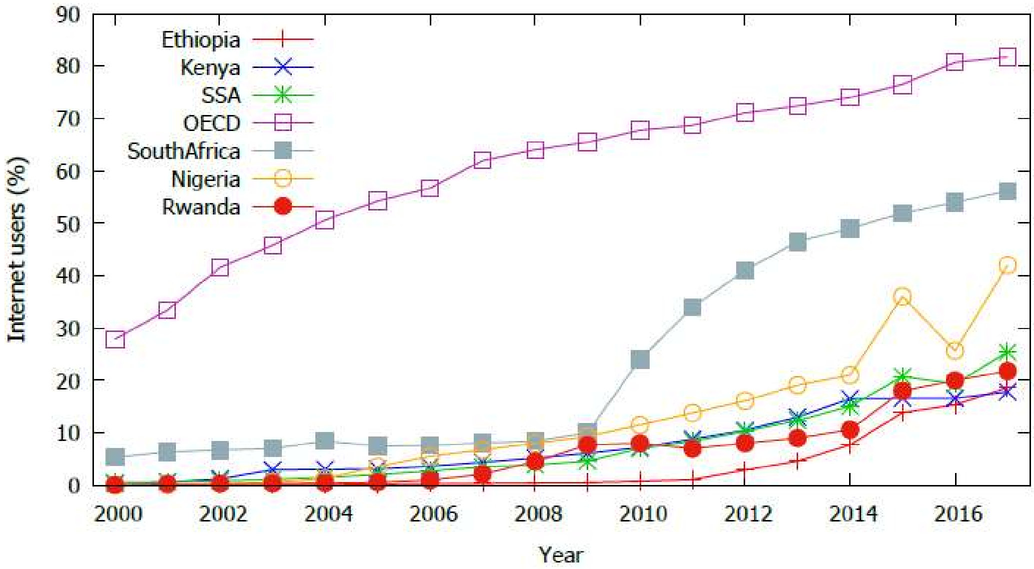
[5] The growth accounting starts from cobb-Douglas production function of the form $Y_{it} = A_{it}K_{it}^{\alpha}(H_{it}L_{it})^{\beta}$ where Y is GDP, and H, L and K are human capital, total employment, and capital stock, respectively. Using α =0.4 and β=0.6, total factor productivity is calculated as $A_{it} = \frac{Y_{it}}{K_{it}^{\alpha}(H_{it}L_{it})^{\beta}}$

Figure 3. 8: Digital divide inside African countries

Source: World Bank, 2016

As mentioned in the introduction, the digital divide within countries is as high as between them. Figure 3.8 shows the difference in Internet access between different economic and social groups. The biggest domestic digital divide is between rural (10%) and urban (26%) residents in the continent. Demographically, domestic digital divide between young (20%) and mature (8%); and men (18%) and women (12%) are also high. Since Internet is not cheap in low-income countries, the Internet access difference between the bottom 40% and upper 60% is far from negligible.

Figure 3. 9: Trends of Internet penetration in SSA



Source: International Telecommunication Union

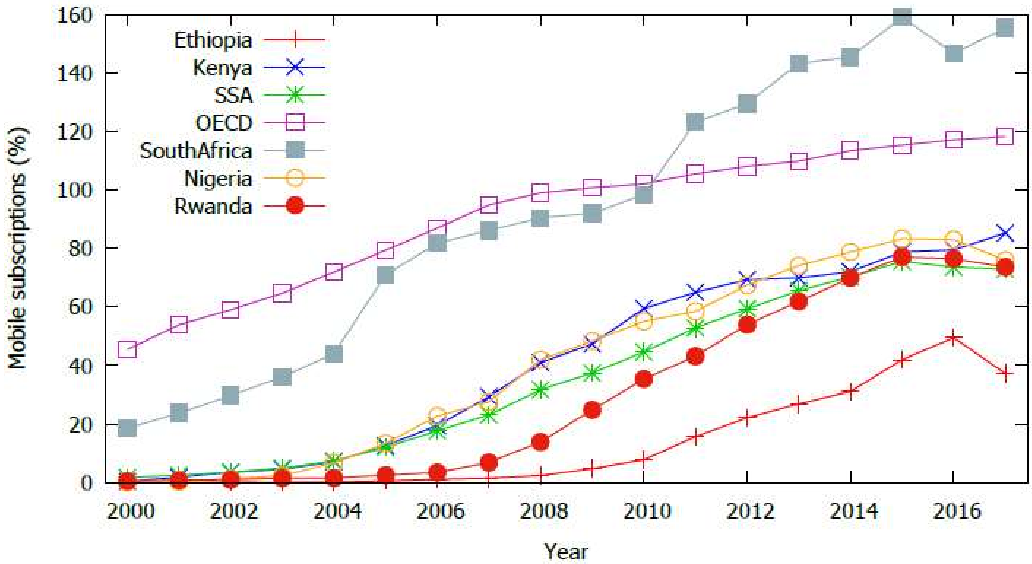
Regarding digital technologies usage in Sub-Saharan Africa, the Internet has been lagging while mobile telephony is widespread. Moreover, Internet penetration in SSA is considerably low particularly compared to OECD countries[6]. Figure 3.9 shows that the percentage number of Internet users in SSA (25%) in 2017 is lower than OECD (28%) in 2000. In OECD countries, Internet penetration leapfrogged from 28% in 2000 to 82% in 2017. Indeed, the Internet penetration rates of developed countries are significantly higher than the SSA countries. Figure 3.9 also shows the Internet penetration of five SSA countries (Ethiopia, Kenya, Rwanda, South Africa, and Nigeria). Together, these countries account for more than 40

[6] We used the OECD Internet penetration rate for the purpose of comparison with SSA countries.

percent of the continent's population. The Internet penetration of countries like Kenya was above the mean of SSA before 2014, while in 2017 it is lower than the regional average (17% versus 25%). In Rwanda, the Internet penetration rate was less than 10% before 2013 and reached 17% in 2017. The Internet penetration in Ethiopia (19%) is substantially lower than the average of the region with a recent convergence. In all the five countries, Internet penetration rate was lower than 10% before 2009 with a subsequent significant improvement in South Africa and Nigeria.

When it comes to mobile subscriptions, Figure 3.9 shows that there has been a considerable convergence between SSA and OECD countries. The recent average in SSA is 73% in 2017 compared to 118% in OECD. In 2017, the mobile telephone penetration in Kenya (85%) is higher than the SSA average and that of other African countries. Some consider Kenya as "Silicon Savanah" with a savvy digital ecosystem. The country has a popular mobile payment system called M-Pesa and 70% of the population have mobile money account. Mobile subscription in South Africa (155% in 2017) is higher than both in SSA and OECD average. In Nigeria and Rwanda, the rate of diffusion is closer to the regional average, 76% and 74% respectively. On the other hand, mobile penetration in Ethiopia is 37%, half lower than the SSA average. Worldwide, only a handful of countries, including Ethiopia, Djibouti, and Eritrea in the Horn of Africa region, still maintain state-run monopolies in the provision of mobile services and the Internet, and they have generally not fared as well as their neighbours. Mobile penetration is only half of the level of Kenya in the countries that have retained monopolies.

Figure 3. 10: Mobile subscriptions

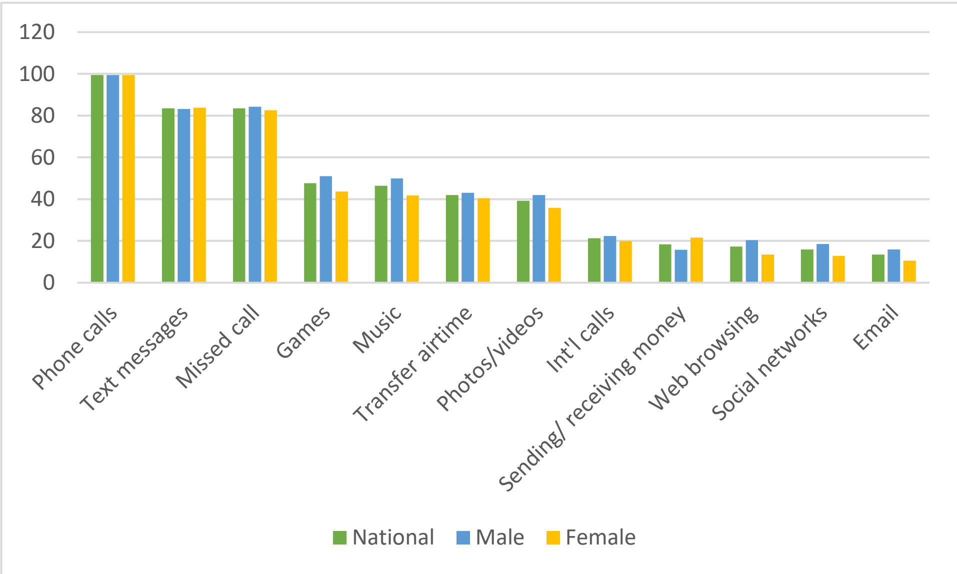


Source: International Telecommunication Union

The utilization of digital technologies also varies in Africa as shown in Figure 3.11. A survey from 12 African countries in 2012 showed that majority of the people use mobile phones (99%) for calls and Internet for social networking (41%) daily.

Email from mobile phones (14%) is the lowest which implies it is unlikely to use mobile phones to exchange work related information and documents.

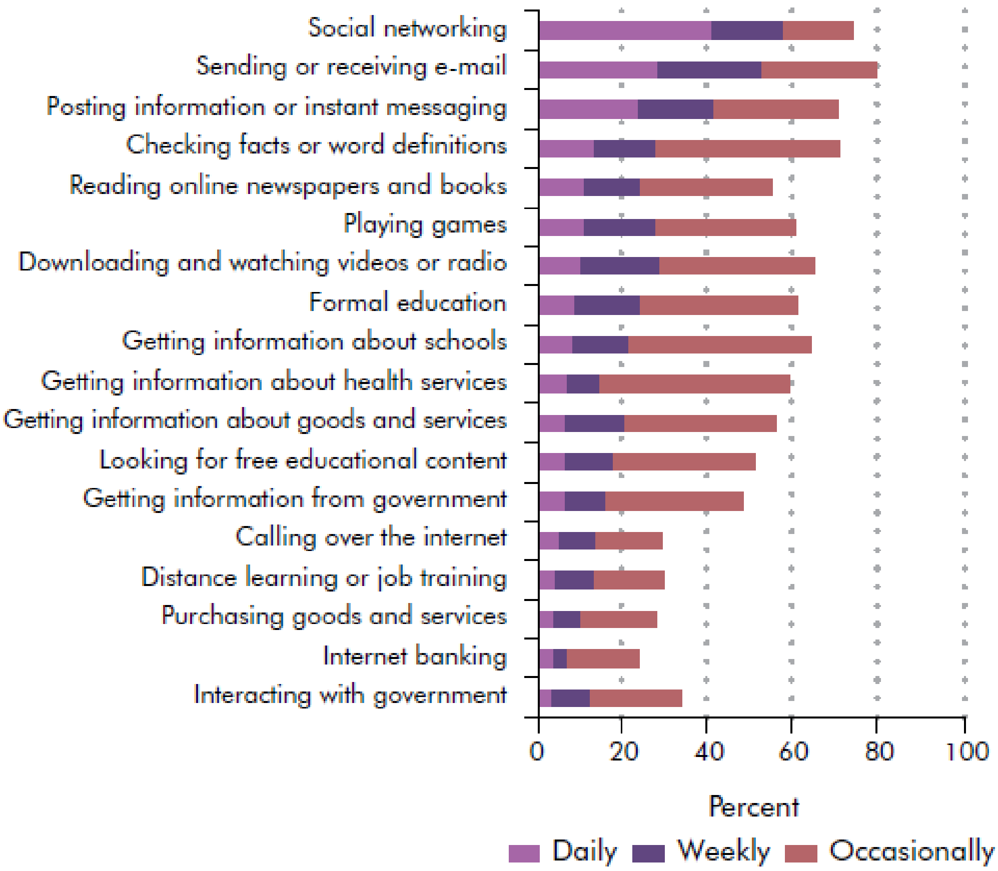
Figure 3. 11: Percentage of mobile users reporting each type of use



Source: World Bank, 2016

As Nkohkwo and Islam (2013) analysed the literature on the challenges of e-government initiative, ICT infrastructure, human resources, legal framework, Internet access, the digital divide, and connectivity are among the most common themes on the challenges to the successful implementation of e-government initiatives in Sub-Saharan African countries. Moreover, high dependency on public finance make initiatives unsustainable. This could result in lower engagement of citizens in government matter.

Figure 3. 12: Percentage of individuals using Internet reporting each type



Source: World Bank,2016

Figure 3.12 shows that most people use their internet access for social networking, sending, or receiving emails and posting information or instant messaging. Calling over the Internet, distance learning/job training, Internet banking and purchasing goods and services have lower than 40% of Internet utilization by individuals. In fact, financial inclusion is low in Africa. For instance, the account ownership at a financial institution or with a mobile-money-service provider (% of population ages 15+) are less than 50% in 2017. Although there is considerable gender digital divide in access to Internet as we have shown in Figure 3.8, there is not a big difference in the utilization of mobile phones for different purposes.

To summarize, this chapter's descriptive statistics and recent trends of digital technologies suggest that access to the technology itself is the main problem in SSA. Hence, investment on the digital technology diffusion could solve many of the problems. It is not to underestimate the digital skill problem since the contribution of lower level of education is found to be negligible for digital technologies diffusion. For instance, Penrad et al. 2015 reported very low difference between people with formal education and primary school certificate holders of Internet use. However, access to the technology could help to improve these problems.

The economic implications of digital technologies have been the focus many development studies as shown in chapter 2. The literature and recent data suggest that the impact of digitalization on financial sector, labour market, inequality, education, and public service is appreciable. Not shown in the analysis, for instance, in the second half of 1990s, the underlying difference of labour productivity between EU (1.4%) and US (2.5%) was attributed to low digital technologies investment and diffusion in EU countries. In Africa, only a few of countries have achieved inclusive growth during this ICT era.

Moreover, digital technologies are less integrated to the economic and business environment in the region. This is clear from both mobile and Internet utilization data. As a result, both the diffusion process and its economic benefits are less than expected. Countries with mobile-money-service have better digital technology diffusion and improved their per capita consumption.

One of the unique characteristics of digital technologies is that they are relatively easy to reach the mass population unlike other infrastructures. The reason could be the marginal cost Internet is close to zero once adopted particularly through its high non-rival properties. Consequently, some of them has reached to many people before accessing basic infrastructures like electricity. For instance, in Kenya, while the mobile phone diffusion has reached 80% in 2016, electricity access is limited to 65% of the population. In fact, the rate of growth of more advanced digital technologies is low.

CHAPTER FOUR

INTERNET DIFFUSION IN SUB-SAHARAN COUNTRIES: AN ECONOMETRIC ANALYSIS

Based on previous analytical frameworks, we construct an econometric model for Internet diffusion. We use the statistics of Internet users for Internet diffusion rates. Although the diffusion itself cannot cover the issue of the quality of connection and services, processing speed, and other capabilities of the computer used, it is widely available for many countries in SSA and for a reasonable length of time The average number of Internet users over the period 2006-2016 is regressed on a set of explanatory variables to assess their relative contribution to Internet diffusion.

4.1. Data sources

We used a panel of macroeconomic and digital technologies data to carry out the empirical analysis. Digital technology data (number of Internet users, broadband and mobile subscriptions) are obtained from International Telecommunication Union (ITU). Macroeconomic data on the other hand are obtained from World Bank's *World Development Indicators* database. Our data covers a decade of Internet era with a considerable diffusion in SSA.

4.2. Sample of the study

The sample consists of 41 countries in Sub-Saharan Africa. The study adopted the World Bank's list of SSA countries since this is the major source of our dataset (World Bank. 2019). The time series for the variables consists of 11 years from 2006 to 2016. SSA countries with missing data values and countries in North Africa are excluded from our analysis[7]. The list of countries used for the study are mentioned in the appendix. This sample has been the focus of many research works (Myovela, 2020; Asongu et al., 2017, 2018; Haftu, 2019; Penard et al., 2015; Birba and Diagne, 2012; Murthy et al., 2015; Ojuloge and Awoleye, 2018). However, our data covers a longer period with considerable expansion of the Internet technology in most SSA countries. Previous studies focused on the impact of digital technologies on economic growth and development. Our analysis focus on the technology itself since it is overlooked in the literature. Despite the longer time advantage, data unavailability limits our focus on the most important economic and technology variables.

[7] The 7 SSA countries not included in the sample are Cape Verde, Republic of Congo, Djibouti, Eritrea, Sao Tome and Principe, Somalia, and South Sudan. These countries are characterized by small population size and low Internet diffusion. The countries excluded in the North African are Algeria, Egypt, Tunisia, and Morocco.

Figure 4. 1: Map of sub-Saharan African countries

4.3. Econometric technique

The empirical analysis is made using dynamic panel data econometrics technique. Panel data analysis has several advantages over cross-section and time-series. The main advantage of panel data is the increased efficiency owing to pooling several time periods of data which provides more degrees of freedom. The dynamic panel data model is based on Generalised Method of Moments (GMM) used in situations when the number of panels is greater than the number of periods aiming to address endogeneity concerns (Roodman, 2006). Using the Arellano-Bond (1991) estimator, higher lagged values of the dependent variable and the exogenous regressors from all periods can be used as instruments for the individual-specific effects. According to Roodman (2006), the Difference GMM is used to improve efficiency of estimators as well as to avoid finite sample biases that result from weak instruments. Therefore, we applied Difference GMM (two-step) to identify the determinants of Internet diffusion. We also employed fixed-effect approach to exploit information contained in the dataset of the cross-country variation in the sample. Finally, we also employed an OLS model as a benchmark of our analysis.

In order to ensure robustness of the results of this study, the validity tests of the instruments used in the GMM estimation was carried out (a scenario whereby the instruments are correlated with the error process makes the validity of the instruments questionable). One of such tests is Arellano and Bond's (1991) specification test for lack of second-order serial correlation in the first-difference residuals. The second specification test is the Sargan's test of over-identifying restrictions. To check the validity and the robustness of our results, the two tests are employed. Finally, time dummies are included in the regression to prevent any possible cross-individual correlation.

4.3.Econometric model

To explore the determinants of Internet diffusion in SSA, we used the following dynamic panel data model.

$$Int_{it} = \alpha_i + +\beta_{1t}lnGDPpc_{it} + \beta_{2t}Mob_{it} + \beta_{3t}Urbn_{3t} + \beta_{4t}Broad_{it} + \beta_{5t}Int_{it-1} + \eta_i + \varepsilon_{it}$$

Where *Int* is the number of Internet users expressed as a percentage of the population with the purpose of measuring access and use. In our data, Internet users are those who have used Internet within the last 12 months from any device (ITU, 2010). ln*GDPpc* denotes the log of GDP per capita, *Mob* represents mobile subscription, Urbn represents urbanization, Broad represents broadband subscriptions and η_i represents the country fixed effect term and ε is an error term. Letters i and t are individual country and time specific indicators. Including the lag of the dependent variable (Int_{it-1}) is important to measure the network effect. Even if network analysis is relevant in most technology diffusions, the feature of Internet is more open for this kind bolstered by social networking i.e. current number of users of Internet may depend on past number of Internet users.

4.4.Definition of variables

We used GDP per capita, mobile subscriptions, broadband subscriptions, and urbanization as important variables for the digital divide based on economic theory and findings presented in previous literature (Andres et al., 2010; Li and Shiu, 2012; Myovela, 2020; Haftu, 2019; Shiferaw, 2015; Murthy et al., 2015; Wunnava and Leiter, 2009; Stier, 2017). Variables such as education, access to energy infrastructure and income inequality are found to be relevant for the paper. However, data unavailability and methodological problems (high collinearity) for obliged us to exclude these variables from the analysis. The dependent variable is the percentage of population using the Internet.

Table 4. 1: Definition of variables

Variable name	Definition
GDP per capita (GDPpc)	GDP per capita (constant 2010 US$)
Urbanization (Urbn)	Urban population (% of total population)
Broadband subscriptions (Broa)	Fixed broadband subscriptions (per 100 people)
Mobile subscription (Mob)	Mobile cellular subscriptions (per 100 people)
Internet user (Int)	Individuals using the Internet (% of population)

We expect the higher the country's GDP per capita the higher the diffusion rate of Internet. Income allows countries to invest in innovation and cover the cost of Internet diffusion (Wunnava and Leiter, 2009). Information and communication infrastructures are also expected to be a significant contributor of higher digital technology diffusion. Telecommunication and information infrastructures are a key determinant of Internet adoption because Internet requires a proper telecommunications network to operate (Li and Shiu, 2012; Wunnava and Leiter, 2009). Urbanization is expected to have a positive effect on Internet use since cities are better networked than rural areas (Murthy et al., 2015). Lag of Internet use are also expected to have a positive effect on Internet use (Andres et al., 2010; Li and Shiu, 2012).

Table 4. 2: Correlation coefficients matrix for SSA sample

GDPpc	Urbn	Broad	Mob	Int	
1.0000	0.6143	0.3704	0.4330	0.5409	GDPpc
	1.0000	0.1166	0.5635	0.3977	Urbn
		1.0000	0.3949	0.5377	Broad
			1.0000	0.7742	Mob
				1.0000	Int

Source: International Telecommunication Union and the World Bank

Table 4.2 reports the correlation coefficients of variables. Internet use has a strong positive correlation with rate of mobile subscriptions, GDP per capita and broadband subscriptions with correlation coefficient of 0.8, 0.54 and 0.53, respectively. Internet use has also a moderate positive correlation with urbanization. It is interesting to found Internet has a stronger correlation with mobile phones than broadband subscription.

4.5. Results and analysis

4.5.1. Descriptive statistics

We have reported the summary statistics for the dependent and independent variables in table 4.3 below. The mean of Internet use is 10% with a standard deviation of 12. The rate of mobile subscription is much higher than Internet with a mean value of 59% and higher standard deviation of 38. The mean of GDP per capita is USD 2454.

Table 4. 3: Summary statistics

Variable	Mean	Median	S.D.	Min	Max
GDPpc	2454	932	3598	220.	20513
Urbn	39.7	39.4	16.3	9.62	88.6
Broad	0.492	0.0789	1.69	0.00033	16.8
Mob	58.7	50.4	38.2	1.10	164
Int	10.1	5.55	11.7	0.228	56.5

Source: International Telecommunication Union

4.6. Determinants of Internet diffusion

For estimating the determinants of Internet diffusion, we used OLS, fixed effects and GMM techniques. The results are reported in Table 4.4, 4.5 and 4.6.

Table 4. 4: Result of pooled OLS estimation

Dependent variable: Int

	coefficient	std. error	t-ratio	p-value
const	−22.3495	7.44068	−3.004	0.0046 ***
l_GDPpc	3.8008	1.35198	2.811	0.0076 ***
Urbn	−0.1653	0.06836	−2.419	0.0202 **
Mob	0.1928	0.02511	7.679	0.0000***
Broad	1.2504	0.425160	2.941	0.0054 ***
R-squared	0.70			

*significant at 10%. **at 5% and *** at 1% level

Robust standard errors

The results of OLS estimation shows log of GDP per capita, and rate of mobile and broadband subscriptions have a positive effect on economic growth. Moreover, all three variables are significant at a 1% level. Urbanization entered with a negative coefficient. However, GDP per capita has a strong impact (3.8) on cross-country Internet penetration differences.

Table 4. 5: Result of fixed effects estimation

Dependent variable: Int

	coefficient	std. error	t-ratio	p-value
const	−10.2776	7.74059	−1.328	0.2138
l_GDPpc	2.04229	1.11227	1.836	0.0962 *
Urbn	−0.0429403	0.0588445	−0.7297	0.4823
Mob	0.190827	0.0170926	11.16	0.0001 ***
Broad	1.84314	0.372357	4.950	0.0006 ***

*significant at 10%. **at 5% and *** at 1% level

Robust standard errors

The result of fixed effects model shows the same result as the OLS model in terms of signs of the coefficient of independent variables. Mobile and broadband subscription are significant at 1% level. Urbanization indicator has a negative coefficient and is not significant. The impact of GDP per capita decreased in the fixed effect model (2.04) compared to the OLS model and is significant at 10% level.

Table 4. 6: Result of two-step dynamic panel model

Dependent variable: Int

	coefficient	std. error	z	p-value
Int (-1)	0.67521	0.09669	6.983	2.90e-012 ***
l_GDPpc	6.20755	2.30249	2.696	0.0070 ***
Urbn	0.46154	0.19034	2.425	0.0153 **
Mob	0.02914	0.01643	1.773	0.0762 *
Broad	0.46622	0.43304	1.077	0.2816

Test for AR (1) errors: z = -1.92432 [0.0543]

Test for AR (2) errors: z = 0.461202 [0.6447]

Sargan over-identification test: Chi-square (8) = 8.30934 [0.4039]

*significant at 10%. **at 5% and *** at 1% level

Asymptotic standard errors

Number of instruments = 22

The result of the dynamic panel model is different from the OLS and fixed-effect model. For instance, the impact of urbanization is positive and significant in the dynamic model. Broadband subscription on the other hand has a positive but insignificant effect. The change in the sign and coefficients of the variable could arise from endogeneity bias in OLS specifications (Andres at al., 2010; Myovella,2020, Li and Shiu, 2012).

Results from the estimation procedure show that the null hypothesis of joint insignificance of the coefficients of all independent variables is rejected. This is confirmed by the Wald- test. This shows that variables selected for the estimation procedure are jointly valid. The Arellano-Bond test for zero autocorrelation in first differenced errors at order 1 and 2 shows that errors are not serially correlated implying consistency of the parameters.

The Arellano-Bond GMM estimation shows that the diffusion coefficient (the lag of the dependent variable) is positive and highly significant indicating that the diffusion model cannot be rejected. A 10% change in the number of Internet users last year lead to a change of about 7% in the number of Internet users this year. The importance of the lagged dependent variable is in line with the results of several papers including (Andres et al., 2010; Li and Shiu, 2012; Godwin, 2019; Haftu, 2019; and Shiferaw, 2015).

GDP per capita has a significant positive effect on Internet use. A 10% increase in GDP per capita is associated with a 62% increase in the number of Internet users. The result implies that economic strength is an important determinant of Internet use in developing countries. In general, GDP per capita, being one of the key determinants in explaining global digital divide has been verified to be positively related to ICT diffusion and hence Internet as observed in previous studies (Andres et al., 2010; Wunnava and Leiter, 2009; Andres et al., 2010; Shiferaw, 2015).

Our results also demonstrate that telecommunication infrastructure growth plays an essential role in terms of Internet diffusion. Our model shows that a 10% rise in mobile subscriptions is associated with a 3% increase in Internet penetration. Thus, an increase in the number of mobile telephones available in a country is likely to have a positive effect on Internet diffusion. The result is consistent with Oyelaran and Lal, (2005) and Birba and Diagne, (2012). Instead, the impact of broadband is negligible. The fact that low broadband expansion could be one possible factor for the result in SSA.

CHAPTER 5

CONCLUDING REMARKS AND POLICY CONSIDERATIONS

The role of the digital technologies revolution in different sectors of the global economy is a well-established fact in the economic literature. The main channels of development are innovation, efficiency, and inclusion. On the other hand, digital divide in access, use and skills is one of the major challenges. The diffusion of digital technology is therefore different across countries and regions depending on the level of development and the state of technology. Hence, it is germane to study the dynamics of diffusion and investigate the policy implication of different penetration rates of digital technologies across countries. Our study focuses on Internet diffusion in SSA countries using a panel data model. In SSA, the rate of digital technologies diffusion has improved, especially, over the last decade. However, lack of infrastructure and proper governance limit the diffusion process. The considerable diffusion of mobile technology in which expensive infrastructure does not constrain its availability and utilization shows the magnitude of the problem. Most of the successful countries have a decent road networks, rural electrification, and mobile networks. The average number of mobile subscribers in Sub-Saharan Africa was 73% in 2017. On the other hand, the diffusion of Internet (25%) and other digital technologies is significantly lower than in developed countries.

According to International Telecommunication Union, globally, a 10% rise in mobile broadband penetration yields an increase of 1.5% in GDP, and that the impact is greater in less developed countries than in developed countries. A follow-up study focusing on the African region suggests a 10% increase in mobile broadband penetration in Africa would yield an increase of 2.5% of GDP per capita. Even if there are individual success stories, the comprehensive social, economic, and political benefits of digital technologies are less than expected. For instance, the level of e-commerce and financial inclusion in most African countries is at infant stage.

In SSA, most countries had an Internet penetration of less than 30% in 2017 and 5% in 2010. In countries like Kenya even if 70% of the population have mobile banking, Internet users are less than 20% in 2016. In Ethiopia, the share of Internet users was less than 1% of population until 2010 although it reached 18% in 2017. The diffusion process is hampered not only by infrastructure but also by unsustainable public financing, low market competition, lack of proper governance and technological capabilities; these are also the most frequently mentioned factors affecting the diffusion of Internet and other digital technologies in developing countries. The focus of this study is therefore to investigate the sources of different cross-country Internet diffusion rates.

We applied a panel data model using data from World Bank and International Telecommunication Union. We selected a sample of 41 countries to study the dynamics of Internet diffusion during the period 2006-2016. We used GDP per capita, urbanization, broadband and mobile subscriptions as independent variables. Internet users as a percentage of population is used as a dependent variable. We employed pooled OLS, panel fixed effects and, finally, two-step dynamic panel GMM techniques to capture endogeneity problem.

The results show that the impact of GDP per capita and mobile subscriptions is positive and significant consistently in all three models. Broadband subscriptions and urbanization are also positive even if they are statistically insignificant in the dynamic panel GMM model. The lagged of the dependent variable (Internet) is significant in the GMM model. The results are consistent with literature, in which economic strength, urban development and infrastructure improve Internet connectivity.

Therefore, countries in SSA should give priority to Internet infrastructural expansion to realize the full benefit of technology. Smart phones, broadband networks, and computers are important to access Internet. Unlike developed countries, in which 83% of households possess personal computer, only 36% households in developing countries own personal computers. Additionally, enhancing electricity and digital literacy would increase Internet diffusion. The

World Bank report showed that the expansion of digital technologies has been faster than some basic infrastructures in SSA. For instance, the average number of populations with lack of access to electricity is 57% in 2016 lower than the mobile penetration of most countries. Improvement of infrastructure requires strong commitment from governments and private participation.

Diversifying the use of Internet will help to integrate the technology with economic activities and facilitate innovation. The diffusion coefficient in GMM model confirmed that the present users of Internet attracts future users at a higher speed. To bolster the diffusion process, countries should support small transaction using mobile technologies. Mobile banking, for example, allowed farmers to access financial services and per capita consumption in some African countries.

The diffusion also highly depends on the state of the technology itself and level of development of the countries. Therefore, digital divide is partly a consequence of development divide. Promoting the affordability of digital technologies by adopting appropriate policy and regulation would help countries to enhance the diffusion.

Africa is urbanizing faster than other world regions. It is projected that 60 percent of the population of Africa will live in urban areas by 2050 from 46 percent in 2017. Urbanization is usually demonstrated by the expansion of infrastructure, mainly roads and buildings. Even if the expansion of infrastructure is the positive side of the urban growth, urban poverty and inequality are big challenges in developing countries. There are also evidences for a positive association between urbanization and inequality. However, the diffusion of digital technologies in urban areas is much higher than in rural areas due to the availability of digital literacy, market, and infrastructure advantages. Since the pattern of developing countries is different from developed ones, there is a gap in the backbone infrastructure, especially in rural areas. In that regard, governments intervention is necessary to fill the urban-rural gap.

APPENDICES

Countries used in the analysis

Angola	Equatorial Guinea	Mali	South Africa
Benin	Ethiopia	Mauritania	Sudan
Botswana	The Gambia	Mauritius	Swaziland
Burkina Faso	Ghana	Mozambique	Tanzania
Burundi	Guinea	Namibia	Togo
Cameron	Guinea-Bissau	Niger	Uganda
Central African Republic	Kenya	Nigeria	Gabon
Chad	Lesotho	Rwanda	Zambia
Comoros	Liberia	Senegal	Zimbabwe
Congo (Brazzaville)	Madagascar	Seychelles	
Ivory Coast	Malawi	Sierra Leone	

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