The Nexus between Infrastructure Quantity, Quality and Economic Growth in Sub Saharan Africa

By

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ABSTRACT

Public infrastructure is believed to be important to economic growth through its role as a complementary production factor or an additional input of production. Investigation of the growth effects of infrastructure has been one of the favourable areas in academic and policy circles. Despite increased attention received in the literature on the infrastructure-growth relationship, there still exist important research gaps in the areas such as aggregate infrastructure-growth nexus, direction of infrastructure-growth causality, electricity growth effects in presence of energy-related CO_2 emissions, and spatial spillovers of infrastructure investment. In these various areas, the most serious gap is failure to account for infrastructure quality. The knowledge of the quantitative and qualitative growth impacts at both aggregated and individual infrastructure sector levels, including the infrastructure spatial spillovers in Sub Saharan Africa (SSA) is extremely important in the design of optimal infrastructure investments and implementation of cost-sharing structures in the presence of vital spillovers. This thesis examines four critical themes in the infrastructure quantity and quality literature.

The first essay examines the growth effects of aggregate infrastructure stock and quality, and the direction of infrastructure-growth causality. Exploiting advances in applied econometrics, the results reveal strong evidence of a positive effect of infrastructure on economic growth with most contribution coming from infrastructure quality. More so, the findings show evidence of a unidirectional causality from aggregate infrastructure to growth, which is based on hybrid indices that simultaneously capture the quantity and quality features. While SSA should continue solving the infrastructure shortage problem, the results in this essay also give much credence to infrastructure quality enhancement. This study argues that causality testing based on quantitative measures alone is not adequate as quality developments are omitted, thus the use of hybrid indices tend to be superior.

The second essay presents new evidence on the economic growth effects of the stocks and qualities of electricity, telecommunication, transportation, water and sanitation infrastructures in both long-run and short-run using a five step panel analysis. The results reveal long-run positive growth effects from the stocks of electricity and telecommunication. While water stock shows no significant long-run impact, transport stock has a negative impact. Moreover, the qualities of telecommunication, transport and sanitation exhibit positive long-run growth effects. For short-term dynamics, the findings suggest positive growth effects from the stocks of electricity and telecommunication, whereas transport and water stocks suggest negative growth effects. While telecommunication and sanitation quality developments can raise short-run growth, transport and water qualities have no significant contribution. Electricity quality exerts a downward pressure on growth in SSA. Based on the hybrid indices, the long-run and short-run growth effects across the infrastructure sectors are basically positive except for electricity in the long-run. Moreover, the negative growth effects from transport stock may imply shifting of vital resources away from other investments during construction while their under (or unproductive) utilisation yields economic benefits below construction costs.

The third essay critically analyses the extent of electricity shortage, efficiency, key sources and opportunities for SSA in comparison with other regions. The essay proceeds to address the issue of how electricity-related CO2 emissions may alter the growth contributions of both electricity stock and quality. First, as in essay two but here with a different approach and different proxy for electricity stock, the results suggest positive effects from electricity stock but the quality effects are negative. Second and most importantly, a high level of electricity-related CO2 emissions lower the growth contributions of electricity stock and exacerbate the negative growth impact of electricity quality. The key conclusion established is that electricity-related CO2 emissions adversely affect the economic contribution of electricity sector. This may give an insight on proper design of carbon taxes (where applicable) yet comparing the opportunity cost of carbon taxes versus investment in carbon capture technologies.

Finally, the last essay analyses the spatial spillovers from aggregate infrastructure stock and quality among SSA countries. The results indicate evidence of positive and robust spillover effects from foreign aggregate infrastructure quality while the foreign aggregate stocks of infrastructure imply negative spillovers. Thus, whereas infrastructure quality enhancement invigorates the surrounding regions, infrastructure stock development may provide a competitive advantage that draws economic factors from the surrounding regions and hence exerting negative pressure on their respective economic activity. To buttress these findings, panel Granger causality tests show evidence of causality (mostly bi-directional) between the infrastructure (domestic and foreign) variables and economic growth. This essay is crucial for two key policy concerns, which are the implementation of optimal infrastructure investments and credibility of cost-sharing structures in the presence of spillovers.

Keywords: Aggregate infrastructure, economic growth, spillovers, GMM, Panel VAR, SSA

JEL Classification: H54; O40; Q43; Q56; R53; R11; R12; O55

DECLARATION

I, **Chengete Chakamera** with student number 970815, hereby declare that this PhD dissertation in my own work except as indicted in the references and acknowledgements. The research was conducted at Wits Business School (WBS) under the supervision of Prof. Paul Alagidede. It is submitted in fulfilment of the requirements for the award of Doctor of Philosophy at the University of Witwatersrand. This work is not a reproduction in part or in whole of any research presented for the award of a degree.

Chengete Chakamera

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Parktown, Johannesburg (South Africa)

Signed on the 24th day of January, 2018

DEDICATION

To God the Almighty, Be Exalted!

To my wife Kundiso Destiny Chikohwera and Kendra Tachel Chakamera

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The usual caveats apply.

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LIST OF ACRONYMS

Africa Infrastructure Country Diagnostic	AICD
African Development Bank	AfDB
Aggregate infrastructure stock	AIS
Aggregate infrastructure quality	AIQ
Augmented Dickey Fuller	ADF
Carbon dioxide	CO2
Central Africa	CA
CO2 emissions from electricity and heat production	CO2EM
Common Market for Eastern and Southern Africa	COMESA
Community of West African States	ECOWAS
Cross-dependence	CD
Cross-sectionally ADF	CADF
Cross-sectionally augmented IPS	CIPS
Democratic Republic of Congo	DRC
Domestic aggregate infrastructure quality	DAIQ
Domestic aggregate infrastructure stock	DAIS
Dumitrescu-Hurlin	D-H
Dynamic Ordinary Least Squares	DOLS
Early childhood care and education	ECCE
East Africa	EA
East African Community	EAC
Economic Community of East African States	ECCAS

Economic Community of West African States	ECOWAS
Electricity consumption	ELEC
Electricity transmission and distribution losses	RETDL
Energy market integration	EMI
Environmental Kuznets Curve	EKC
First principal component	PC1
Second principal component	PC2
Foreign aggregate infrastructure quality	FAIQ
Foreign aggregate infrastructure stock	FAIS
Fully Modified Ordinary Least Squares	FMOLS
Generalized Method of Moments	GMM
Gross Domestic Product	GDP
Homogenous non-causality	HNC
Hybrid Infrastructure Index	HII
Im, Pesaran and Shin	IPS
Impulse response functions	IRF
Information and computer technologies	ICT
Information technology	IT
Instrumental variables	IV
International Finance Corporation	IFC
International Monetary Fund	IMF
Kuznets curve	EKC
Levin, Lin & Chu	LLC

Maximum likelihood	ML
Method of moments	MM
Middle East & North Africa	MENA
Millennium Development Goals	MDGs
Modified electricity consumption	MELEC
Modified ratio of electricity transmission and distribution losses	MRETDL
Moment and model selection criteria	MMSC
Non-renewable electricity consumption	NRELC
North American Free Trade Agreement	NAFTA
Ordinary Least Squares	OLS
Organisation of Economic Co-operation and Development	OECD
Preferential Trade Area	PTA
Principal Component Analysis	PCA
Principal components	PCs
Ratio of electricity transmission and distribution losses	RETDL
Renewable electricity consumption	RELC
Seemingly unrelated regression estimation	SURE
Singular value decomposition	SVD
Social overhead capital	SOC
Southern Africa	SNA
Southern African Development Community	SADC
Sub Saharan Africa	SSA
Sustainable Development Goals	SDGs

Total factor productivity	TFP
U.S. Energy Information Administration	US EIA
United Nations Children’s Fund	UNICEF
United Nations Education, Scientific and Cultural Organization	UNESCO
United States	US
Vector autoregression	VAR
Vector of moving average	VMA
West Africa	WA
West African Economic and Monetary Union	WAEMU
World Development Indicators	WDI
World Health Organisation	WHO

CHAPTER ONE

INTRODUCTION

1.1 Background

Africa at large is a continent of approximately 1.2 billion people (World Population Review, 2017) with an annual Gross Domestic Product (GDP) per capita about US$1588 in 2015, which is far less than the Euro area (US$34182) and even Latin America and Caribbean (US$8364) in the same year based on the World Development Indicators (WDI). Economic growth in SSA dropped to 3.5% in 2015, which is the lowest in 15 years (IMF, 2016). However, robust growth attained in West African Economic and Monetary Union (WAEMU) economies persists, buoyed by infrastructure investment (World Bank, 2017). GDP per capita has frequently been used as a proxy of economic growth in theoretical and empirical literature. Determining the factors that drives economic growth is vital for the developmental path of every nation or region.

Theoretically, it is imperative to track the evolution of infrastructure in the growth literature back to the neoclassical growth theory. In the realm of neoclassical, broadly defined capital accumulation stimulates economic growth in the short-run, however, capital ultimately succumbs to diminishing returns, so the long-run growth is completely due to exogenous technical progress (Stiroh, 2001). Solow's (1956, 1957) publications underpin the neoclassical growth theory. One of the key features of the Solow growth model is convergence of economies to a steady state. The neoclassical assumption of diminishing returns underlies the notion of convergence since it causes a country's growth rate to fall as it approaches its stead state (see Dowrick & Rogers, 2002)[1]. Nevertheless, the convergence theory raises an important question as to why poor countries are failing to catch up with rich countries in the same way that, for instance, the low income states in the US have been catching up with the high income states (Romer, 1994). Moreover, failure to provide a good explanation for the crucial United States' productivity trends such as the post 1973 productivity slowdown is among the shortcomings of the neoclassical model (Stiroh, 2001). These failures motivate growth models that relax the two neoclassical assumptions of exogenous technological change and same technological opportunities available in all nations (Romer, 1986; Lucas, 1988). Thus, the endogenous growth theory was developed to go

[1] This assumption suggests that richer countries grow at a slower rate than poor countries, *ceteris paribus.*

beyond the neoclassical theory by relaxing the diminishing returns assumption or by describing technical change due to specific actions.

Endogenous growth theory works with the AK model, that is, $Y = AK$. The assumption of the neoclassical growth theory of diminishing returns is replaced by constant returns to capital that comes from adding other kinds of reproducible capital (like human capital) to physical capital (Hussein & Thirlwall, 2000). According to Hussein and Thirlwall (2000), neglecting the reasons behind differences in productivity of capital treated as the dependent variable, and the extent of growth rate differences between nations that can be described by difference in physical investment ratio alone are among the limitations of the endogenous growth theory. Closely linked to this issue, some scholars (for example, Jorgenson & Griliches, 1967) argue that it is imperative to consider heterogeneity of capital inputs. Furthermore, the concept of capital itself was further extended to include investment in human capital and the final extension to notice is public infrastructure investments (Stiroh, 2001). This brings us to the central theme of this study, that is, the impact of public infrastructure on economic growth.

Social overhead capital (SOC) or infrastructure's role in economic development can be traced to Rostow's growth theory (see Rankin, 2009; Gilman, 2003). In his 1956 paper, Rostow calls for construction of railways or other large overhead capital with long gestation period, which are fundamental for take-off (Rostow, 1956; Rankin, 2009). Therefore, the concept of infrastructure-growth nexus is found in the early growth theories though in those years it had not yet received much attention. According to Calderon and Serven (2004), renewed concern with infrastructure can be linked to two main developments worldwide. First, retrenchment of the public sector from its monopoly position in infrastructure provision, following increasing pressure of consolidation and fiscal adjustment. Second, the liberalization of infrastructure industries to private participation. The fiscal adjustments especially in Africa need careful reflection. Most African economies have unnecessary public expenditures against their limited budgets, thus drawing pressure from the International Monetary Fund (IMF) that persistently advises them to cut their expenditures. It is vital to know the kind of public investments to prioritise such as infrastructure development. The core justification for infrastructure provision that emerges from the theoretical literature is that it increases the marginal product of other production factors (Fedderke & Garlick, 2008), while it may also be treated as input of production (see Barro, 1990).

From empirical perspective, the necessity of infrastructure provision has earned enormous support. A major empirical literature of Aschauer (1989) showed econometrically that much of the decline in productivity experienced by the US in the 1970s followed an earlier downturn in infrastructure investment. When Aschauer pressed this magic button, Gramlich (1994) pointed that “beefing up of infrastructure investment became simultaneously the liberal’s political war cry of the early 1990s and one of the favorite topics for econometric research,…” (p.1177). Nonetheless, Gramlich (1994) questioned the contribution of certain categories of infrastructure. He argued that a particular percentage of public stock representing educational buildings, miscellaneous offices, hospitals and conservation should not have significant short-term impact on the supply of national output as it is now quantified. Therefore, some authors (for instance, Rubin, 1991) applied various measures of infrastructure and found most explanatory power emerging from the ‘core’ infrastructure component. This was also revealed by Aschauer (1989) whose estimated elasticity of the ‘core’ infrastructure (highways, airports, mass transit, electrical and gas facilities, sewers, waters) with respect to private business economy was 0.24. It was when these infrastructures were modelled in a fixed coefficient and hence a percentage increase in the core infrastructure would raise productivity by 0.24% each year.

Since the seminar work of Aschauer (1989) a number of studies (for example, Barro, 1990; Cronin, Parker, Colleran, & Gold, 1991; Demurger, 2001; Esfahani & Ramirez, 2003; Fedderke & Bogetic, 2006; Kodongo & Ojah, 2016; Chakamera & Alagidede, 2016) have demonstrated the importance of infrastructure in economic growth. Besides the positive growth effects, empirical research shows the importance of various infrastructures in reducing poverty, for instance, road infrastructure (see Kwon, 2005; Fan, Zhang, & Zhang, 2002; Mu & Van de Walle, 2007), electricity (see Yoo 2006; Chen, Kuo, & Chen, 2007; Deininger & Okidi, 2007), irrigation (Balisacan & Pernia, 2002; Fan et al., 2002; Bhattarai & Narayanamoorthy, 2003) and communication (see Cronin et al., 1991; Datta & Agarwal, 2004; Roeller & Waverman, 2001). However, our study focuses on the growth effects of infrastructure. The earlier literature was mainly plagued by failure to control for endogeneity between infrastructure and economic growth. Recently, most authors (for example, Roeller & Waverman, 2001; Calderon & Serven, 2004) have implemented strategies that account for endogeneity of infrastructure.

Based on the review of literature, untangling the direction of causality between infrastructure and growth, failure to account for infrastructure quality, and lack of studies that quantify infrastructure spillovers from both aggregate infrastructure stock and quality remain existing remarkable gaps. It leaves policymakers with vital missing piece of potential information for investment decision making.

1.2 Problem statement

This study selects four fundamental aspects in the literature of infrastructure-growth relationship of which the problem statement revolves. These four key aspects are: (i) *infrastructure-growth nexus* (ii) *direction of infrastructure-growth causality*, (iii) *electricity consumption, CO2 emissions and growth*, and (iv) *spatial spillovers of infrastructure investment*. These are discussed in detail.

i. Infrastructure-growth nexus: While GDP per capita growth is a common measure of economic growth, various proxies have been used for infrastructure in the literature. Public expenditure towards infrastructure development can be used in the analysis of infrastructure-growth nexus. However, not all expenditure may translate into actually physical infrastructure stocks. Other factors such as corruption may lead to diversion of funds. Consequently, other studies consider the stock (or quantity) of infrastructure (for example, the total length of roads, number of telephone subscriptions, kilowatt hour of electricity). Nevertheless, failure to account for the quality features of infrastructure has been the most critical problem as pointed out by Fedderke and Garlick (2008). According to Fourie (2007), both researchers and policymakers still tend to focus on 'more' infrastructure than 'better' infrastructure. The key reason is that infrastructure quality is difficult to estimate. In a handful of studies that have accounted for infrastructure quality (for example, Calderon & Serven, 2010; Calderon, 2009; Loayza & Odawara, 2010; Chakamera & Alagidede, 2016), both infrastructure stock and quality were found to have significant effects on growth in Africa. The analysis of infrastructure-growth cannot be complete when little is known about the effects of infrastructure quality on economic growth and how quality developments may affect the contribution of the available infrastructure stocks. As a result, this research considers both the growth effects of infrastructure stock and quality, mainly to deepen our understanding of the implications of the state (or quality) of infrastructure in SSA.

ii. Direction of infrastructure-growth causality: Aspect (i) shows the first way of looking at the relationship between infrastructure and growth, which in most cases include other control variables in a regression model. One may infer that infrastructure causes economic growth if the coefficient for infrastructure (treated as an explanatory variable) is statistically significant. However, the existence of a strong relationship between infrastructure development and economic growth does not essentially entail a causal relationship (Yoo, 2006). Referring to electricity infrastructure and growth, Yoo argues that the relationship may run either/or both ways but the key question is which of the indicators should take precedence over the other - is electricity a driver for economic growth or does economic growth gives impetus to electricity consumption?

Consequently, disentangling the direction of causality between infrastructure and growth has been another theoretical and empirical problem that requires further scrutiny as also pointed by Schiffbauer (2007 & 2008). Theoretically, it is possible to accept that infrastructure can extend the productive capacity of a region by both facilitating productivity of existing resources and increasing the resources. On the other hand, although infrastructure development may influence output and productivity, economic growth can also influence the supply and demand of infrastructure, which may possibly lead to overestimates of the infrastructure contribution if endogeneity is not controlled for (Esfahani & Ramirez, 2003). This implies the possibility of feedback effects between infrastructure and economic growth, that is, infrastructure drives growth and the reverse through the need for more infrastructure as an economy grows. Empirically, it has not been clear whether the direction of causality is one way or bidirectional (see for example, Munnell, 1992; Perkins, Fedderke, & Luiz, 2005; Kularatne, 2006; Maparu & Mazumder, 2017). In view of this empirical gap, this thesis examines the infrastructure-growth causality in a new way that involves a joint capture of aggregate quantity and quality features of infrastructure. This study calls the index that simultaneously capture the quantity and quality infrastructure features a “hybrid” index; this index is discussed in detail in chapters two and three.

iii. Electricity consumption, CO2 emissions and growth: Electricity generation produces CO2 emissions, especially from coal sources. The World Development Indicators show that a greater proportion of CO2 emissions in SSA are from coal energy sources, while gas energy sources are the major emitters of CO2 emissions in the Middle East & North Africa (MENA). These emissions pose a great threat to environment and are believed to have an adverse effect on economic growth. Empirically, a number of studies (for example, Cowan, Chang, Inglesi-Lotz, & Gupta, 2014; Saidi & Hammami, 2015; Ahmad et al., 2016; Bouznit & Pablo-Romero, 2016; Esso & Keho, 2016; Mezghani & Haddad, 2017) investigated the relationship between electricity consumption, CO2 emissions and economic growth. Most previous studies focused on cointegration and causality between these three variables yet no consensus has emerged. Apart from the mixed findings, an examination of how the electricity-related CO2 emissions may influence both the nature and magnitudes of electricity stock and quality growth contributions has not been interrogated. In the analysis of this study, the effects of electricity-related CO2 emissions on growth are indirectly inferred by looking at the changes in the growth effects of electricity stock and quality when these emissions are accounted for. This extended knowledge could be useful for proper design of carbon taxes wherever possible.

iv. Spatial spillovers of infrastructure investment: Possible spillovers from infrastructure development have been of concern especially for policy making. A country's infrastructure endowment may stimulate development in the surrounding regions. However, these spillovers might be negative (Sloboda & Yao, 2008; Zhang, 2008). Most studies examined spillover effects based on the quantities of individual infrastructure sectors (mostly, transport and telecommunication) measures. Thus, despite a reasonable amount of previous studies in the area of infrastructure spillovers, an analysis from aggregate infrastructure stock and quality perspective is something that has not been done to the best of our knowledge. It would be interesting to have an understanding of how the combined infrastructure systems of an economy may impact growth in the surrounding countries through spatial spillover effects.

1.3 Research objectives

The key objective of this study is to investigate the relationship between infrastructure and economic growth in SSA. Electricity, telecommunication, transportation, water and sanitation infrastructures are the centre of focus. The thesis analyses the infrastructure-growth nexus (of both aggregate and the individual infrastructure sectors); direction of causality between infrastructure and growth; electricity, CO2 emissions and growth; and spatial spillover effects of infrastructure. In particular, this study has five objectives:

- Investigate the nexus between infrastructure and economic growth using both aggregate indices of infrastructure stock (quantity) and quality.
- Analyse the direction of causation between aggregate infrastructure and growth.
- Examine long and short-run growth effects of infrastructure stock and quality (for each type of infrastructure) using a five step panel analysis.
    - Perform cross-section dependency tests

    - Perform cointegration tests
    - Estimate the long-run infrastructure growth elasticities
    - Estimate the short-run infrastructure growth elasticities
- Analyse the influence of carbon dioxide (CO2) emissions on the economic growth effects of both electricity stock and quality.
    - First, examine the growth effects of electricity stock and quality.
    - Second, investigate changes in the growth effects of electricity stock and quality when the electricity-related CO2 emissions (CO2EM) are accounted for.
- Investigate the nature and magnitudes of aggregate infrastructure (stock and quality) spillover effects.
    - First, examine spillover effects from foreign aggregate infrastructure (stock and quality) variables and compare with domestic aggregate infrastructure growth effects.
    - Second, investigate the growth impacts of "effective" infrastructure stock and quality. Effective combines the domestic and foreign aggregate infrastructures.
    - Perform panel Granger causality and Impulse response tests in both cases.

1.4 Research questions

The following research questions are based on the five key objectives above.

- Do aggregate infrastructure stock and quality stimulate economic growth?
- What is the direction of causality between infrastructure and economic growth?
- How do different infrastructure sectors impact economic growth in both short and long-run?
- To what extent are electricity-related CO2 emissions alter the nature and magnitudes of electricity (stock and quality) growth contributions?
- Do foreign aggregate infrastructure stock and quality developments produce vital spatial spillovers that impact domestic economic growth?

1.5 Significance of the study and research contributions

Infrastructure development is critical in the discussion of economic growth. Africa is among the developing regions that require substantial infrastructure investment given an acute shortage of both economic and social infrastructure. The International Finance Corporation

(IFC) mentioned the problem of infrastructure as critical in Africa, which has caused businesses to suffer due to lack of reliable energy, and millions of people are threatened each day by lack of clean water and sanitation (International Finance Corporation, 2015). It is mentioned in the 2010 African Development Bank report that in 2008 only 38 percent of Africans had access to electricity and the figure was even lower (26 percent) in the Sub Saharan Africa (SSA); in terms of SSA's road network, only 25 percent of 204km per 1000km^2 of land area was paved; 13 SSA countries had no functional rail networks; and access to fixed line telephones was below 3 percent. According the AfDB (2010), the African continent had 64 ports but associated with capacity and performance problems, and only 65 percent of Africans had access to clean water. Moreover, 48 SSA countries had a combined power generation capacity of 68 gigawatts, less than that of Spain, and as much as 25 percent of the installed capacity is not functional for numerous reasons (Eberhard, Rosnes, Shkaratan, & Vennemo, 2011).

In terms of funding, approximately US$93 billion financing is required to close Africa's infrastructure deficit (AfDB, 2010). Based on the World Bank 2013 report, the estimated cost of redressing the deficit of infrastructure in Africa stood at US$38 billion of annual investment and an additional US$37 billion in maintenance and operations (World Bank, 2013). This represents a huge problem in SSA given financial challenges encountered by most countries in this region. The above information shows why carrying this research is timely and impetus. If infrastructure is really important for growth purposes, then policy makers should have rich information regarding the gains from infrastructure stock and quality developments. The implications of both poor (and deteriorating) and shortage of infrastructures in SSA are also revealed in this study.

This research is also crucial as it seeks to narrow some crucial existing gaps in the empirical literature. Most importantly, several studies investigated the infrastructure growth nexus using the quantitative measures of infrastructures. Sadly, however, it is not only the volume of infrastructure that matters but the quality of the existing infrastructure too (see Calderon & Serven, 2004, Calderon & Serven 2009). By considering the quality attributes of infrastructure, this study seeks to determine the quality growth effects of the five infrastructure sectors under examination. Additional research gaps have been mentioned earlier, which are found under the other main themes: direction of infrastructure-growth causality; electricity consumption, CO2 emissions and growth; and spatial spillovers of infrastructure investment. In our attempt to narrow these research gaps, we make a number of contributions.

First, taking further from related literature (for instance, Calderon & Severn, 2004, Loayza & Odawara, 2010), our contribution involves not only considering the core infrastructures (telecommunication, roads, and electricity) but we also include water, airports and sanitation in our aggregate indices. Thus, this study adds to the limited knowledge regarding infrastructure-growth nexus from aggregated infrastructure stock and quality.

Second, inspired by Loayza and Odawara's (2010) indices that simultaneously capture the quantity and quality features of infrastructure, we use different approaches to construct the hybrid indices. This study uses a linear aggregator in chapter two and a product aggregator in chapter three. The implication drawn from the application of these two different aggregators is that they perform slightly different but suggesting the same conclusion that quality matters on the performance of the existing infrastructure stocks. Further discussions are given in chapters two and three.

Third, as discussed under section 1.2, disentangling the infrastructure-growth causation issue remains problematic in the literature. Consequently, this study stand out by examining the direction of causality using hybrid indices that accounts for both quantitative and qualitative effects of infrastructure, which is novel in this thesis to the best of our knowledge. The significance of this kind of causality analysis emanate from the view that it could be possible not finding evidence of causality when only the stock measures are utilised but once both stock and quality are jointly captured causality can be established. This is something proven in this study by failing to detect causality using aggregate stock and quality measures separately. Policy wise, evidence of unidirectional causality from infrastructure to growth or vice versa, or bidirectional causality have difference implications for expanding or cutting infrastructure investment. These implications are discussed in chapter two.

Fourth, aside from cointegration and causality between electricity, CO_2 emission, GDP per capita as commonly examined in the literature, this study contributes by scrutinising the signs and sizes of the impact of CO_2 emissions on the growth contributions of both electricity stock and quality. From a policy perspective, policy makers may consider the impact of emissions on electricity stock and quality when formulating and implementing carbon taxes. This is important for an appropriate carbon pricing that will minimise the effects of electricity-related CO_2 emissions yet without discouraging the energy output from the electricity sector. In this essay, we also provide a detailed analysis of the extent of electricity shortage and efficiency in the production and distribution of energy in SSA as compared to other regions and income groups. This additional analysis clearly reveals the extent of gap that SSA needs to cover in order to catch up with other regions in terms of electricity sector performance.

Fifth, despite a reasonable size of studies in the area of infrastructure spillovers, most studies investigated spillovers from the stocks of individual infrastructure sectors. Failure to consider both aggregate infrastructure stock and quality remains a vital gap in the literature. Though single infrastructure sector analysis enables us to know exactly the sectors that imply positive or negative spillovers, it is interesting also to understand how the general infrastructure system of a country may impact other regional areas. Consequently, it is imperative to examine the aggregate measures of infrastructure stocks and quality and see if they yield vital overall spillover effects.

In summary, our contributions in various chapters include: (i) while telecommunication, transportation and electricity infrastructures are commonly investigated, our aggregate indices account for water and sanitation as well, (ii) this study develops and applies hybrid indices that capture the joint effects of aggregate infrastructure stock and quality, (iii) our causality analysis accounts for the joint effects of infrastructure stock and quality, which to the our knowledge has not been done, (iv) investigating the long and short-run growth effects of five infrastructure sectors (electricity, transport, telecommunication, water and sanitation) in a five-step panel analysis is a novel in this study, (v) while some studies investigated the direct effect of CO2EM on economic growth, this study examines the nature and size of CO2EM's influence on the growth contribution of both electricity stock and quality, which is original in this study, (vi) the application of aggregate infrastructure indices to model spillovers across SSA states (vii) unlike most empirical literature, this study does not only consider the quantity of infrastructure but also the spillovers associated with aggregate infrastructure quality developments, which is unique.

1.6 Organisation of the study

The rest of the study is organised as follows: Chapter two provides an analysis of the nexus between aggregate infrastructure and economic growth, including the causality issue. Chapter three conducts a critical analysis of the growth effects of each infrastructure type (or sector). Thus, unlike the first chapter that focuses on aggregate infrastructure measures, this chapter investigates separately the growth effects from electricity, telecommunication, transportation, sanitation and water infrastructures. Chapter four provides a thorough analysis of the electricity sector in SSA in order to reveal the extent of electricity shortages and efficiency. Most importantly, this chapter shows how electricity-related CO2 emissions can hinder the economic growth contributions of electricity stock and quality. Chapter five discusses spillover effects from aggregate infrastructure. These spillovers have important policy implications, including introduction of cost-sharing structures and the creation of optimal infrastructure investments in the presence of spillovers. Chapter six concludes the research with key policy implications and recommendation provided.

CHAPTER TWO

THE NEXUS BETWEEN AGGREGATE INFRASTRUCTURE AND ECONOMIC GROWTH

2.1 Introduction

In a push for much public sector investment, the nexus between infrastructure and economic growth has been a central theme. Infrastructure enters the Gross Domestic Product (GDP) equation as a component of investment, which in turn is a determinant of long-run economic growth. Financing and maintenance of infrastructure as one of the productive sectors of a country is a crucial element of government expenditure (Farhadi, 2015). The theoretical aspect of infrastructure is found in the conventional growth theories, including Rostow (1956) who recognised the fundamental role of overhead capital (such as railways) in the take-off stage. A formal incorporation of infrastructure into the literature of growth was given by Arrow & Kurz (1970). In these classical exogenous growth models, infrastructure is treated as an input of production. The exogenous assumption threatens the application of these models as it often practically fails to hold. As a consequence, Barro (1990) examined the effect of public capital in the endogenous growth model framework. Public infrastructure can complement private investment instead of competing and such public investments facilitate opportunities for private sector and raise productivity as well as demand for private sector output while the shortage of basic infrastructure leads to poverty (Frone & Frone, 2014). Frone and Frone further argue that the unprecedented economic and financial crisis in recent times have reignite the Keynesian theories of government intervention and public works to ease or avoid recession. Also according to Estache (2007), the infrastructure-growth connection seems to be coming back to the research or policy agenda of economists, which is an indication of priority changes in developing states and donor agencies.

For several decades, scholars have empirically investigated the contribution of infrastructure to economic growth following key studies such as Aschauer (1989) and Munnell (1990) who emphasised the critical role of infrastructure in economic development. However, not only Munnell (1992) has doubted the earlier theories' positive growth effect from infrastructure but others (for instance, Gramlich, 1994; Sturm, 1998) have reservations as well. In addition, Holtz-Eakin and Ellen Schwartz, 1994; Ozturk and Acaravci, 2011; Meng and Han, 2016; Canning and Pedroni, 2008 are among those who do not find support of the positive relationship between infrastructure and growth, with the later estimating negative growth effects from transport infrastructure in Africa. Examining the different infrastructure funding tools in six African economies, Estache, Perrault, & Savard (2012) showed that foreign aid can produce Dutch disease impacts and the negative effects depend on the kind of infrastructure in question. Nevertheless, some studies supported the vital role of infrastructure in economic development (for example, Esfahani & Ramirez, 2003; Canning & Pedroni, 2004; Fedderke & Garlick, 2008; Bronzini & Piselli, 2009; Loayza & Odawara, 2010; Kumari & Sharma, 2017). Others found evidence for causality (for example, Wolde-Rufael, 2006; Kumo, 2012; Badalyan, Herzfeld, & Rajcaniova, 2014; Lyke, 2015). Most of these studies are discussed in the next section whereas few of these are discussed in detail in essay two for individual infrastructure categories.

Despite a number of studies in the area of infrastructure-growth nexus, some empirical gaps exist in the literature. First, several studies investigated the impact between individual infrastructure sectors (mostly electricity, telecommunication and roads) and economic growth. Evidence based on aggregated infrastructure measures remains thin. Second, failure to account for infrastructure quality is the most serious problem as also stated by Fedderke and Garlick (2008). According to Fourie (2007), both researchers and policy makers still tend to focus on 'more' infrastructure than 'better' infrastructure. Third, disentangling the direction of causality (or association) between infrastructure and growth is still lacking in the empirics. It has not been clear whether the direction of association is one way or bidirectional, if exists at all. Some authors (see Eberts & Fogarty, 1987; Perkins et al., 2005) found evidence of a bidirectional causality. In contrast, Munnell (1992) found the direction of causation not running from public capital to output but the other way round. Kularatne's (2006) estimations revealed feedback effects between physical infrastructure and output per capita, as well as between physical infrastructure and private investment expenditure. The actual effect of infrastructure on growth and the causality issue thus become the central empirical challenges (Schiffbauer, 2007 & 2008; Esfahani & Ramirez, 2003).

Having identified the key empirical gaps, this study has two major objectives. Firstly, we analyse the relationship between infrastructure and growth using both aggregate indices of infrastructure stock and quality. Secondly, the causality between infrastructure and growth is examined. Infrastructure stock and quality data for 42 countries in SSA over a period 2000-2014 is obtained from various sources (see Appendix 1, Table A.3). SSA is chosen given wider infrastructure gaps in this region as indicated under the introduction section. Our actual contributions in these objectives are specified in the next paragraph.

Taking further from the related studies that accounted for both infrastructure stock and quality (for example, Calderon & Serven, 2004 & 2010; Calderon, 2009), the contributions of this essay include: (i) our aggregate indices account for transportation (roads and airports), telecommunication (landlines and mobile), electricity, water and sanitation infrastructure categories. The synthetic indices in those earlier studies combined information on power, roads and telecommunication (core infrastructures). This study contributes by including water, airports and sanitation infrastructures in the aggregate measures. (ii) We construct and apply 'hybrid' indices that simultaneously capture the stock and quality effects of infrastructure. We are unaware of studies that employed a linear aggregator to combine the selected aggregate infrastructure stock and quality measures, which are based on the several infrastructure sectors applied in this essay. More precisely, we added together the scores of the selected principal components (PCs) (the PCs become the aggregate indices) and divide by the number of PCs. (iii) Causality between infrastructure and growth is examined. Uniquely in this study, the direction of causation question is addressed using a 'hybrid' index. To the best of our knowledge, the use of an index that accounts for both aggregate infrastructure stock and quality when addressing causality has not been done. Principal Component Analysis (PCA) is used to aggregate the infrastructure variables. This essay employs the Generalized Method of Moments (GMM) to model the infrastructure-growth nexus. Finally, the Dumitrescu-Hurlin approach is our panel causality test adopted in this study.

The remainder of the essay is organised as follows: Section 2 provides a brief review of the previous empirical findings. Section 3 outlines the methodology. In addition, this section discusses the data used in this essay and the various data sources. Section 4 discusses the results of the essay, including the implications of the findings. Section 5 concludes the essay.

2.2 Brief literature survey

A detailed theoretical discussion of the evolution of infrastructure into growth literature is provided in the previous chapter. Consequently, this section presence a brief survey of the nexus between infrastructure and economic growth from an empirical perspective. Different models have attempted to model the impact of pubic capital on economic growth. Among the key models, Arrow and Kurz (1970) formally offer an analysis of the impact of public capital on output in which public capital is treated as an input. Unlike this model where economic growth is assumed exogenously determined, Barro (1990) provided the endogenous growth model version. Since the most influential work of Aschauer (1989), several studies have examined the growth contributions of various infrastructure sectors. Aschauer revealed the central role of infrastructure investment for the US economy in the 1970s. However, as discussed in the first chapter, his findings were criticised by Gramlich (1994) who doubted the significance of other types of infrastructures.

Munnell (1992) is among those who challenged the time series estimates of Aschauer (1989) including her own reestimates in Munnell (1990), arguing that the implied effect of public capital stock on the output of private sector emanating from aggregate time series literature is too huge to believe. Her reasoning is that it is not logical for public capital to have a greater impact on private sector output than investment from private sector given considerable public investments that move towards environment and other goals, which are not captured by national output indicators. Some of the critics raised in the literature include common trends in infrastructure and output which may affect results, direction of causality between public infrastructure and output, and the use of aggregate time series instead of first differences (see Tatom, 1991; Jorgenson, 1991), which according to Munnell (1992) they misread the evidence since the effects of public capital on productivity and private sector output have been positive in almost all scenarios.

Despite some reservations, a number of empirical studies found support for a positive infrastructure-growth nexus. Esfahani and Ramirez’s (2003) analysis of infrastructure and growth considers a structural model that accounts for economic and institutional factors that mediate the infrastructure-growth relationship. Their results indicate substantial contribution of infrastructure services to growth, which goes beyond the cost of provision. Another outstanding observation in their paper is the central role of institutional capabilities in the developmental process via infrastructure growth; implying superior growth effects require organisational and institutional reforms than just designing of infrastructure projects. Examining the connection between wastewater sewerage network (share of population connected) and economic growth, Frone and Frone (2014) found a positive association between the two in Romania.

Recently, Kumari and Sharma (2017) found a strong connection between infrastructure (physical and social) and economic growth in India. Czernich, Falck, Kretschmer, and Woessmann (2011) investigated the impact of broadband infrastructure on growth in the OECD economies. Their instrumental variable approach showed an increase in economic growth in the range between 0.9 and 1.5 percentage point from a 10 percentage point broadband penetration. Furthermore, Pradhan, Arvin, & Norman (2015) found evidence of cointegration between information and computer technologies (ICT) infrastructure, financial development and economic growth in Asian economies, with both short-run and long-run causal relationships between ICT infrastructure and growth. In terms of long-run dynamics, Canning and Pedroni (2004) scrutinises the long-run impacts of infrastructure provision using data for a panel of countries over the years 1950-1992 and their findings provide support that infrastructure promotes long-run growth in the majority of cases. Most importantly, however, they found substantial variations in the results across individual economies. This shows the importance of heterogeneity among countries. Moreover, evidence of a long-run relationship between transport infrastructure and economic growth was documented by Maparu and Mazumder (2017) whose study detects a unidirectional causality running from economic growth to transport infrastructure.

Also on the issue of causality, Badalyan et al. (2014) examined the direction of causality and relationship between transport infrastructure and economic growth using a sample of three countries (Turkey, Georgia and Armenia). Their results show evidence of cointegration and transport investment to have a significant positive impact on growth in the short-run. Additionally, they reported evidence of a bidirectional causality between infrastructure investment and economic growth. Based on South Africa, Granger causality between economic growth, economic infrastructure and employment was also investigated by Kumo (2012) who found a robust bidirectional causality between infrastructure and economic growth. Another striking result of their study was a bidirectional causality between infrastructure and public sector employment, which further shows the importance of infrastructure in the area of employment creation.

Another way of scrutinizing the importance of infrastructure is to identify the channels through which infrastructure influences growth. Fedderke and Garlick (2008) identified five channels: as a complement to other production factors; a factor of production; a tool of industrial policy; a stimulus to factor accumulation and a stimulus to aggregate demand. In this regard, Bronzini and Piselli (2009) also demonstrated the indirect impact of infrastructure through total factor productivity (TFP). They found that a 1% increase in public capital raises productivity by roughly 0.11%. More so, Palei (2015) demonstrated that infrastructure is among the factors that determine national competitiveness. In addition, infrastructure factor itself was found to be driven by railroad, quality of roads, air transport and electricity supply.

Closely related to our essay, the previous studies (for instance, Loayza & Odawara, 2010; Calderon & Serven, 2010) that accounted for both infrastructure stock and quality found both positive effects of infrastructure on growth in Africa. However, the results of Calderon and Serven (2010) suggested that the deterioration of infrastructure quality in SSA lowered growth rate in the region by 0.5 per year. Focusing of the Egyptian economy, Loayza and Odawara (2010) demonstrated that a rise in infrastructure expenditure between 5% and 6% of GDP would increase the annual growth rate per capita by roughly 0.5% points in a decade's time and 1% by the 3rd decade.

While the positive impact of infrastructure on economic growth has been established in several studies, it is doubtful in other studies. Holtz-Eakin and Ellen Schwartz (1994) explicitly incorporated infrastructure in a neoclassical growth model. Their findings suggested that increasing the rate of infrastructure investment would have a negligible effect on growth. In the case of 18 OECD economies, Farhadi's (2015) results suggested that infrastructure stocks can positively but not substantially influence both total factor productivity and labour productivity.

To summarise the findings from the work that has been done so far, Holmgren and Merkel (2017) presented a meta-analysis of 776 estimates of the infrastructure growth elasticities. Their results indicated variation in the elasticity of output with respect to infrastructure from 0.06 to 0.52. Based on their analysis, the elasticities tend to vary depending on the infrastructure types. Additionally, the impacts showing high precision were clustered around zero. Elburz, Nijkamp, and Pels (2017) also performed a meta-analysis consisting of 912 observations from 42 studies conducted over the period 1995-2014. The purpose of this meta-analysis was to determine the sources of differences in the empirical outcomes. They found study characteristics to have an impact on the sign and size of the variables in question. Type of infrastructure, time frame methodology, geographical scale and proxies for type of infrastructure were found to have an effect on the results of the primary studies.

From the foregoing, it can be deduced that infrastructure is one of the key drivers of economic growth. However, some studies doubted the robustness of the positive infrastructure-growth estimates. Therefore, the debate persists. Most of the studies examined the relationship between individual infrastructure sectors (especially transport and electricity) and economic growth.[2] In addition, there are discrepancies with regard to the direction of infrastructure-growth causality. Another outstanding observation from the extant literature is that only few scholars have uniquely accounted for infrastructure quality developments and their impact on GDP per capita. Consequently, the existing research gaps include: failure to account for infrastructure quality, limited knowledge of the infrastructure-growth nexus from aggregated infrastructure measures, and failure to address the direction of causation question based on infrastructure measures that capture both the quantitative and qualitative attributes of infrastructure. Regarding the application of aggregate infrastructures, we do not necessarily argue that aggregate measures are superior to individual infrastructures. However, it is our belief that most public infrastructures may complement each other and hence each plays a significant role. Despite the importance of the infrastructures to each other, it is possible that an analysis of a certain individual infrastructure type may suggest little or no significant growth effect. It therefore seems as if such an infrastructure type is not that relevant yet it could be vital to the performance of the entire infrastructure system. For instance, econometrically, roads may imply negative growth effects depending on their productive utilisation (among other factors) that may fail to cover construction costs. But such roads could produce important network dynamics that complement the economic use of other infrastructure sectors in an entire agglomerated area. This essay aims to narrow these gaps and hence our contributions to the body of literature.

2.3 Methodology and Data

2.3.1 Data

Infrastructure stock and quality data for 42 countries in SSA is gathered for the period 2000-2014. The list of countries in the sample is shown in the Appendix 1, Table A.3. Following related studies in the field of study (such as Calderon, 2009; Calderon and Serven, 2004 & 2010), growth in per capital GDP is used as a proxy for economic growth. Although this study is limited to this definition of economic growth, one may also apply inclusive growth measures. Inclusive growth is one that creates opportunities for all population segments and distribute the gains of increased prosperity fairly across society (OECD, 2017).

This essay considers electricity, telecommunication (fixed telephones plus mobile phones), roadways, airports, water and sanitation infrastructures. The infrastructure stocks are

[2] Most of these studies that looked at transport and electricity infrastructure sectors are discussed in the second essay that specialises on the growth effects from various infrastructure sectors.

standardized across all the countries. The total length of roads (number of airports) in a country is divided by the land area of the country to arrive at *kilometres (km) per square km of land area* (*number of airports per sq.km*). The rest of the infrastructure categories are standardized to take into account the size of population as follows: (i) electricity generation capacity - *thousands of kWh per 1000 persons*, (ii) telecommunication - *fixed telephone plus mobile phone subscriptions per 100 persons,* and (iii) water (*percentage of population with access to water for agriculture*). Finding a better proxy for water stock is a challenge and hence we consider agricultural water for the rural people since agriculture is one of the key sectors in Africa. This is the closer proxy found for water stock while unable to find any better proxy for sanitation stock.

The quality measures are as follows: (i) ratio of electricity transmission and distribution losses (RETDL), (ii) ratio of paved roads, (iii) ratio of airports with paved runways,[3] (iv) relative percentage change in persons with access to improved drinking water (v) relative percentage change in persons with access to improved drinking sanitation, and (vi) telecommunication (information technology (IT) infrastructure used as a proxy - *scores*). This measure assesses the risk that the information technology infrastructure will prove inadequate to business needs (Mo Ibrahim, 2016). Since information technology play a key role in the quality of telecommunication services (especially in mobile), the quality of IT infrastructure may be used as a plausible proxy. It is important to clarify that quality in this study shows how good or bad each infrastructure type (or aggregate infrastructure) is or the degree of excellence of the infrastructure.[4]

The control variables include trade openness, financial depth, human development, institutional quality, inflation and terms of trade. The institutional quality variable combines political stability and absence of violence, governance, personal safety, and freedom measures based on principal component analysis (PCA). Data description and the various sources of the data are shown in Table A.3. Firstly, this essay presents the econometric

[3] Based on the CIA Factbooks, airports with paved runways is the total number of airports with paved runways (concrete or asphalt surfaces). For airports with more than one runway, they consider only the longest runway. Airports with unpaved runways refers to the total number of airports with unpaved runways (dirt, grass, sand, or gravel surfaces). Only airports with usable runways are considered in the listing.

[4] It is a practical challenge to precisely assess the quality of the various infrastructure services. For instance, while the ratio of paved roads can be used as quality proxy for road infrastructure, the question remains whether there would be a precise accountability of the potholes on the paved roads themselves. Thus, the issue of quality is limited to the definitions of the indicators used in this study.

models to estimate. The natural logarithms of the variables are considered throughout the study.[5]

2.3.2 Econometric model

Theoretically, we assume a basic production function in which output is function of public infrastructure (g) and a set of standard growth determinants (z), which takes the following form

$$y_{it} = f(g_{it}, z_{it}) \tag{2.1}$$

where y_{it} is the output of any country i at time t. Capital and labour are traditionally the key determinants of output from a Cobb Douglas production function position. However, several augmentations of the original Cobb Douglas function were considered in literature. We do not make restrictions about returns to scale following the new growth theories (for instance, endogenous). The endogenous growth theory was developed to go beyond the neoclassical theory by relaxing the diminishing returns assumption or by describing technical change due to specific actions (Stiroh, 2001). In view of equation (2.1), this study estimates the growth equation on panel data of the form[6]

$$y_{it} = \alpha_t + \phi_i + \psi' y_{i,t-1} + \eta' g_{it} + \theta' z_{it} + \varepsilon_{it} \tag{2.2}$$

where $y_{i,t-1}$ is the lagged GDP per capita, α_t is the unobserved common factor, ϕ_i is the unobserved country-specific effect parameter, and ε_{it} is the disturbance. Our focus variables (indices of aggregate infrastructure stock, quality and the hybrid) are denotes by g_{it} whereas z_{it} is set of control variables that include, human capital, terms of trade, institutional quality, financial depth, trade openness and inflation.[7] These control variables are commonly recognised in the literature.

Given equation (2.2), the main problem that often plague empirical estimations is identification. In regression analysis identification problem arises when it is not possible to identify the best estimate of one or more parameters ($\alpha_t, \phi_i, \psi, \eta, \theta$). The question is whether

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[5] Among other factors, it is sensible to apply logarithms which make interpretation more convenient, reduce skewness, and the coefficients can be thought as elasticities of an output function.

[6] The argumentation involves the realisation of other key factors and alterations of the returns to scale assumptions.

[7] Section 2.3 discusses how the aggregate indices of infrastructure stock and quality are constructed.

the moment conditions contain sufficient information for the success of estimations (Zsohar, 2010). Identification demands that there is enough variation in the moment conditions to uniquely identify the parameters. When there are few moment restrictions in the estimation of equation (2.2) than there are parameters, then the parameters are under-identified. On the other hand, over-identification happens when there more moment restrictions than the parameters. When the moment conditions equals the parameters of interest, the parameters are said to be exact identified. We briefly highlight some of the threats to identification. In the case of under-identification, no consistent parameters can be estimated (see Nielsen, 2005).[8] When having an over-identified situation we cannot identify unique values for the vectors of parameters and hence a potential threat to our estimations.[9] In general, the imposition of moment restrictions should not be done arbitrarily for that cannot yield consistent parameters and undermines the estimations. Econometrically, it is imperative to make reasonable identification prepositions. In this study, we implement the GMM that overcomes the threats to identification and allows for consistency.

First, the method of moment estimators may not produce good estimates when the estimators of a single parameter are more than one. In this case, one moment restriction could be satisfied but not the other.[10] The GMM approach overcomes this identification related problem since the GMM estimators are designed to closely meeting all the moment restrictions instead of meeting one of them through the use of appropriate weights. In other words, the rationale of the GMM is that when it is not possible to obtain a solution for the system of equations provided by sample moment restrictions, we compute for θ that draws the sample moments as close to zero as possible (see Zsohar, 2010).[11] The authors also highlighted that, through the application of optimal weighting matrix, the GMM approach such as the two-step is consistent and efficient. Second, as we demonstrated (see footnote 8)

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[8] For instance, assuming a regression with an intercept and x random variable. In this scenario, if $E(x_i\varepsilon_i) \neq 0$ then one remains with only one moment condition ($E(\varepsilon_i)$) but with two parameters (α, β). Though one can pick any value for $\tilde{\alpha}$ and calculate the value for $\tilde{\beta}$ or choose any value for $\tilde{\beta}$ and compute the $\tilde{\alpha}$, such arbitrary parameter estimates fail to satisfy the consistency property and hence a threat.

[9] It becomes problematic to pick among numerous method of moments estimators in over-identifying case.

[10] For example, suppose two method of moment estimators (g_{T1}, g_{T2}) of one parameter ($\tilde{\beta}_i$) with $E(x_i\varepsilon_i) = 0$ and $E(\varepsilon_i) = 0$ held as restrictions, it is often difficult to meet both moment restrictions. It's often that when a particular estimator (e.g. g_{T1}) is used, $E(\varepsilon_i) = 0$ can be satisfied but not $E(x_i\varepsilon_i) = 0$ while the other estimator (g_{T2}) satisfies $E(x_i\varepsilon_i) = 0$ but violates $E(\varepsilon_i) = 0$.

[11] In the case of over-identifying restrictions, the number of estimators converge to the same outcome, in probability, and hence ensuring consistent parameters.

that the correlation between the covariates and error terms can threaten identification and consistency, the GMM mitigate this challenge by employing instrumental variables (IV), which also depend on covariance restrictions and exclusion to produce consistent parameters.[12] Third, the GMM offers basis for empirically testing the over-identifying constraints that helps to see if the data and estimated model are in support.

2.3.3 Principal Component Analysis

2.3.3.1 Rationale

We found PCA to be the most appropriate method for its intended use (i.e. constructing aggregate indices) in this study. It is a commonly used multivariate approach that allows for data reduction with only the most relevant information retained (Davo et al., 2016; Karamizadeh, Abdullah, Manaf, Zamani, & Hooman, (2013). Thus, PCA extracts crucial information from a dataset and express it as a set of new orthogonal variables (Rancher, 2002). Moreover, PCA can reveal latent structures in data (Markaki, Chadjipandelis, & Tomaras, 2014). Wording differently, it reveals patterns in data and make it simple to analyse (see Unglert, Radic, & Jellinek, 2016). Rancher (2002) specified two situations where PCA is useful: (i) if a number of covariates are highly correlated, and (ii) if the number of covariates is huge relative to the number of observations. In addition, one can apply PCA to any distribution of variable y. Finally but not least, PCA lowers the noise in data by selecting the maximum variation and hence automatically neglecting the small variations in the background (Karamizadeh et al., 2013). In general, according to Abdi and Williams (2010), “PCA is very versatile, it is the oldest and remains the most popular technique in multivariate analysis.” Despite these benefits of PCA, we are also aware of its potential problems. If not carefully organised, PCA could generate results that have no economic implications since the technique is pure mathematically based (Zhang, Shi, & Sheng, 2015). These authors applied an extended version of PCA called the dynamic PCA when they examined energy market integration (EMI), arguing that too much information in EMI may not originate only from various dimensions but also from the trans-temporal change of every dimension. Nevertheless, it is our belief that PCA can adequately achieve our objective.

[12] GMM which requires no strong assumptions about the underlying model, it needs only identifying relevant instruments (Hansen and West, 2004).

2.3.3.2 PCA framework

The origin of this technique can be traced back to Pearson (1901) but attracted several re-inventions like Hotelling (1933) with the notion of linear combination of variables initiated and variation of components emphasised (Bro and Smilde, 2014). The goals of PCA include simplification of data, data reduction, modelling, outliers detection, variable selection, classification, and prediction (Wold, Esbensen, & Geladi, 1987; Abdi & Williams, 2010). PCA's key assumptions are (i) mean and variance are adequate (ii) linearity-i.e. linear combination of variables and (iii) important dynamics come from large variances.

Technically, PCA analyses a data matrix X comprising of I rows (typically observations) and K columns (typically variables), thus an $i \times k$ matrix with its generic element $x_{i,k}$. In particular, $x_{i,k}$ denotes an individual observation i in the k - dimensional space. The data matrix requires pre-processing before PCA has been performed. The columns of the matrix X are centred such that the mean of each column is equal to 0. Furthermore, it is a general procedure to standardize each variable to unit norm when dealing with variables measured in different units. Bro and Smilde (2014) state that if rescaling is not done, PCA will concentrate on those variables with large numbers, thus a pre-processing tool (called *autoscaling*) exists which makes the columns being of equal 'size' with similar chance of being modelled. We consider the pre-processing aspect.

This study analyses the infrastructure dataset (matrix X) with I rows and K columns (5 infrastructure types per each country). PCA is utilised to aggregate the different infrastructure stock measures {i.e. electricity (S_E), roads (S_R), air (S_A), telecommunication (S_T), and water (S_W)} and the quality measures for the same variables but now with sanitation (i.e. Q_E, Q_R, Q_A, Q_T, Q_W, Q_S). The goal of PCA in this study is to identify the principal components that provide greater explanation of the infrastructure dataset. Identifying for instance, the first principal component Z_1 which is a linear combination of X original variables (i.e. standardized infrastructures):

$$Z_1 = u_1 X_1 + u_2 X_2 + ... + u_j X_j , \qquad (2.3)$$

such that the maximum variance is attained for possible weighting selection. Equation (2.3) is defined by a vector of weights $u = (u_1, u_{2,...,} u_j)$ where the weights are normalized by making the sum of squared values equal to 1 (see Wold et al., 1987; Calderon, 2009). The new variable Z_1 provides a good description of the underlying structure of X variables if the variance is large. The trick is to find the optimal weights $(u_1, u_{2,...,}u_j)$ that maximize the variance

$$\arg\max_{w=1} \text{var}(Z), \qquad (2.4)$$

hence Z becomes an appreciable aggregate index. This is a linear algebra phenomenon that can be tackled by performing a singular value decomposition (SVD). Without mining deeper into SVD, the optimal u is the standardised first eigenvalues of the covariance matrix $X^T X/(n-1)$ or corresponding to cross-product matrix $X^T X$ (Wold et al., 1987). SVD is associated with eigenvectors and eigenvalues, which are necessary for analysing the structure of a matrix.[13] Therefore, applying the PCA as discussed, we build the aggregate indices of infrastructure stock (AIS) and infrastructure quality (AIQ).

2.3.3.3 Selecting principal components

This section is key for our PCA since our objective is to obtain new variables that combine information of various infrastructure sectors. The new variables are the principal components (PCs). The PCs are ordered such that the first principal component (PC1) provides the greatest explanation of the dataset, followed by PC2 and so on. Determining the number of principal components to retain is one of the central aspects in PCA. This study employs two of the criteria that can be used to decide on the number of components to retain: (i) consider the components whose eigenvalues are larger than the average of the eigenvalues; when applying the correlation matrix this boils down to eigenvalues greater than unit (Rencher, 2002), (ii) apply a scree plot that allows a break between the bigger eigenvalues and the smaller eigenvalues. Our key criterion is the first one which is commonly applied in most literature. Furthermore, it shows a huge gap between the eigenvalues that lies on both sides of the average. Interestingly, the two guidelines often lead to the same conclusion. As alternative, one might consider the components that account for a particular percentage of variance or test the significance of the initial components (those with bigger eigenvalues). According to Rencher (2002), when a particular variance is chosen, one may consider components that are variable specific or sample specific and hence a problem.

[13] An eigenvalue (γ) describes the association between original variables and the components. An eigenvector of a matrix X can be defined as a vector μ that satisfies equation $X\mu = \gamma\mu$, where γ is a scalar termed eigenvalue (Abdi, 2010).

We are also aware of the reservations associated with the chosen guidelines. The scree plot/or elbow test is subjective while the first guideline (eigenvalues > average) may potentially neglect some essential information (Abdi & Williams, 2010). In this study, the chosen guidelines confirm each other and the selected aggregate infrastructure indices are used in infrastructure-growth analysis based on the GMM technique. The GMM is described in the next sub-section.

2.3.4 Generalized Method of Moments

2.3.4.1 Rationale

The GMM technique is adopted in this analysis for a number of reasons. Unlike the static models, GMM is best suited for dynamic panel data. Most importantly, with GMM one cannot only account for country-specific and unobserved time effects but also for endogeneity of independent variables (Calderon, 2009; Loayza & Odawara, 2010). Among other benefits, unlike the maximum likelihood (ML), econometricians do not need to make strong distributional assumptions (Jogannathan, Skoulakis, & Wang, 2002; Arellano & Bond, 1991; Arellano & Bover, 1995; Hansen & West, 2002). Thus, the interested variables can be conditionally heteroscedasticity and serially correlated (see also Hansen, 1982). Moreover, it can be found that GMM estimators are quite efficient than other popular estimators like the two stage least squares and Ordinary Least Squares (OLS) when auxiliary assumptions such as homoscedasticity fail to hold (Woodridge, 2001). GMM in time series econometrics is among the most crucial advancement in the last 35 years but surprisingly its application is sparse. In view of the above, GMM is our estimation technique.

2.3.4.2 GMM framework

Assume a regression model $y_i = \beta x_i + \varepsilon_i$. Generally the first two moments are $E(y)$ and $Var(y) = E[(y-\mu)^2]$. OLS works under the assumptions that the disturbance has a zero mean ($E(\varepsilon)=0$) and it is not correlated with each explanatory variable ($E(x_i,\varepsilon_i)=0$). In nonlinear dynamic models, this is unlikely but rather often characterized by heteroscedasticity and correlation between the covariates and the disturbance ($E(x_i,\varepsilon_i)\neq 0$). In such scenario, OLS will not be appropriate but other alternatives exist that include GMM. The application of GMM in the presence of heteroscedasticity was discovered by Cragg (1983), which requires the extraction of additional moment conditions (Wooldridge, 2001). The GMM technique brings up the use of instrumental variables. For instance, z is an instrumental variable of covariate x if it is correlated with x but uncorrelated with the disturbance. Thus, we have $E(x_i, \varepsilon_i) \neq 0$ but $E(z_i, \varepsilon_i) = 0$. Assume X is $n \times k$ matrix of explanatory variables and Z is $n \times l$ matrix of instruments, the moment conditions are: $E(Z', \varepsilon) = 0$ where Z' is a matrix of instruments. The GMM estimator chooses parameter estimates such that the correlation between the error terms and the instruments are as close to 0 as possible by using an appropriate weighting matrix (Eviews, 2015). In particular, it identifies the parameter of interest (θ) that minimizes:

$$\min[(Z'\varepsilon)'C(Z'\varepsilon)] \qquad (2.5)$$

where C is the weighting matrix that weights every moment condition. An optimal weight is often depicted as $C = \hat{\Omega}^{-1}$, where Ω is the long-run covariance matrix of the moments. Since $\varepsilon = Y - \beta X$, substitute in equation (2.5) we have: $\min[(Z'(Y - \beta X)'C(Z'(Y - \beta X)]$. The optimal θ can be written as:

$$\hat{\theta} = (X'ZCZ'X)^{-1} X'ZCZ'Y \qquad (2.6)$$

Note that the GMM is a step from the method of moments (MM), famously introduced in the field of econometrics by Hansen (1982) as a remedy to a situation where there are many moment conditions as there are parameters (Zsohar, 2010). When the moment conditions are equal to parameters then GMM=MM. Therefore, GMM is adequate to deal with both a situation where the number of moment conditions equals the number of unknown parameters (just-identified) and where the moment conditions exceed number of parameters (over-identified) (Imbens, 2002).

2.3.4.3 Our application of GMM in panel data

Panel data are well suited for the investigation of dynamic effects (Greene, 2003). Our estimation is based on the following dynamic (first order) model:

$$y_{it} = \psi y_{i,t-1} + \beta_i' x_{it} + \phi_i + \alpha_t + \varepsilon_{it} \qquad (2.7)$$

where y_{it} is the dependent variable, x_{it} is a vector of explanatory variables, $y_{i,t-1}$ is the lagged dependent variable, α_t is the unobserved common factor, ϕ_i is the unobserved country-specific effect parameter, and ε_{it} is the disturbance. The involvement of $y_{i,t-1}$ in the dynamic model allows for additional information in the system. However, in both fixed and random effects frameworks, the challenge is that the lagged dependent variable and the disturbance are often correlated and this is more vivid in the random effects model (Greene, 2003). As a result, this study deals with the problem of correlation or endogenous in the data by adopting a GMM approach developed by Arellano and Bond (1991) and Arellano and Bover (1995) that relies on instrumental variables. Thus, the following dynamic model is estimated:

$$\ln \Delta y_{it} = \psi \ln y_{i,t-1} + \theta_i' g_{it} + \lambda_i' z_{it} + \phi_i + \alpha_t + \varepsilon_{it} \tag{2.8}$$

Equivalently,

$$\ln \Delta y_{it} = \psi \ln y_{i,t-1} + \beta_i' x_{it} + \phi_i + \alpha_t + \varepsilon_{it} \tag{2.9}$$

where y_{it} is GDP per capita, g_{it} is a vector of infrastructure variables, z_{it} is a set of control variables (including, human capital, terms of trade, institutional quality, financial depth, trade openness and inflation), x_{it} is a set made up of g_{it} and z_{it} explanatory variables (in logarithm), β_i' is a vector of parameters (includes both θ_i' and λ_i'), and $\ln \Delta y_{it} = \ln y_{it} - \ln y_{i,t-1}$. In order to control for endogeneity of the explanatory variables, Arellano and Bond (1991) suggested the use of appropriate lags of the explanatory variables as valid instruments. Endogeneity of the lagged dependent variable might be caused by the presence of heterogeneity (country-specific effects) (see Hansen & West, 2002). In the spirit of Arellano and Bond (1991), heterogeneity can be eradicated by taking first differences as follows:

$$\ln \Delta y_{it} = (1+\psi)\Delta y_{i,t-1} + \beta_i' \Delta x_{it} + \Delta \varepsilon_{it} \tag{2.10}$$

$$\Delta y_{i,t-1} = y_{i,t-1} - y_{i,t-2}\, ; \Delta x_{it} = x_{it} - x_{i,t-1}\, ; \Delta \varepsilon_{it} = \varepsilon_{it} - \varepsilon_{i,t-1}$$

Equation (2.10) may show evidence for correlation between the lagged dependent variable and the disturbance. Given our longer time series horizon, further lagged dependent differences of real GDP per capita ($y_{i,t-2} - y_{i,t-3}, \ldots$) and/or lagged levels ($y_{i,t-2}, y_{i,t-3}, \ldots$) are used as valid instrumental variables. According to Arellano and Bond (1991), the covariates matrix may contain a combination of both predetermined (*lags* or *internal instruments*) and strictly exogenous variables. Similar studies (see Calderon & Serven, 2004; Calderon, 2009) considered current and lagged demographic indicators (urban population, population density, labour force) as external instruments. This study relies on internal instruments.

Following Arellano and Bond (1991) we implement *difference*-GMM to examine the infrastructure-growth nexus. By selecting suitable lagged values of x_{it} and y_{it} as valid instruments and assuming no correlation between them and the time-varying disturbance, we outline a set of moment conditions for the *difference*-GMM as follows:

$$E\left[\begin{pmatrix} x_{i,t-1} \\ \downarrow \\ x_{i,t-p} \\ y_{i,t-1} \\ \downarrow \\ y_{i,t-p} \end{pmatrix} \left(\varepsilon_{it} - \varepsilon_{i,t-1}\right)\right] = 0 \;\; ; \; t \geq 3; p \geq 2; \qquad (2.11)$$

N/B: This is a condition for all valid instruments in the differenced equation for period p

Given the moment conditions specified in equation (2.11), the GMM optimal estimator ($\hat{\delta}$) of the parameter vector of interest (β, α) (based on Arellano & Bond, 1991) is:

$$\hat{\delta} = (\tilde{X}'Z\Omega^{-1}Z'\tilde{X})^{-1}\tilde{X}Z\hat{\Omega}^{-1}Z\tilde{y} \qquad (2.12)$$

$$AVAR(\hat{\delta}) = (\tilde{X}'Z\Omega^{-1}Z'\tilde{X})^{-1} \qquad (2.13)$$

where $\tilde{X}$ is a stacked $n \times k$ matrix of regressors including the lagged dependent variable $y_{i,t-1}$, Z is the $n \times l$ matrix of instrumental variables arose from the moment conditions, ($l > k$ i.e. over-identified), $\tilde{y}$ is the dependent variable stacked in both differences and levels, $\hat{\Omega}^{-1}$ is an estimate of the long-run covariance of the moment conditions.[14] It can be demonstrated that an essential (but not sufficient) condition for obtaining efficient estimate of $\hat{\delta}$ is to set a weighting matrix equal to the inverse of the covariance matrix ($\hat{\Omega}^{-1}$) of the

[14] The challenge of the GMM is to obtain an optimal weighting matrix $\hat{\Omega}^{-1}$. It can be shown that $\hat{\Omega}^{-1} = \left(N^{-1} \sum_i Z_i'\hat{v}_i v_i' Z_i \right)^{-1}$ where the v_s are the residuals. For a two-step estimator you replace Z and v with Z^+ and v^+, respectively (see Arellano and Bond, 1991).

sample moment conditions (Eviews, 2015). At times the lagged levels of the independent variables cannot be strong instruments when the variables are persistent over a period of time (Blundell & Bond, 1998). Therefore, one can apply a *system*-GMM which allows for a combination of regressions in differences and in levels (Arellano & Bover, 1995; Blundell & Bond, 1998; Calderon, 2009). The next chapter discusses briefly the additional moment conditions of the system- GMM. In this essay, our instruments based on the *difference*-GMM are sufficient to reveal the infrastructure-growth relationship. It is imperative to carry out specification tests. The essay employ the Sargan test (based on J-statistic) for over-identifying restrictions, thus examining the validity of the instruments. In addition, the m-statistic test for second-order serial correlation in the first difference residuals is used.

2.3.5 Dumitrescu-Hurlin Non-Causality test

2.3.5.1 Rationale

We chose this modern technique due to its suitability in heterogeneous panels. Dumitrescu and Hurlin (2012) demonstrated a number of benefits associated with this test, including: (i) controlling for both the heterogeneity of the regression model and heterogeneity of causal relationships, (ii) a test that is based on average individual Wald statistics of Granger non-causality converge sequentially to a standard normal distribution, and (iii) even in the existence of cross-sectional dependence, the standard panel statistics show good small sample properties using Monte Carlo simulation.

2.3.5.2 Dumitrescu-Hurling (D-H) ideology

This test realises the major concern associated with panel data, that is, the specification of heterogeneity between cross-section units. As a result, this causality approach accounts for both heterogeneity of the regression model and that of causal link between x and y (Dumitrescu & Hurlin, 2012). Following the Dumitrescu-Hurlin (D-H) technique, the following heterogeneity autoregressive model is considered:

$$y_{it} = \alpha_i + \sum_{l=1}^{L} \gamma_i^l y_{i,t-l} + \sum_{l=1}^{L} \beta_i^l hii + \varepsilon_{it} \qquad (2.14)$$

where y_{it} is the growth (GDP) per capita in country i in year t, hii is the hybrid infrastructure index that accounts for both aggregate quantity and quality effects of infrastructure, ε_{it} is the error term, γ_i^l and β_i^l are autoregressive coefficients that differ across units (countries). This homogenous non-causality (HNC) test (as also known) proposes the null hypothesis of no causal relationship from x to y for all cross-sections,

$$H_0 : \beta_I = 0, (i = 1,..., N),$$

against the alternative hypothesis

$$H_1 : \beta_i = 0, (i = 1,..., N_1); \beta_i \neq 0, (i = N_1 + 1, N_2 + 2,..., N)$$

where $H_i (N > 0)$ is saying causal relationships occur for at least one cross-section unit. Rejecting H_0 with $N_1 = 0$ implying that infrastructure development (x) Granger causes economic growth (y) for all the countries in the panel. This entails a homogeneous result. Rejecting H_0 with $N > 0$ shows causal relationships from infrastructure to economic growth in some of the countries (heterogeneous causal relationships) (see Tugcu, 2014). It is under these heterogeneous circumstances that Dumitrescu and Hurlin (2012) proposed the average of the individual Wald statistics associated with the null of HNC hypothesis as follows:

$$W_{N,T}^{HNC} = \frac{1}{N} \sum_{i=1}^{N} W_{i,T} \quad (2.15)$$

where $W_{i,T}$ represents the individual Wald statistics for i^{th} cross-section unit associated with the individual test $H_0 : \beta = 0$. To investigate the causality between aggregate infrastructure and economic growth, this study relies on this D-H test that accounts for potential heterogeneity across the countries investigated.

The GMM and the Dumitrescu-Hurlin tests are therefore the key econometric estimation techniques used to address the two major objectives of this study. The GMM reveals the infrastructure-growth nexus while the Dumitrescu-Hurlin test discloses the direction of association between aggregate infrastructure and growth. The results from these tests are discussed in the next section.

2.4. Results and Analysis

All econometric tests are performed through the use of Eviews 9. We start by constructing our aggregate measures of infrastructure stock and quality using PCA.

2.4.1 Principal Components Analysis

The first two principal component analyses are performed using the infrastructure stock and quality measures of electricity, roads, airports, telecommunication, water and sanitation. However, it is restated that sanitation does not appear among the stock measures for the reason outlined under the data sub-section. The infrastructure quality measures are rescaled to have a scale of 0-1 (*0 means poorest, 1 is best*).[15] Both infrastructure stock and quality measures are transformed to logarithms. For the infrastructure quality values, all scores are between 0 and 1 with no absolute zero and hence no problems encountered with logarithm transformation of zero. The infrastructure measures are standardised (*have a mean of zero and a unit variance*) to reduce biasness. The key results are presented in Tables 2.2 and 2.3. In these tables, panels I and II show the two major principal component analyses undertaken in order to construct aggregate indices of infrastructure stock and quality, respectively. Panel III shows the PCA for institutional quality that combines information on each country's political stability and absence of violence, freedom, governance, and personal safety. Before the interpretation of the PCA results, this essay presents the ordinary correlations of the variables.

2.4.1.1 Ordinary correlations

The ordinary correlations are displayed in Table 2.1. In the table (panel I), the highest correlation (0.72) is between road and airport infrastructures, which are both under the transportation sector. Water and airport infrastructures show the lowest correlation (-0.005). Except for roads and airports, a striking observation is that all the infrastructure stocks are positively correlated. Consequently, one may say investment in these particular infrastructure sectors tend to move together. This may happen as a response to increase in population size or urbanization, which can be regarded as a determinant of infrastructure growth (see Canning, 1998). In terms of infrastructure quality (panel II), the correlations are negative for electricity versus roads, water and airports. The negative correlations might suggest some trade-off in public investments between the respective infrastructure categories; may be due to budget constraints. All correlations between the institutional quality measures (panel III) are positive and greater than 0.49. This suggest that these four different institutional quality measures tend to improve or deteriorate together in SSA. This is not surprising as it makes

[15] Telecommunication, water and sanitation quality scores were originally in the scale 1-100 from their original sources. In line with the related literature (see for instance, Calderon 2009; Calderon and Serven, 2010) we rescaled these other quality indictors to be in the scale 0-1 by dividing each score by 100.

sense in practice that, for instance, the residence of a country that respects human rights and rule of law (which are part of governance) tend to have more freedom and better personal safety. These translate into political stability and reduces violence in a country. From a political standpoint, governments should avoid violating one of these four institutional quality measures because several of them will be adversely affected with political instability as the worst nightmare.

Table 2. 1: Ordinary correlations

Panel I: Correlation matrix for infrastructure stock measures						
	LWATS	LELES	LRODS	LAIRS	LTELS	
LWATS	1.000					
LELES	0.135	1.000				
LRODS	0.017	0.124	1.000			
LAIRS	-0.005	0.517	0.723	1.000		
LTELS	0.295	0.484	0.164	0.229	1.000	
Panel II: Correlation matrix for infrastructure quality measures						
	LELEQ	LTELQ	LRODQ	LWATQ	LSANQ	LAIRQ
LELEQ	1.000					
LTELQ	0.176	1.000				
LRODQ	-0.016	0.488	1.000			
LWATQ	-0.072	0.635	0.401	1.000		
LSANQ	0.081	0.613	0.516	0.605	1.000	
LAIRQ	-0.176	0.224	0.432	0.346	0.264	1.000
Panel III: Correlation matrix for institutional quality measures						
	LPSAV	LFD	LPS	LGV		
LPSAV	1.000					
LFD	0.558	1.000				
LPS	0.684	0.493	1.000			
LGV	0.682	0.788	0.621	1.000		

Note: LELES, LTELS, LRODS, LWATS & LAIRS are the infrastructure stocks of electricity, telecommunication, roads, water and airports in logs, respectively. LELEQ, LTELQ, LRODQ, LWATQ, LAIRQ & LSANQ are the infrastructure qualities of electricity, telecommunication, roads, water, airports and sanitation in logs, respectively. Panel C presents the institutional quality measures in logs, that is, LPSAV (political stability & absence of violence), FD (freedom), PS (personal safety) & GV (governance). Freedom covers civil liberty and political rights. Personal safety is based on political terror. Human rights and rule of law are also accounted for in governance.

Most importantly for our objective are the correlations between the original variables and the principal components. These are shown in the next sub-section, Table 2.3. An analysis of the components is mainly based on which variables have a strong correlation with each component (that is, positive and negative values that are furthest from zero). Thus, the correlations can be negative or positive.

2.4.1.2 Eigenvalues and Eigenvectors

Table 2.2 presents the eigenvalues of the three different principal component analyses performed in this study. As expected the eigenvalues (or importance of components) decrease monotonically from the first principal component to the fifth.

Table 2. 2: Eigenvalues

	Eigenvalue	Proportion	Cumulative
Panel I: PCA for infrastructure stock			
PC1	2.184	0.437	0.437
PC2	1.288	0.258	0.694
PC3	0.844	0.169	0.863
PC4	0.536	0.107	0.970
PC5	0.149	0.030	1.000
Panel II: PCA for infrastructure quality			
PC1	2.850	0.475	0.475
PC2	1.191	0.198	0.673
PC3	0.750	0.125	0.799
PC4	0.541	0.090	0.889
PC5	0.383	0.064	0.952
PC6	0.285	0.048	1.000
Panel III: PCA for institutional quality			
PC1	2.917	0.729	0.729
PC2	0.588	0.147	0.876
PC3	0.309	0.077	0.953
PC4	0.187	0.047	1.000

Note: The eigenvalues show the importance of each principal component (PC).

In panel I, the first PC has the greatest eigenvalue (2.18) in the infrastructure stock dataset. This component also accounts for the greatest proportion of variance (43.7%) while PC2 only explains 25.8% of the dataset. Apart from PC1 and PC2, the rest of the components have eigenvalues less than unit. Principal component five accounts for less than 5% proportion. The cumulative proportion of the components equals 1, implying that all the variance in the dataset has been fully captured. Like the infrastructure stock, the first two principal components of infrastructure quality accounts for more than a unit variance and both explain 67.3% of the dataset. The main conclusion drawn from Table 2.2 is that PC1 and PC2 both capture the most important part of the datasets. In terms of institutional quality, only PC1 has an eigenvalue (2.92) greater than unit and accounts for 72.9% of total variation in the dataset.

The eigenvectors from each PCA are presented in Table 2.3. These eigenvectors are the rows of each matrix with the elements of an eigenvector showing the loadings (or weights). They show how the variables contribute to each PC. In terms of infrastructure stocks, the first principal component (PC1) carries positive weights across all the infrastructure categories. The weights of the infrastructure sectors in PC1 are above 0.41 except for water. An important observation is that even though LRODS, LAIRS, LRODQ and LWATQ have lowest correlation with LWATS (see Table 2.1), their correlation with PC1 are positive and above 0.44. A simple reason is that despite their low corrections with water stock (both negative and positive ordinary correlations), their correlations with other variables are not negative and not necessarily very low. PC1 that shows a linear combination for a number of variables in each panel has positive loadings suggesting that the component (i.e. new variable) increases as the original variables increase.

The rest of the components (PC2-PC5) have a mixture of positive and negative weights. A negative (positive) loading implies a negative (positive) correlation between a variable and a principal component.

Table 2. 3: Eigenvectors (loadings)

	Components					
Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC6
Panel I: Eigenvectors for infrastructure stock (in logs)						
LWATS	0.165	0.594	0.707	0.344	-0.030	----
LELES	0.493	0.253	-0.536	0.467	0.433	----
LRODS	0.466	-0.471	0.434	-0.253	0.555	----
LAIRS	0.580	-0.355	0.017	0.240	-0.692	----
LTELS	0.419	0.484	-0.153	-0.736	-0.156	----
Panel II: Eigenvectors for infrastructure quality (in logs)						
LELEQ	0.014	0.799	0.510	0.244	0.061	0.196
LTELQ	0.483	0.278	-0.181	0.054	-0.551	-0.592
LRODQ	0.442	-0.113	0.398	-0.694	-0.216	0.324
LWATQ	0.481	-0.026	-0.407	0.414	-0.112	0.647
LSANQ	0.487	0.156	-0.184	-0.171	0.790	-0.225
LAIRQ	0.320	-0.497	0.591	0.505	0.093	-0.193
Panel III: Eigenvectors for institutional quality (in logs)						
LPSAV	0.501	0.377	-0.759	-0.177	----	----
LFD	0.487	-0.637	0.141	-0.581	----	----
LPS	0.477	0.598	0.636	-0.101	----	----
LGV	0.533	-0.307	0.015	0.788	----	----

Note: The eigenvectors show the weights that each variable carries in each principal component.

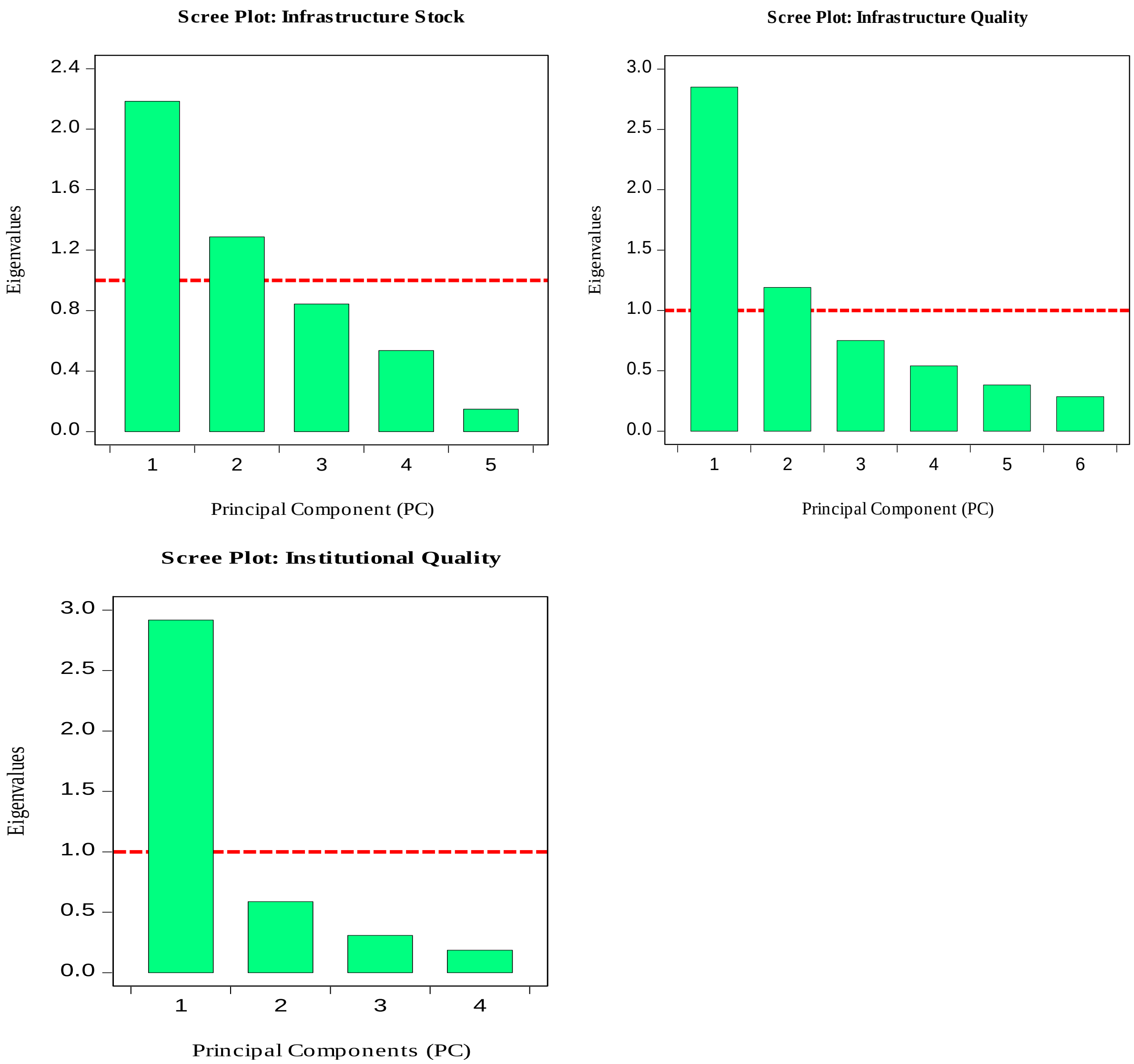
On the other hand, PC1 for infrastructure quality attaches a very small weight (0.014) to the quality of electricity. All other infrastructures have weights above 0.30. Consequently, PCI for the infrastructure quality draws more information from water, sanitation, road and telecommunication and airport infrastructures. However, electricity quality dominates the second aggregate infrastructure (PC2) with a weight of roughly 80%. Electricity is therefore the most important factor in PC2 for infrastructure quality. In the last PCA, the weights for the institutional quality measures are positive and all above 48% in PC1. The remaining three components have a mixture of positive and negative weights.

2.4.1.3 Principal components selection

As discussed in section 2.3.3.3, we consider two guidelines in determining the number of principal components to retain. Our standard guideline is to consider components whose eigenvalues are greater than the average of the eigenvalues. Since we applied a correlation matrix, it is the choice of eigenvalues greater than 1. In Table 2.2 (panel I), only PC1 and PC2 for infrastructure stock have eigenvalues greater than the average. The first guideline, therefore, suggests that only the first two principal components should be retained. These components account for 69%. The other components have smaller proportion of variance (below 0.17). In panel II, our first guideline also suggests that the first and second principal components for infrastructure quality should be retained. PC1 has the largest proportion of variance (roughly, 48%) and PC2's proportion of variance is about 20%. The cumulative proportion of PC1 and PC2 for infrastructure quality is approximately 67%. The results in the last panel implies that only the first principal component (PC1) should be retained, accounting for 73% of the dataset.

Now we consider the scree plot as our second guideline. It helps us to view the rate at which the variation explained by principal components declines with additional components. The scree plots are shown in Figure 2.1. Should all components contribute the same, they will be at the red line in the scree plots with the same proportion of variance. In the first two scree plots, PC1 and PC2 explain a great proportion of the dataset and are the only components above the cut-off line. All subsequent components fall below the cut-off line since they have small variance proportions. Based on this criterion we should ignore all the components from PC3 as they have little explanation of the dataset. In the last scree plot for the institutional quality PCA, only the first principal component is retained. Our second guideline confirms the first across all the principal component analyses performed. Both suggest we should primarily focus on PC1 and PC2 of infrastructure stock and quality whereas only PC1 is significant for institutional quality.[16]

[16] Though the chosen aggregate infrastructure indices based on the two guidelines used cannot explain 100% of the data variation, we believe that these indices are satisfactory for the purpose of this particular essay as we have revealed the infrastructure-growth nexus and the direction of causality.



Note: Plots based on Eviews. The red line is the cut-off point and all the components below this line explain relatively small variation of the data matrix. The first two scree plots show our aggregate indices of infrastructure stock (AIS1 & AIS2) and quality (AIQ1 & AIQ2)), which are PC1 and PC2 above the cut-off line.

Figure 2. 1: Scree plots

Source: Author's computation based graphs.

Having retained only PC1 and PC2 for infrastructure stock and infrastructure quality, these components are the aggregate infrastructure variables used to meet the research objectives of this essay. The following section presents these infrastructure components, which are new variables.

2.4.1.4 New infrastructure variables

The selected principal components become our aggregate indices of infrastructure stock and quality. These new variables are calculated as a linear combination of the original variables and the loadings (weights) (see equation 2.3). The first and second principal components for the infrastructure stock are transformed into a single aggregate infrastructure stock (AIS) index. This is done for the sake of analytical and interpretational convenience. Thus, we consider an average of the two selected principal components.[17] A similar transformation applies in the development of a single aggregate infrastructure quality (AIQ) index.

2.4.1.4.1 Aggregate Infrastructure Stock

Figure 2.2 shows the aggregate infrastructure stock levels. The estimates are based on the averages and medians of infrastructure scores between 2000 and 2014. The scores are in logarithms. In the figure, the Southern Africa (SNA) has relatively larger average infrastructure stock (0.523), followed by East Africa (-0171), West Africa (-0.224), and finally the Central Africa (-0.328) at the bottom. The average stock level for the Sub Saharan Africa hovers around zero with only SNA on top. Sub Saharan Africa's stock level is between the highest and the lower levels since it is an average of the four sub-regions. The median depicts the same picture as the averages.

[17] Taking an average is plausible given the combined variables are in same unit of measure (scores).

Note: AIS is average score of PC1 and PC2 for the instrastructure stock PCA. PC1 and PC2 are the selected PCs. SSA, SNA, WA, EA & CA stands for Sub Saharan Africa, Southern Africa, West Africa, East Africa, and Central Africa, respectively. 'avg' means average and 'med' means median.

Figure 2. 2: Aggregate infrastructure stock (AIS)

Source: Author's computation based graph.

2.4.1.4.2 Aggregate Infrastructure Quality

In terms of average infrastructure quality (Figure 2.3), it is relatively high in SNA (0.783). WA comes second (-0.233), followed by EA (-0.361) and CA (-0.576) at last. When considering the entire region, the average quality level in SSA is higher than WA, EA and CA. The median shows the same. In summary, SNA leads in terms of both infrastructure stock and quality levels while CA has the lowest levels. Although EA has higher aggregate stock levels than WA, it is not true for quality between these two regions. In Calderon (2009), among these regions, SNA shows to be better also with only North Africa on top.

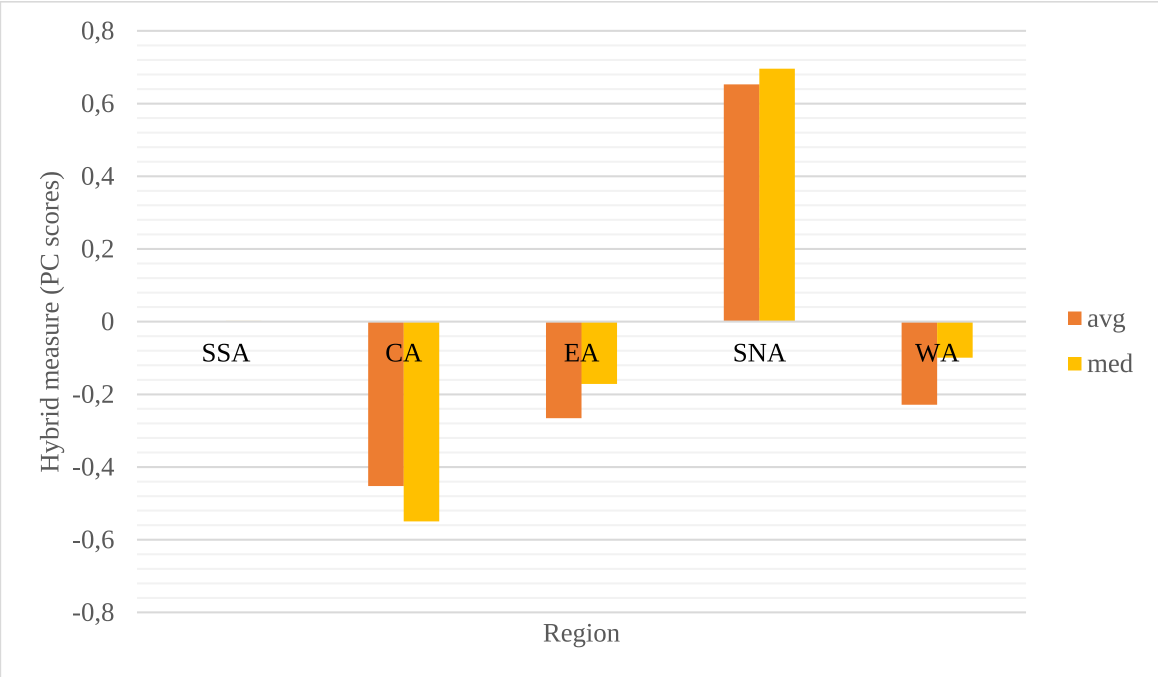
Note: AIQ is average score of PC1 and PC2 for the instrastructure quality PCA. PC1 and PC2 are the selected PCs.

Figure 2. 3: Aggregate Infrastructure Quality (AIQ)

Source: Author's computation based graph.

2.4.1.4.3 Hybrid Infrastructure Index (HII)

This essay develops another additional aggregate measure of infrastructure. The idea behind the hybrid infrastructure measure is borrowed from Alvarez, Arias, and Orea (2006) who stated the issue of an effective stock of public capital in a region that divert from the within-region stock measure by considering the stocks of other regions. One can use a product aggregator to combine the within and outside public capital stock. Besides, the authors specify that the application of a linear aggregator to develop the effective stock of public capital is another alternative that has not been explored. In our case, the hybrid index is meant to jointly capture both the quantitative and qualitative features of aggregate infrastructure. One may think of it as an effective aggregate infrastructure. The hybrid index has two advantages: (i) when the product aggregator is used, it is possible to view the introduction of quality as a potential moderator in the relationship between infrastructure stock and economic growth, and (ii) it allows for causality testing from an index that has both infrastructure stock and quality features. Between the product and linear aggregators, this essay applies the later. The hybrid index based on product aggregator shows a distribution which is far from normality, worse than the separate distributions of aggregate stock and quality indices (even after mean centring). On contrary, the linear aggregator produces a distribution that is approximately normal. However, for separate infrastructure sectors in chapter 3, a product aggregator does not really worsen the distribution. In chapter 3 the product aggregator is therefore applied, mostly also to understand the moderation effect of the quality features. As for this essay, the hybrid infrastructure measure as illustrated in Figure 2.4 are constructed by taking an average of linear aggregates of the selected PCs. In particular, we add together the selected PCs for stock (PC1s, PC2s) and quality (PC1q, PC2q) and divide by 4 to get an average aggregate score that has stock and quality effects and hence our HII.



Note: HII is an average of PC1s, PC2s, PC1q and PC2q (i.e. PC1s+PC2S+PC1q+PC2q)/4). PC1s and PC2s denote the first and second principal components for infrastructure stock, respectively. PC1q and PC2q denote the first and second principal components for infrastructure quality, respectively.

Figure 2. 4: Hybrid Infrastructure Index (HII)

Source: Author’s computation based graph.

Figure 2.4 has a similar shape as Figures 2 and 3 but in terms of the hybrid indices WA comes second after SNA though it is on third position on stock levels. While EA’s infrastructure stock level is higher than WA, its quality level is lower than WA. For this reason, WA has surpassed EA when the stock and quality levels are combined.

We graphically present more information regarding the infrastructure levels in SSA and its sub-regions in Appendix 2. The graphs show some improvements in the stocks and quality of infrastructure in SSA and across all the sub-regions over 2000-2014. Except for WA, the rate of change in infrastructure stock declines between the periods 2005-2009 and 2010-2014 across the regions as depicted by 'stock-change' (see Figures 2.6-2.9, Appendix 2). There was also a negative change in infrastructure quality in the same period. It may mirror poor performance in the post 2008 global financial crisis phase. Despite some notable improvements between 2000 and 2014, infrastructure development (both stock and quality) is very poor across the four sub-regions. This supports the argument by various authors and other organisations (such as the African Development Bank; World Bank) that Africa at large requires a massive investment in infrastructure development and maintenance. For policy makers, the issue of infrastructure financing is a matter of concern in Africa. Relying on government revenue and donor support to close these infrastructure gaps (depicted in Figures 2-4) may not be effective for a number of reasons. These include huge sizes of underground economies (or informal sectors) in several African states, which can undermine their tax revenue and possibly hinder the respective governments' ability to fund infrastructure projects. Moreover, an effective attraction of donor funds often requires sound structural and institutional quality, which are still inferior in Africa. Thus, from a policy perspective, boosting private participation in the provision of certain public infrastructure (for example, electricity and telecommunication) is the way forward.

In terms of economic comparison, South Africa is often regarded as superior to other African nations. In the figures above, one may wonder if SNA group may remain on top in terms of infrastructure levels when South Africa is excluded from the group. This was tested in our working paper Chakamera and Alagidede (2017) and we observed that both SNA's aggregate stock and quality levels remain higher than EA, WA and CA.

2.4.2 Summary statistics

A brief explanation of the properties of the data is given first. The descriptive statistics of the variables are presented in Table 2.4. Our aggregate infrastructure quality (LAIQ) and hybrid (LHII) indices are positively skewed whereas the aggregate infrastructure stock (LAIS) has a negative skewness; these three focus variables have kurtosis below the threshold of 3. Thus, the kurtosis values entail that the distributions of these three aggregate infrastructure measures are not fat tailed. Absence of fat tails may imply some form of mean-reverting process. Furthermore, the log averages of these three variables hovers around zero with the standard deviation relatively greater for AIQ.

Table 2. 4: Summary statistics

Variable	*Obs*	*Mean*	*Std.Dev*	*Min*	*Max*	*Skew*	*Kurt*
LGDP	630	6.823	1.161	4.691	10.105	0.768	2.754
LAIS	630	0.000	0.932	-2.738	2.264	-0.081	2.952
LAIQ	630	0.000	1.006	-2.523	2.526	0.137	2.901
LHII	630	0.000	0.913	-2.201	2.201	0.155	2.799
LHD	630	3.949	0.237	3.254	4.463	-0.136	3.149
LTOT	588	4.676	0.354	3.055	5.564	-0.673	6.808
LINQ	630	0.029	1.717	-4.769	4.290	0.114	2.671
LFDP	603	2.626	0.885	-1.618	5.076	-0.144	4.703
LTRA	618	4.285	0.475	3.043	5.861	0.305	2.940
LINF	611	1.729	1.032	-3.219	6.244	-0.297	5.062

Note: LAIS, LAIQ and LHII are the aggregate infrastructure measures. LINQ is the first principal component of several stability measures in logs.

Though the averages are approximately zero, these zeros are vital in this analysis as the scores have a mixture of positive and negative values generated by the PCA.[18] Only terms of trade (LTOT), financial depth (LFDP) and inflation (LINF) have kurtosis greater than 3 and hence their distributions are characterised by fat tails. Human development (LHD), LTOT, LFDP and LINF are the control variables with negative skewness. The GMM approach does not rely on strong distributional assumptions and hence the few variables with excess kurtosis and some that show skewness will not affect the identification of parameters. The lags of the variables are used as instruments in the estimation of parameters.

Taking the logarithms of the original variables helps us to lower kurtosis and skewness. Note that the presence of fat tailed and skewed variables violates normality assumptions which may possibly threaten identification when failure to satisfy certain moment restrictions is linked to non-normality in the distribution of data. However, we overcome this challenge by adopting the GMM technique that does not require any distribution assumptions (see Hansen & West, 2002). The violations of normality assumptions are disturbing if the test is norm-referenced (Shiken, 1997). In addition, the interpretation of kurtosis and skewness statistics must be done in terms of the purposes and types of tests performed.

[18] It is important to note that this essay takes the logarithm of the various original infrastructure sectors prior to PCA. PCA generates the new indices that become our aggregate infrastructure stock (AIS) and quality (AIQ). Both AIS and AIQ have scores ranging from negative to positive and hence their mean values hovers around zero. Since the logarithms were already taken prior to PCA, we believe their effect is carried in AIS and AIQ and hence could not take the logs of these new indices.

2.4.3 Stationarity tests

The variables are tested for stationarity using three different tests for panel data. Table 2.5 shows the results for stationarity proprieties based on Im, Pesaran & Shin (IPS), ADF-Fisher (ADF, for short), and Levin, Lin & Chu (LLC) panel unit root tests. The first two tests (IPS and ADF) assume individual unit root process while the LLC test assumes a common unit root process. This study relies more on the first two tests since they account for heterogeneity by assuming individual unit root process. However, the LLC test is also considered. The application of these three tests ensures robustness of the results. We allow for individual intercept for all test equations while the maximum lags are automatically selected based on Akaike Information Criterion (AIC).

Table 2. 5: Panel stationarity tests

	Im, Pesaran & Shin (IPS)		ADF-Fisher (ADF)		Levin, Lin & Chu (LLC)	
Variable	Level	Fist Difference	Level	First Difference	Level	First Difference
LGDP	-1.672**	-12.813***	124.432***	293.833***	-10.038***	-19.609***
LAIS	2.185	-9.245***	62.746	235.862***	-6.228***	-12.778***
LAIQ	-8.417***	-11.286***	174.159***	287.388***	-16.850***	-17.102***
LHII	-2.408***	-7.566***	132.416***	206.952***	-10.368***	-9.846***
LHD	-3.778***	-16.775***	145.330***	394.138***	-9.442***	-20.299***
LTOT	-0.683	-13.419***	102.859*	317.668***	-4.202***	-18.527***
LINQ	-3.982***	-20.135***	153.218***	448.960***	-7.001***	-25.196***
LFDP	2.484	-10.684***	70.328	269.339***	-3.403***	-13.663***
LTRA	-3.342***	-15.668***	132.395***	374.723***	-5.524***	-20.350***
LINF	-6.995***	-14.675***	194.529***	346.611***	-7.147***	-16.260***

Note: Eviews estimations. Estimations include individual intercept with automatic lag selection based on AIC. ***, ** & * denote significance at the 1%, 5% % 10%, respectively.

Except for aggregate infrastructure stock, terms of trade and financial depth, the IPS suggests that all other variables are integrated of order 0, which means stationary in levels. This is confirmed by the ADF unit root test but unlike the IPS, ADF statistic shows that even the terms of trade are stationary in level. However, the variables that are not stationary in levels are stationary in first difference. The LLC rejects the null hypothesis of a common unit process (*in levels*) across all the variables. Having almost all variables being stationary in levels including all the focus variables, it is our belief that there are no stationarity related threats to our estimations.

It is not econometrically plausible to work with non-stationary data for this may threaten the identification of parameters and leads to spurious results. This essay applies the first differences of the variables. This enables us to examine the growth effects in terms of change in GDP per capita from a unit change in aggregate infrastructure.

2.4.4 Interpretation of key results

This section discusses the empirical results of this essay. The findings from a panel of 42 SSA economies (full sample) are discussed first and followed by those of the 4 sub-regions within SSA, that is, Southern Africa, West Africa, Central Africa and East Africa. A separate section for the implications of the results follows after the discussion. It is imperative to check the adequacy of the regression models. This is shown on each of the Tables 2.6-2.9 for GMM results. We cannot reject the null hypothesis of correct specification across all models as suggested by the J-statistic (Sargan) test of over-identifying restrictions. Furthermore, the m-statistic suggests that the hypothesis of absence of second-order serial correlation cannot be rejected. The specifications passed diagnostic test and hence validate our results. This holds across all our GMM results.

2.4.4.1 Sub Saharan Africa - Full Sample

Our key results for the infrastructure-growth nexus in SSA are presented in Table 2.6. Economic growth is represented by log change in GDP. Infrastructure in this study refers to the public infrastructure and hence not covering private infrastructure or capital.[19] Private capital is excluded from our analysis because of too many missing observations for a number of countries in the sample. Three separate models are performed using the *difference*-GMM technique. Model 1 and Model 2 show the impact of aggregate infrastructure stock and quality, respectively. The hybrid (or joint) effect of aggregate infrastructure stock and quality on economic growth is shown in the last column (Model 3).

Three remarkable results are shown in Table 2.6: First, both AIS and AIQ have positive and significant growth effects in SSA. The annual contribution of infrastructure stock to economic growth per capita is 19.4 basis points and quality contributes 19.8 basis points over a 15 year period. Thus, infrastructure development has been a key factor that underpins economic growth in SSA; enhancing the achievement of the millennium goals. This is expected given the direct effect of public infrastructure in boosting productivity of private capital and as a complement to private investment (see Agenor & Moreno-Dodson, 2006).

Second, it is important to note that the quantitative and qualitative growth effects are almost the same, with the infrastructure quality impact slightly surpasses the impact of stock. While

[19] Though some public infrastructure (such as telecommunication) involves private sector participation, most of these have a great deal of government control and we broadly view them as part of public infrastructure provision.

the elasticity of infrastructure stock in respect to growth is 0.194, the growth elasticity of quality is 0.198. This is contract to other studies such as Calderon and Serven (2004) who found weaker growth effects emerging from the qualitative measures. The positive effect of infrastructure quality shows the importance of the various infrastructures that are combined together but it is necessary to bear in mind that some of the individual infrastructure qualities might not positively impact economic growth (this is demonstrated chapter three). The coefficient of AIS which is slightly lesser than that of AIQ may also reflect the missing sanitation stock features on AIS.

Table 2. 6: Aggregate infrastructure effect - SSA

Independent variables	Model 1 (AIS)	Model 2 (AIQ)	Model 3 (HII)
Focus variables			
Aggregate Infrastructure Stock (AIS)	0.194***		
Aggregate Infrastructure Quality (AIQ)		0.198***	
Hybrid Infrastructure Index (HII)			0.399***
Control variables			
LGDP(-1)	0.078***	0.138***	0.090***
LHD	0.835***	0.762***	0.880***
LTOT	0.509***	0.458***	0.538***
LINQ	0.033***	0.016**	0.030**
LFDP	-0.179***	-0.107***	-0.165***
LTRA	0.092***	0.106***	0.141***
LINF	-0.034***	-0.006	-0.045***
RECDUMMY	-0.050***	0.000	-0.008
No. of Obs	371	413	317
No. of countries	42	42	42
Diagnostic tests			
1. J-Statistic	39.169	38.154	38.513
(p-value)	(0.213)	(0.247)	(0.234)
2. m-statistic-2nd order	-1.249	-1.534	-0.399
(p-value)	(0.212)	(0.125)	(0.690)

Note: GDP per capita is the dependent variable. LHD, LTOT, LINQ, LFDP, LTRA, LINF are the logs of human development, terms of trade, institutional quality, financial depth, trade openness and inflation, respectively. RECDUMMY is the recession dummy. All the GMM estimates are performed including an intercept and periodic dummies that accounts for recession periods but the intercepts are not shown in the table. We apply only internal instruments across all the models. The lags of the instrumental variables are selected automatically from lag one in the GMM procedure, thus no maximum number of lags is specified by the user.
*** denotes significance at the 1% level.

Third, another fascinating observation is that the joint effect of aggregate stock and quality (0.399) is higher than both the separate effects of stock (0.194) and quality (0.198). Therefore, the complementarity between infrastructure quantity and quality is expected to have much impact on growth. This may also depend on the stock and quality levels of a country's infrastructure system.

We do not expect the qualities of all the infrastructure categories to assume a negative effect on growth. For example, in practice, there have been some improvements in the qualities of telecommunication and water in most African countries. Infrastructure quality benefits are expected since for instance, paved roads enhance the durability of motor vehicle use and lessen time taken to travel between locations, enhanced telecommunication services via information technologies are vital for closing business deals (permit sharing and conduct of trade-related businesses among economic agents) and safe water is necessary for health. All these benefits are expected to enhance the productivity of a nation. However, it is possible that some infrastructure sector developments in SSA may negatively impact economic growth. For example, the widespread outages of electricity are worrisome in SSA and these may dampen economic growth. There have been deterioration in electricity quality as indicted by a rise in the electricity transmission and distribution losses (ETDL) (see Appendix 3, Figure 3.2), which may negatively impact economic growth. The high percentage of ETDL lowers the potential kWh that reach the end users.[20] This includes also the poor state of roads in most SSA countries such as Zimbabwe.

In addition, our results suggest that previous GDP, human development, favourable terms of trade, enhanced institutional quality and trade openness have positive growth effects in SSA. Human development and terms of trade have relatively high growth elasticities, 0.84 and 0.51, respectively. Education has been the driving force for human development in Africa (Escosura, 2013). In empirical studies some use different measures of education, others use human development (which is comprised of health) as proxies for human capital. Whatever proxy is used, human capital tend to have a positive effect on economic growth. Despite the benefits obtainable from education as part of human capital, the education levels are still low in SSA as compared to the averages for developing countries. The average years of schooling for male (female) has been 6.0 (4.2) in SSA, which is less than 7.3 (5.4) average years for developing countries, and 11.5 (11.0) for the Organisation of Economic Co-operation and Development (OECD) (Human Development, 2015). SSA shows some evidence of uneven progress towards education for all (EFA) since 2000 (UNESCO, 2015). Pre-primary enrolment increased by almost two and half times between 1999 and 2012, lower secondary gross enrolment ratio (GER) rose from 24% to 50% in 2012, while adult literacy rate increased from 53% to 57%. Though the number of children with access to education

[20] In view of the poor supply of rid-electricity, a number of people supplement or substitute with off-grid power systems such as solar energy and diesel generators. However, due to difficulties in obtaining the time series data for these off-grid systems, this study does not account for their role.

increases in SSA, many remain outside of schools (Lewin, 2009). Education in SSA is facing a number of obstacles including high costs of early childhood care and education (ECCE), shortage of trained teachers, and lack of sufficient, equitable and sustainable educational finance (UNESCO, 2015). While this study does not precisely estimate the impact on economic growth of additional years of schooling, it is believed that more years of education improves one's knowledge and skills that are necessary for economic development. THE AFRICA-AMERICA INSTITUTE (2015) pointed that a year increase in average tertiary education would lead to 0.39% of annual GDP growth in Africa.

The positive effect of terms of trade on growth is consistent with similar studies (for example, Calderon, 2009; Calderon & Serven 2004 & 2010; Loayza and Odawara, 2010) that focus on Africa. Our results agree with the view that trade liberalization facilitates economic growth.[21] It broadens the market for trade, enhancing cross-border transfer of knowledge and technology, and allows a greater pool of productive resources. Trade openness in SSA is a direct consequence of both regional integration processes and specialisation mainly in primary products. In terms of specialisation, the majority of SSA economies export raw products such as minerals, oil and agricultural products (see Sundaram, Schwank, & Arnim, 2011; Douillet, 2012). The European Union was traditionally the most important trading partner (Hartzenberg, 2011). Recently Africa has become less dependent on developed economies as Asia has emerged as a key trading partner with China's demand for primary products propelling this trend (Sundaram et al., 2011). On the other hand, regional integration arrangements such as the Economic Community of West African States (ECOWAS), the Economic Community of East African States (ECCAS) and the Preferential Trade Area (PTA) covering Southern and East Africa are key to the African integration (Hartzenberg, 2011). According to Hartzenberg, a current commitment made by member states of Southern African Development Community (SADC), East African Community (EAC) and Common Market for Eastern and Southern Africa (COMESA) to establish a Tripartite Free Trade Area for 26 countries of these regional integration arrangements are taken as a crucial step in solving the problem of overlapping membership. These arrangements that facilitate trade openness though African intra-trade is still considered low as compared to other developing states in South America and Asia (see Hartzenberg, 2011). Small growth effects from trade liberation in SSA may be attributed to poor infrastructure such as weak transport system,

[21] Despite the logic of trade liberalisation, it is also essential to be aware of protectionists arguments that exist in support of trade barriers. Their arguments include the need protect infant industries, protection against cheap foreign labour (mainly the idea of some unions) and anti-dumping, among others.

unreliable power supplies, and other non-tariff constraints such as delays at ports, roadblocks and onerous customs procedures (Business Innovation & Skills, 2011).

Most importantly, improved institutional quality guarantees a favourable investment atmosphere, reduces corruption and ensures better use of resources. In this respect, the non-existence of a democratic political system in a number of SSA states is still a major challenge. Alence (2004) indicated that only Benin, South Africa, Botswana, Namibia, Madagascar, Mozambique, Malawi and Mauritius were regarded democratic as of 1999. Major gains in the number of democracies in SSA took place in the 2000s (Burchard, 2014). An improvement in procedural democratic practices (i.e. meeting most important democratic practices: elections) in SSA is remarkable, however, the substantive definition of democracy (which includes conduct of free and fair elections, absence of violence, freedom of the press, freedom of speech) is not yet met in most countries (Burchard, 2014). The author states that governance deteriorated in countries such as Libya, Mauritania, Central African Republic, Madagascar and Eritrea with some of them have experienced coup d'etat at least once since 2000. Zimbabwe, Nigeria, DRC are among the countries whose elections were associated with violence and loss of lives. Gambia and Kenya are among the recent countries that encountered disputed elections. Using the substantive definition of democracy, democratic political system does not exist in several SSA states.

Only inflation and financial depth have negative effects on GDP per capita. The negative effect of inflation is expected because price instability makes it difficult for investors to plan, increases the risk of investment, and erodes the wealth of fixed income earners, among other adverse outcomes. Financial development is usually expected to have a positive growth effect but this study proves otherwise (see also Kumar, Stauvermann, Loganathan, & Kumar, 2015). This entails the poor development of the financial system in SSA. The banking and financial systems remain underdeveloped. In particular, the banking systems are highly concentrated and often inefficient at financial intermediation, which presents one of the key obstacles to economic activity (European Investment Bank, 2013). Moreover, it seems most countries in SSA still suffer from financial repression which can negatively affect economic growth by hindering the effectiveness of financial institutions in carrying out their resource allocation role (Ncube, 2008; Yusuf, Malarvizhi, & Jayashree, 2014). Ngongang's (2015) results suggested that stock market capitalisation has an insignificant impact on economic growth in SSA, the outcome which the author has linked to high levels of financial repression and weak stock markets that are incapable of facilitating a solid economic development. Furthermore, Triki, Kouki, Dhaoua, and Calice (2017) demonstrated that financial repression in the form of price controls adversely impact the efficiency of small banks in Africa. To mitigate the problems of financial repression and improve financial infrastructure, several SSA countries have implemented financial reforms since the 1980s (Ncube, 2008). However, Ncube points that these countries have been less successful in lessening financial repression through bank restructuring. Regarding the structure of the domestic financial system in Africa at large, there has been a decrease in the number of state controlled banks and a rise in private banks. According Nyantakyi and Sy (2015), the continent's banking system has benefited from the participation of foreign banks such as Bank of Africa (operates in 36 African states) and Ecobank (operates in 14 African states).

2.4.4.2 Sub-regional effects

We perform additional GMM tests for the sub-regions within SSA. Except for the infrastructure quality in East Africa (EA), the results for the sub-regions regarding the impact of infrastructure (stock & quality) on growth confirm the evidence of a positive infrastructure-growth nexus in SSA (see Tables 2.7-2.9) and hence the implications are similar. Thus, much focus is on the comparison between the magnitudes of infrastructure contribution among the sub-regions. Table 2.7 presents the results for the effect of aggregate infrastructure stock on GDP per capita. The results indicate a greater contribution of infrastructure stock on the growth rate of Southern Africa (SNA), followed by West Africa (WA), East Africa (EA) and Central Africa (WA). Per every percentage increase in aggregate infrastructure stock, it yields 0.41% of GDP per annum in SNA, 0.28% in WA, 0.14% in EA and 0.08% in CA over a 15 year period investigated. It is of great interest that the rate of return per unit of infrastructure investment is higher in SNA, the region with relatively high level of infrastructure stock while it is lower in CA which has the lowest stock levels (see Figure 2.2). Consequently, this essay has established the gains obtainable from infrastructure investment, which are higher (lower) in a sub-region with relatively narrow (wide) infrastructure gap.

Table 2. 7: Regional stock effects

Independent variable	SNA	EA	WA	CA
Focus variable				
Aggregate Infrastructure Stock (AIS)	0.408***	0.137**	0.280***	0.075**
Control variables				
LGDP(-1)	-0.034	0.116***	0.151***	0.071***
LHD	0.685***	0.881***	0.477***	0.859***
LTOT	0.427***	0.629***	0.474***	0.498***
LINQ	-0.013	0.009	-0.026***	0.072***
LFDP	-0.117***	-0.151***	-0.100***	-0.189***
LTRA	0.139***	0.050***	0.105***	0.107***
LINF	-0.024***	-0.038***	-0.009**	-0.020**
RECDUMMY	-0.369***	-0.052	-0.080	-0.150***
No. of Obs	376	410	413	371
No. of countries	42	42	42	42
Diagnostic tests				
1. J-Statistic	36.396	38.681	37.511	38.029
(p-value)	(0.314)	(0.228)	(0.270)	(0.251)
2. m-statistic-2nd order	-1.065	-1.510	-1.196	-0.555
(p-value)	(0.287)	(0.131)	(0.232)	(0.579)

Note: see Table 2.6 footnotes. Appendix 1, Table A.3 presents the countries that falls within each sub-region.
*** & ** denote significance at the 1% and 5% % levels, respectively.

The impact of aggregate infrastructure quality is presented in Table 2.8. The coefficients of the aggregate infrastructure quality are positive and statistically significant in SNA, WA, and CA but negative in EA. The benefit of infrastructure quality development is higher in SNA (0.67%), then WA (0.30%) and CA (0.14%) while EA show growth losses (-0.29%). In general, our results indicate the importance of enhancing infrastructure quality as previously mentioned. It is difficult to pinpoint the actual reason for the implied negative growth effect of infrastructure quality development in EA.

The negative growth effects might be linked to individual country specific factors, including the infrastructure costs involved, productive or economic use of the infrastructure to generate benefits beyond and above the costs, substantial shift of resources from other investments, and the extent to which infrastructure improvements are funded from tax revenue. Interestingly, the qualitative effects that are essentially greater than the stock effects though it might be due additional effects from sanitation under quality but not appearing under the stock measure.

Table 2. 8: Regional quality effects (AIQ)

Independent variable	SNA	EA	WA	CA
Focus variable				
Aggregate Infrastructure Quality (AIQ)	0.669***	-0.293	0.300***	0.140***
Control variables				
LGDP(-1)	0.000	0.119***	0.851***	0.068***
LHD	0.968***	0.798***	0.495**	0.791***
LTOT	0.486***	0.617***	0.402***	0.457***
LINQ	0.081***	0.018***	0.046***	0.069***
LFDP	-0.107***	-0.185***	-0.103***	-0.100***
LTRA	0.157***	0.026*	0.112***	0.054*
LINF	-0.019***	-0.037	-0.022***	-0.019**
RECDUMMY	-0.670***	-0.154	-0.120***	0.134***
No. of Obs	376	413	371	376
No. of country	42	42	42	42
1. J-Statistic	38.510	39.190	35.585	38.312
(p-value)	(0.234)	(0.212)	(0.348)	(0.241)
2. m-statistic-2nd order	-0.815	-0.681	-0.917	-1.516
(p-value)	(0.415)	(0.500)	(0.359)	(0.130)

Note: see Table 2.7 footnotes.
***, ** & * denote significance at the 1%, 5% % 10%, respectively.

The hybrid effects of the aggregate infrastructure stock and quality are shown in Table 2.9. The contribution is highest in SNA then followed by WA, EA and CA at the bottom. We may think of the combined stock and quality features as a representation of a country's effective infrastructure level. Thus, a 1% increase in effective infrastructure level raises GDP per capita in SNA, WA, EA and CA by 0.54%, 0.46%, 0.21% and 0.12%, respectively. Like the stock effects, it is also remarkable that the hybrid effect is highest in SNA that has higher effective infrastructure levels yet it is lowest in CA where the levels are lowest. Another notable observation is that the hybrid effects are greater than the separate effects emerging from infrastructure stock across all regions. As a results, improvement in quality can generally enhance the performance of the existing infrastructure stocks. As far as this essay goes, our aggregate measures of infrastructure show a gradual rise in infrastructure quality levels across all sub-regions, however, quality for certain infrastructure sectors has been deteriorating in certain individual countries within SSA. Another cause of concern to note is that paved roads in some of the countries are fundamentally existing in terms of records but realistically in a very bad state (with pot holes) that may amount them as good as dust (non-paved) roadways when it comes to performance.

Table 2. 9: Joint effect of infrastructure quality and stock (HII)

Independent variables	SNA	EA	WA	CA
Focus variable				
Hybrid Infrastructure Index (HII)	0.543***	0.209***	0.462***	0.117***
Control variables				
LGDP(-1)	0.078***	0.070***	0.119***	0.100***
LHD	0.911***	0.827***	0.607***	0.927***
LTOT	0.597***	0.466***	0.466***	0.575***
LINQ	0.024***	0.057***	0.019*	0.019
LFDP	-0.135***	-0.102***	-0.074***	-0.087***
LTRA	0.080***	-0.051***	0.089***	0.030**
LINF	-0.009*	-0.002	-0.006	-0.020***
RECDUMMY	-0.019***	0.172**	-0.011	0.146**
No. of Obs	334	376	413	402
No. of country	42	42	42	41
Diagnostic tests				
1. J-Statistic	39.006	38.604	36.515	37.323
(p-value)	(0.218)	(0.231)	(0.309)	(0.238)
2. m-statistic-2nd order	-1.516	-0.719	-1.186	-1.159
(p-value)	(0.130)	(0.472)	(0.236)	(0.246)

Note: see Table 2.7 footnotes.
***, ** & * imply significance at the 1%, 5% % 10%, respectively.

2.4.4.3 Further comments

While it is important to examine the growth effects of infrastructure based on aggregate indices, it is possible that some individual infrastructures may overwhelm others. In our paper, Chakamera and Alagidede (2017) we suspected that electricity quality overwhelmed other infrastructure sectors' quality considerations and hence we made another estimation with electricity excluded. Without electricity, the stock effect dropped while the quality effect increased. In that paper, it confirmed our initial thought that deterioration in electricity quality was the core reason for negative growth effects suggested by the second measure of AIQ which was dominated by electricity. In the same paper we also examined the long-run growth effects of aggregate infrastructure and found AIQ to have greater long-term effect while the long-term effect of AIS was similar to the short-term impact. This thesis reveals more information regarding the short-term and long-term effects of various infrastructure sectors in the next essay.

2.4.4.4 Direction of causality

As discussed in chapter one, this section is motivated by fact that the existence of a relationship between infrastructure and economic growth does not really entail a causal relationship (see Yoo, 2006). Police wise, the knowledge about causality has vital insights. A unidirectional relationship from infrastructure to economic growth implies that reducing infrastructure development could cause a decline in economic growth. On the other hand, a unidirectional causality running from economic growth to infrastructure development implies that policy measures for lessening infrastructure development could be adopted without affecting economic growth. A bilateral causality suggests that a rise in the development of infrastructure induces economic growth while higher growth may require more infrastructure. Thus, we aim to reveal the direction of causality.

The Dumitrescu-Hurlin panel causality results are presented in Table 2.10. The central statistic of focus is the W-statistic which shows the average of the test statistics obtained from individual cross-section regressions. The p-values of the causality tests performed on the first differences of the hybrid infrastructure index (HII) (*an index that captures both quantity and quality effects of infrastructure*) and economic growth are shown. In panel I, we reject (at 10% significance level) the hypothesis that ΔHI does not homogeneously cause ΔGDP at lags 1 but we fail to reject in the opposite. In other words, changes in the combined aggregate infrastructure (i.e. telecommunication, electricity, roads, air, water and sanitation) in a country tend to cause changes in GDP per capita but not the other way round. These results suggest a unidirectional causality running from infrastructure development to economic growth. However, causality is not detected at lag 2 and hence the effects of infrastructure development in the last two years cannot cause current GDP. Unlike the usual infrastructure-growth causality literature, this is a synchronised effect of both aggregate infrastructure stock and quality.

We expand our analysis to examine the direction of causality using the aggregate infrastructure stock and quality separately. The results are presented in panel II. Unexpectedly, the estimations entail no causality between infrastructure stock, quality and growth in both lags. This kind of evidence is important given plenty of studies that rely on infrastructure stock alone when performing infrastructure-growth causality tests. Based on the causality analysis of this study, the most striking result is that infrastructure tend to cause growth when both quantity and quality features of infrastructure are combined but this is not the case when these features are separately applied. It seems useful therefore to employ a hybrid index that accounts for both infrastructure stock and quality when performing causality tests. The advantage being that more infrastructure information is incorporated.

Table 2. 10: Dumitrescu-Hurlin (individual coefficients)

Null Hypothesis:	W-Stat	Zbar-Stat
Panel I: Hybrid Infrastructure Index		
Lag 1		
ΔLGDP does not homogeneously cause ΔLHII	1.02378	-0.677
ΔLHII does not homogeneously cause ΔLGDP	0.69610	**-1.658***
Lag 2		
ΔLGDP does not homogeneously cause ΔLHII	2.85654	0,08568
ΔLHII does not homogeneously cause ΔLGDP	2.48666	-0.475
Panel II: Stock and Quality separately		
Lag 1		
ΔDLAIS does not homogeneously cause ΔLGDP	1.06931	-0.541
ΔDLGDP does not homogeneously cause ΔLAIS	1.14924	-0.302
ΔLAIQ does not homogeneously cause ΔLGDP	1.15885	-0.273
ΔLGDP does not homogeneously cause ΔLAIQ	1.60801	1,07163
Lag 2		
ΔLAIS does not homogeneously cause ΔLGDP	2.30639	-0.748
ΔLGDP does not homogeneously cause ΔLAIS	2.20154	-0.907
ΔLAIQ does not homogeneously cause ΔLGDP	2.98078	0,27392
ΔLGDP does not homogeneously cause ΔLAIQ	3.22440	0,64307

Note: LHII is the hybrid infrastructure index that combines both aggregate infrastructure stock and quality (in logs). LGDP is the gross domestic product per capita (in logs). The Zbar statistics in bold is the only significant parameter. Δ means a change or the first difference of the variable.* denotes significance at the 10% level.

The use of infrastructure stock alone (as common in literature) might fail to pick the direction of causality at all or rejects the hypothesis of causation from infrastructure to growth. We assume that the power to discover causality from infrastructure stock to economic growth in this study fails due to missing information regarding the quality features of the infrastructure stocks in SSA, *ceteris paribus*. When quality is accounted for, this causality might be in the form of causing the impact on growth to rise or decline, depending on the quality level. This preposition is also based on our findings of the infrastructure-growth nexus based on hybrid index (see Table 2.9). In this case, the impact of the hybrid infrastructure on growth tend to be higher than that of infrastructure stock alone, which is reasonable especially in the presence of additional effects emerging from infrastructure quality attributes.

Overall, our results suggest a unidirectional causality running from joint development in aggregate infrastructure stock and quality to economic growth. This contradicts some studies (for instance, Eberts & Fogarty, 1987; Perkins et al., 2005) who found evidence for a bidirectional causality. The results in this study generalise the whole SSA. Nevertheless, the W-statistic shows the average of the test statistics obtained from individual cross-section regressions and hence not invalidating different outcomes in some of the countries. The findings of Canning and Pedroni (2008) suggest that while infrastructure seems to cause long-run economic growth, it varies across countries. The causality analysis in this study has gone beyond the common routes in two ways: (i) most literature focus on the causality between the individual infrastructure categories and growth; this study applies aggregate measures, and (ii) we uniquely apply a hybrid index that captures both the stock and quality effects of the aggregate infrastructure measures. It is our belief that this approach provides robust results when addressing the direction of causation question.

2.4.5 Implications of results

For growth purpose, the results of this study suggest that infrastructure is one of the key drivers for economic growth. Thus from policy perspective, investment in both public infrastructure stock and quality is warranted as justified by the positive growth effects of infrastructure stock and quality. Our findings are relevant to policy makers as the necessity of other determinants of economic growth may change with time. For example, the relevance of labour as a key determinant of economic growth has been weakening due to rise in labour-saving technologies (see Streimikiene & Kasperowicz, 2016). As a result, a continuous investigation of other key growth factors is needed, of which herein public infrastructure has proven relevant.

Furthermore, our results are relevant to ordinary people who are part of the end users of infrastructure. Effective use of infrastructure by the public can aid economic growth in various ways. Firstly, the durability of infrastructure is prolonged when the public carefully use the available infrastructures. Secondly, to reap more from infrastructure quality the public should not vandalise the existing infrastructures, which is often a challenge in Africa. When malicious destruction of infrastructure (for example, public tapes, electricity and telephone cables) is avoided, it reduces the cost of maintenance and focus on upgrading. Our results therefore are not only vital to policy makers but even to the layman.

To both researchers and policy makers, the hybrid index results suggest that it is possible to underestimate or exaggerate the benefits obtainable from aggregate infrastructure stock when the infrastructure quality features are not properly captured. It will be underestimated when all vital quality improvements are not adequately reflected in the selected proxy for infrastructure stock. Over estimation may happen when deterioration in infrastructure quality is not fully represented in the infrastructure stock measure. In practice, it is tempting to make projections solely based on infrastructure stock levels. However, to have a better picture, it seems imperative to jointly incorporate the quality effects. The quality of infrastructure often deteriorates over a period of time and hence persistent maintenance and upgrading is required. As estimated by the World Bank (2013) the US$37 billion of annual investments for infrastructure maintenance and operations is justified if African states are to apprehend the potential benefits of their infrastructure stocks.

One of the remarkable implications derived from this essay is the size of infrastructure quality growth impacts that are essentially greater than the stock effects though this may reflect the absence of sanitation features on the stock side. Consequently, while the respective governments are argued to continue addressing the shortage of infrastructure, it is extremely important to ensure a proper allocation of funds towards improvement of infrastructure quality. This can boost efficiency in the provision and use of infrastructure, raising productivity and ultimately leading to robust GDP per capita. The supply of infrastructure is inevitable yet the quality of such infrastructure matters as long as economic growth in concerned.

For policy purpose, the essence of infrastructure provision in SSA is reinforced by our observation that the growth effects are relatively high in a region with higher infrastructure levels (SNA) while the lowest growth effects are reported in a region with the lowest infrastructure levels (CA). Despite the positive gains, it is also important to bear in mind that the sub-regions are still facing lower levels of infrastructure, including SNA itself. SNA which has relatively high stock and quality levels, the average and median log scores are less than 1. Calderon (2009) shows other regions (for example, Western European economies and East Asian “miracle” economies) with medians above 1, based on the aggregates of telecommunication, electricity and roads. In their study, all sub-regions in SSA’s medians were in the negative zone but the median for North Africa was positive. Governments in SSA need to invest substantially in infrastructure. Despite the financial problems, sometimes it is an issue of setting priorities right and avoiding unnecessary public expenditures. These expenditures may take the form of bigger parliament sizes and massive spending on cars for politicians, among others.

Failure to detect causality from growth to aggregate infrastructure (opposite direction) might suggest that infrastructure development in SSA is mainly based on political decisions rather than economic reasoning. By economic reasoning you expect a rise in GDP to cause public infrastructure development, either due to increased demand for infrastructure or the proceeds of GDP feed into government revenue which in turn channel into more infrastructure, creating a virtuous circle. Unfortunately, this might not be the case especially in Africa, where generally due to budget constraints, the decision to invest more or less in infrastructure may not necessarily depend on the size of annual GDP but political priorities. In practice, one can often observe active infrastructure projects during election phases when the politicians seek for votes. Such motives are not economically sustainable.

Based on control variables, measures such as export incentives are supported in SSA to constantly improve the performance of terms of trade. Moreover, since our institutional quality index is an aggregate of governance, political stability and absence of violence, freedom and personal safety, results suggest that an improvement in these measures enhances economic growth. Enhanced institutional qualities provide a conducive environment for investments. Democratic political systems and political stability do not only attract foreign direct investment but improve also the productivity of local investments. Furthermore, political stability, degree of freedom, governance and personal safety are often used to determine if a country is less risky and profitable to invest (see Perera & Lee, 2013). From a policy position, the results infer that African governments should focus more on the improvement of institutional qualities. Dealing with respect of human rights, rule of law and corruption are still central in SSA. The understanding of the pivotal role of institutional qualities remains fundamental to the growth trajectory of Africa. The institutional quality results are also relevant to the ordinary people regarding the merits of public investments when the politicians are held accountable for their decisions.

Finally, the positive growth effects of trade liberation backs continuous opening up of Sub Saharan African states. This embraces the implied merits of free trading blocs (for example, Southern African Development Community, Common Market for Eastern and Southern Africa, Southern African Customs Union). On the other hand, the negative coefficient of financial depth implies lack funds to finance productive activities. It is imperative to improve financial systems in SSA which can become a key pool of funds for investment purposes.

2.5 Conclusion and recommendations

Sub Saharan Africa is experiencing a critical shortage of infrastructure and the problem is worsened by the poor qualities of the existing infrastructure. It has been held as one of the key factors that slows economic growth in this region. Both infrastructure stock and quality levels are still low in SSA though some improvements since the year 2000 are noticeable. Limited knowledge regarding the impact of infrastructure quality on growth infrastructure has been a key challenge in the literature. This study examines the relationship between infrastructure and growth using data for 42 countries in SSA over a period 2000-2014. The analysis is based on aggregate indices of both infrastructure stock and quality. These aggregates are further combined to construct 'hybrid' indices that simultaneously capture stock and quality effects of infrastructure. Unlike the common causality approaches in the existing literature, we apply a hybrid index to address the infrastructure-growth causation question. To the best of our knowledge, our analysis is novel in introducing a hybrid index which is used to examine both the infrastructure-growth nexus and the direction of causation. The infrastructure categories considered are: electricity, telecommunication, roads, airports, water and sanitation. PCA is used to aggregate these infrastructure measures. The infrastructure-growth nexus is investigated using the GMM technique. The Dumitrescu-Hurlin test that controls for heterogeneity in panel data is adopted to detect the direction of causality.

Our GMM results reveal strong evidence for a positive effect of infrastructure development on economic growth with most contribution coming from infrastructure quality. Furthermore, this study realized that the combined effect of stock and quality (see our hybrid index) is larger than the stock effect alone. Consequently, the linear aggregator based hybrid indices suggest that when capturing the quality effects there will be additional growth effects. Given both the shortage and poor quality of infrastructure in SSA, if quality should act a weight then we do not expect the hybrid effect to exceed the stock effect. This issue is detailed further in the next chapter where a product aggregator is used to construct the hybrid indices. Despite the fact, the implication is that the infrastructure-growth analysis based on infrastructure stock alone may not be complete if the quality features of infrastructure are not precisely captured. However, in this case, a hybrid index that captures both stock and quality features seem superior. Moreover, infrastructure quality might act as a moderator that improves the relationship between infrastructure stock and growth. This is merely drawn from the behavior of the separate effects of infrastructure stock and quality versus their combined effect. The next chapter that applies a product aggregator is best placed to reveal the possibility of moderation. In terms of causality, we find evidence of a unidirectional causality from aggregate infrastructure to growth. Most importantly, this evidence is based on the application of a hybrid index that accounts for both infrastructure stock and quality effects. When the stock and quality effects are separated, we cannot detect causality between infrastructure and growth.

Based on the findings of this essay, it is vital to account for both infrastructure stock and quality when analysing the infrastructure-growth nexus, and addressing the causation question. We emphasise that future studies should consider applying hybrid indices especially when investigating the direction of causation as infrastructure stocks alone may fail detect causality. While investing in more infrastructure, we also argue countries in SSA to consider almost an equal proportion of funds towards infrastructure quality development. Thus, considerable investments in the maintenance and improvement of infrastructure quality is required as much as additional infrastructure stocks are needed. Infrastructure quality enhancement improves the economic growth effects of infrastructure stocks. Given the corruption levels in most African countries, appropriate monitoring and evaluation of various infrastructure projects is necessary to minimise the misuse of funds. Future research should investigate the potential moderation role of infrastructure quality in the nexus between infrastructure stock and growth. It should be done using moderation analysis techniques that reveal the moderator's size of effect. This will further motivate for the use of hybrid measures that combine stock and quality features of infrastructure. There is also need to continue looking for improved measures of infrastructure quality. Our results could serve as one of the policy guidelines for the SSA states and other economies in a similar scenario.

CHAPTER THREE

LONG AND SHORT-RUN GROWTH EFFECTS OF INFRASTRUCTURE STOCK AND QUALITY IN SUB SAHARAN AFRICA: A FIVE STEP PANEL ANALYSIS

3.1 Introduction

The shortage and poor state of infrastructure in Sub Saharan Africa (SSA) is disturbing. This remains a key obstacle in SSA's development trajectory; for instance, unreliable electricity supply is causing businesses to suffer while lack of improved sanitation and water threatens millions of lives (see International Finance Corporation, 2017). Accordingly, poor infrastructure is believed to be among the crucial factors for slow and even negative growth rates in countries such as Zimbabwe whose growth declined from 3.8% in 2014 to 1.5% in 2015 (AfDB, 2017). As in most developing countries, financing infrastructure projects in SSA is held back by lack finance.

While public infrastructure is universally acknowledged as a necessity for the wellbeing of every economy, the question that stands is whether increased supply of these infrastructures would warranty increased GDP per capita. As discussed earlier, theoretical models (see for example, Arrow & Kurz, 1970; Barro, 1990) were developed to understand the impact of infrastructure on growth. Policy makers are much interested in the practical performance of infrastructure investments. Aschauer's (1989) seminal paper revealed the importance of infrastructure investment for the United States (US) in the 1970s. Aschauer's estimates were, however, challenged by Gramlich (1994) whose view was that certain classes of infrastructure should not have significant output contribution. Since then, several studies have attempted to investigate the relationships between various infrastructures (mostly electricity, telecommunication & transportation) and economic growth, yet empirical gaps still exist in the literature.

Failure to consider both the stock and quality features of each infrastructure sector when analysing cross-sectional dependence, cointegration, long-run and short-run relationships between infrastructure and growth in SSA is the key challenge. Little is known especially on the short-run and long-run economic growth effects that emerge from infrastructure quality developments. A handful of studies (for example, Calderon, 2009; Loayza & Odawara, 2010) accounted for infrastructure quality in a GMM framework. Moreover, to the best of our knowledge, the application of hybrid indices that simultaneously capture both stock and quality features of each infrastructure sector has not been done. Furthermore, evidence in the extant studies remain inconclusive regarding the relationships between various infrastructure sector developments and growth in both long-run and short-run, which is a vital empirical gap for policy making. According to Deng (2013), mixed results could be attributed to (i) various ways of measuring a similar phenomenon (for instance, those applied to describe the covariates, dependent variable, estimation approach of the empirical model, functional specification), and (ii) different context (for example, period of study, capability of the economy in facilitating economic development, geographical scale), among other factors. Of these, our results mainly help to untangle the issues related to functional specification; underscoring the importance of incorporating infrastructure quality features on the infrastructure-growth models, which can affect both the nature and size of infrastructure-growth elasticities.

This study attempts to narrow these empirical gaps. This chapter uses both stock and quality data of the key infrastructure sectors (electricity, telecommunication, transport, water and sanitation) for 42 SSA countries over 2000-2014 period (see Appendix 1, Table A.3).[22] First, we investigate evidence for cross-sectional dependence which further informs the most appropriate unit root test. Second, we perform unit root tests in which Pesaran's cross-sectionally augmented IPS (CIPS) approach is most preferable in the presence of cross-section dependency. Third, cointegration tests are conducted to examine long-run equilibrium relationship between the infrastructure measures and economic growth.[23] Given that cointegration is established, the fourth step is to estimate the long-run infrastructure growth elasticities. Finally, we examine the short-run impact of each infrastructure sector on growth. Hybrid indices of each infrastructure sector are applied as well. These should contain rich information of each infrastructure sector, including the possibility of quality moderating the relationship between the infrastructure stock and growth. This essay makes the following assumption: *Quality may act as potential moderator in the relationship between infrastructure stock and economic growth*. The reason or logic behind this assumption is that while it is beneficial to have access to a particular infrastructure, the gains are somehow dependent on the quality of the infrastructure. For instance, the stock of roads with several paved roadways could be more beneficial than the stock with lots of dust roads. Moreover, high benefits from telecommunication are expected when subscriptions are accompanied by

[22] Transport stock is the first principal component of the total number of roads and airports. Transport quality is the first principal component of the ratio of paved roads and ratio of total airports with paved runways. This study has failed to find a proper proxy for sanitation stock and hence this particular sector appears only under infrastructure quality.
[23] We only consider the variables that are integrated of order one as required by our cointegration techniques.

excellent connectivity. Unlike the time series approach that focuses on individual countries and often hindered by small sample sizes, this essay is able to exploit additional power from a combination of time series and cross-sectional data.

This essay contributes to the existing infrastructure-growth literature in a number of ways: We take a step further from the earlier studies such as Calderon (2009), Calderon and Serven (2010), and Loayza and Odawara (2010) that focussed on Africa by also considering economic growth effects of the single infrastructure sectors in a five-step panel approach (cross-dependence, unit root, cointegration, long-run elasticities, short-run elasticities). Those earlier studies mainly focused on aggregate infrastructure indices that combine transportation, telecommunication and electricity sectors with estimations done using GMM. The second contribution is the application a hybrid index of each infrastructure sector that captures both the quantitative and qualitative attributes of infrastructure.[24] To the best of our knowledge this is perhaps the first attempt to specifically use hybrid indices of the single infrastructure sectors when examining the long-run and short-run infrastructure-growth effects in SSA. As mentioned in chapter two, the logic of hybrid indices is derived from the Loayza and Odawara's (2010) indices that simultaneous capture the quantity and quality features. However, we depart from these authors who focused on aggregate indices based on telecommunication, transportation and electricity by developing hybrid indices for single infrastructure sectors that include water as well. Using a product aggregator to develop the hybrid indices permits to investigate our assumptions that quality may act as potential moderator in the relationship between infrastructure stock and economic growth. Furthermore, this essay proffer key implications drawn from the findings. Most importantly, the results of the hybrid indices show an implication that the quality (or state) of infrastructure tend to moderate the relationship between the existing infrastructure stock and economic growth. In other words, the quality features of infrastructure may act as a weight that alters the effective contribution of infrastructure quantity. We found the absolute economic growth impacts of the hybrid indices to be essentially smaller than the stock effects alone. The implication here is that when the quality effects (which are generally poor) are explicitly accounted for (using a product aggregator to construct hybrid indices), the projected economic growth contributions of the existing infrastructure sectors in SSA are even lower.

[24] Note that the hybrid indices in this study are for each infrastructure sector and not for aggregated or clustered infrastructure sectors as shown in the previous chapter.

The rest of the study is structures as follows: Section 2 provides a brief literature regarding each infrastructure sector and economic growth. Section 3 describes the model and the econometric approaches of the study. Section 4 discusses the results and provide the key implications. Section 5 draws conclusions and suggests possible areas for further study.

3.2 Brief literature survey

Theoretically, each public infrastructure fortifies economic growth in different ways. For example, the development of roads affords knowledge spillovers emanating from an entire agglomerated area via network dynamic externalities (Tripathi & Gautam, 2010). Roadways can open up unconnected areas to trade, investment and employment opportunities. According to Larsen (1968), these benefits to the users are measured in terms of time saved, tyre wear, fuel consumption, car repairs and reduced accident risk. Telecommunication facilitates trade and production by allowing dissemination of information among economic agents (see Ismail & Mahyideen, 2015). It is believed to be associated with a rise in total factor productivity (TFP) and also providing the whole economic system with vital technological externalities (Antonelli, 1996). The collaboration between telecommunication network providers and telecommunication equipment producers shapes technological change that is necessary for TFP. Electricity is an indispensable factor that assumes a vital role in the production process and lightning (Abbas & Choudhury, 2013). Safe drinking water and sanitation are critical for good health that helps in reducing healthcare expenses and loss of working days due to illness (Minh & Hung, 2011). Each infrastructure type is therefore imperative for production in industry and service sectors and ultimately economic growth. It is important to present some evidence from of the previous empirical studies.

3.2.1 Transportation

Evidence on the growth contribution of transportation infrastructure is still mixed in the empirical literature. Studying 82 cities of the world's 100 busiest airports in 10 regions, Murakami, Matsui, and Kato's (2016) models for metropolitan output per capita suggest that cities with airport-rail links (or shorter access time due to rail connections) experience higher productivity than those without. They argued that it is justified to make considerable investments in airport-rail links. Also most recently, Ismail & Mahyideen (2015) investigated the effect of infrastructure on growth and trade. Their results indicated positive growth effects from transport infrastructure (air transport for registered freight & passengers and road network) with a 10% rise in paved roadways increases economic growth by at least 5%.

Improved quality of roads enhances worker productivity and lessens vehicle maintenance costs. Some have looked at transport infrastructure spillovers. For instance, Ozbay, Ozmen-Ertekin, and Berechman, (2007) make a striking observation that the spillovers from highway investments decline with distance from the investment location, such that there exist a positive time lag effect between time of investment and the effect on growth. Focusing on the SSA, Boopen's (2006) results suggested a positive contribution of transport infrastructure to economic growth. Furthermore, Siyan, Eremionkhale, and Makwe (2015) used both primary and secondary data and found a positive effect of roads on economic growth in Nigeria.

While evidence of a positive growth contribution from transport infrastructure is found, in other studies this is much doubtful. With reference to the US and other studies that examined the effect of highways in the US cities, Turner (2013) mentioned that in terms of development, roads require a careful scrutiny if not absolute scepticism. In particular, he states that highways seem to display far lesser definite returns than probable investment alternatives such as education and healthcare. He argues therefore that although transportation and road infrastructures enhance specialisation and trade, it is vital to formulate transportation policy to balance the merits against the challenge of environmental and economic costs associated with roads. Tripathi & Gautam (2010) examined road transport infrastructure and economic growth in India from a VAR analysis. They identified positive long-term elasticities of output and employment with respect to public capital. However, what is remarkable in their findings is that growth in the length of highways does not only crowd out gross private capital formation but shows no effect on output and negative effect on employment. Accounting for externalities, their results exhibit a long-term link between network dynamic externalities from road transport and output. Furthermore, Yu, De Jong, Storm, and Mi (2012) investigated the impact of transport infrastructure on growth in the Chinese regions. They found the effect to be varying across regions with unique characteristics. In particular, the impact on output tends to be more noticeable in intermediate regions than the congested ones, while benefiting the lagging regions is not likely.

Using Granger causality, Meng & Han (2016) demonstrated that improvement in road infrastructure does not contribute to economic growth but raises CO_2 emissions in the case of Shanghai. Other studies examined the issue of decoupling economic growth from transportation; seeking to boost economic growth but with less transport (see Stead &

Banister, 2003).[25] In terms of transport infrastructure quality, some studies (for example, Yu, 2010; Kuo, 2011; Wanke 2013; Wanke, Barros, & Nwaogbe, 2016) adopted input-output based methods to assess the productive efficiency of airports. It is worth noting, however, that this study uses a combination of paved roads and ratio of airports with paved runways as proxy for transportation quality.

3.2.2 Telecommunication

This is one of the most fast-growing sectors with huge ripple effect on overall economy (Yang, Lee, Hwang, & Shin, 2013, Czernich et al., 2011). According to Bandias & Vemuri (2005), telecommunication provision can facilitate sustainable economic development, and without necessary policy intervention the sustainability of rural areas will be threatened given a rise in reliance on communication technology networks. Based on the UK data, Correa (2006) presented evidence that telecommunication productivity surpassed both other sectoral productivity and economy-wide's productivity.

Roller and Waverman's (2001) study is among those that demonstrated the significant growth contribution of the telecommunication sector using OECD and newly-industrialised non-OECD countries. Furthermore, using US twenty century data, Crandall (1997) found evidence that the economic growth impact of new telecommunications infrastructure was weak to finalise that it has already produced enormous externalities. In the same century, Cronin et al. (1991) found evidence for a two causal hypotheses between the size of US telecom investment and economic activity. Thus, the two are reliable predictor of each other. It is also demonstrated that there is a causal connection between telecommunication infrastructure and total factor productivity and that productivity from this sector is measurable and considerable (Cronin, Colleran, Herbert, & Lewitzky, 1993). In the case of Eastern European economies, Dvornik and Sabolic (2007) found the direction of causality to be running from telecommunication to GDP.

Maiorano and Stern (2007) also demonstrated a positive contribution of mobile penetration to GDP per capita in 30 middle and low-income economies. In addition, they found evidence confirming that regulatory institutions have positive impact on mobile telecom penetration. Rohman and Bohlin (2014) made an interesting discovery that telecom sector's coefficient multiplier declined to approximately 1.3 by end of 2008 from roughly 1.8 in the 1980s, implying changing trends of the telecom output since the cellular era. They believe it could

[25] Decoupling is beyond the scope of this study.

be as a result of mobile uses which are not linked to business activities. Closely related, Ward and Zheng (2016) found greater contribution of mobile services to economic growth but this deteriorates as the province develops further. Focusing on the Small Pacific Island States, Kumar, Kumar, and Patel's (2015) results suggested that telecom services contribute 0.43% in the long-run and 0.33% in the short-run. They also found a one way causality from telecommunications to output. Other studies such as Wolde-Rufael (2007) found evidence for bi-directional relationship between telecommunication development and growth. Moreover, Lam and Shiu's (2010) findings suggested a bidirectional relationship between telecom development and GDP in European and high-income nations. When mobile services are considered separately, they found this bi-directional relationship not only limited to high-income nations.

While acknowledging a critical role of telecommunication industry in economic development, one fundamental issue to digest is the extent to which public sectors can effectively and efficiently ensure sound telecommunication infrastructure. The pace at which technological changes manifest in communications and electronics offers a robust argument against government to construct modern telecom infrastructure, which often become obsolete within a short space of time (Crandall, 1997). Consequently, this suggests that it could be logical to open the telecommunication sector to private participation while the government assumes a regulation role.

3.2.3 Water and sanitation

Water and sanitation in SSA are among the key sectors that have been receiving international aid and loans though domestic finance is greater than aid-related funds (AfDB, 2011). According to Howe (1976), when water is a constraint to economic undertakings, its delivery or improved quality forms a vital condition for economic growth. Despite the fact, Howe argues that there is no assurance that such supply of water will be satisfactory to initiate additional growth.

A growth model by Barbier (2004) suggested that a rise in the rate of water utilisation by 10% could raise the average growth of the 163 countries investigated from 1.30% to 1.33%. Most importantly, the author's results show robust evidence in support of the inverted-U hypothesis of the nexus between the rate of water utilisation and economic growth. According to Barbier (2004), "Growth is negatively affected by the government's appropriation of output to supply water but positively influenced by the contribution of increased water use to capital productivity, leading to an inverted-U relationship between economic growth and the rate of water utilisation” (p. 1).

In addition, Minh and Hung (2011) discovered that an inability to reach the Millennium Development Goals (MDGs) targets for sanitation and water would have costs (or consequences) around US$38 billion at global level, with sanitation accounting roughly 92% of this figure. On the other hand, each US$1 invested in meeting universal sanitation access in the non-OECD economies would be associated with US$11.2 of global return. The evidence compiled in their paper indicted that sanitation is economically and socially valuable. Also in terms of universal sanitation access, Hutton (2012) demonstrated that the benefit-cost ratio ranges from 2.8 in SSA to 8.0 in East Asia and that of drinking water ranges from 0.6 in Oceania to 3.7 in South Asia. They also found sanitation to have the greatest benefits, roughly US$54 billion out of US$60 billion of water and sanitation combined. Major contributions were in the form of health care savings in SSA and South Asia.

Moreover, the WSP (2012a) found sanitation to have considerable economic consequences in Bangladesh. In particular, the predicted annual economic impact of inadequate sanitation was roughly 6.3% of GDP and that of water-related was approximately 0.3% of GDP in 2007. It is also shown in the report that productivity losses make up 33% of helminthes effects, 18% of diarrheal effect, 6% of ALRI effects and 0.05% of malaria effects. In addition, their meta-analysis indicated that the relative risk for diarrheal is lessened by 45% from hygiene intervention, 32% from sanitation intervention, and 25% from improved water supply. According to the WSP (2012b), 18 African economics are losing roughly US$5.5 billion annually due to poor sanitation, in which the annual economic losses ranges between 1% and 2.5% of GDP every year.

Despite improvements in water and sanitation, maintenance of the existing infrastructures is a challenge for most governments in developing countries. In the case of Zimbabwe, water treatment has been failing to meet the standards due to dysfunctional infrastructure at waste water treatment plants (Thebe & Mangore, 2012). Poor management is also pronounced in rural areas. According to Ducrot (2016), community based management are now common in many developing countries due to perceived governments’ failure to implement and manage rural water supply. We reveal the implications of these infrastructure developments on growth.

3.2.4 Electricity

A number of studies have found evidence in support of a positive growth impact of electricity on growth. Ciarreta & Zarraga's (2010) results suggested that a 1% rise in electricity consumption will lead to 0.05% increase in growth in European countries. The positive contribution of electricity consumption to income was also demonstrated by Tang and Tan (2013) in the case of Malaysia. Hamdi, Sbia, and Shahbaz, (2014) also found that a percentage increase in electricity consumption can increase growth by 0.46% (in the long-run) in the Kingdom of Bahrain.

While several scholars have attempted to investigate the direction of causality between electricity and economic growth, the results are mixed across countries. Apergis and Payne (2011) classified 88 countries based on income (high, upper-middle, middle, and low) in which they found a long-run cointegrating relationship between coal consumption, labour, capital and GDP for the panels of high, upper-middle and middle income countries. Their results for the electricity-growth causality is mixed based on income levels and whether it's short-run or long-run. Apergis, Chang, Gupta, and Ziramba (2016) applied 1965-2012 data for 10 major hydro-electricity consuming economies. Their results revealed evidence of (i) cointegration between hydro-electricity and growth, and (ii) unidirectional causality from GDP to hydro-electricity consumption in both long-run and short-run for the period before 1988 and bi-directional causality in the post 1988. In addition, Kantar, Aslan, Deviren, and Keskin, (2016) found a robust relation between electricity consumption and growth in all income categories (low, middle, and high).

Furthermore, Belaid and Abderrahmani (2013) documented evidence of short-run and long-run bidirectional causal relationships between electricity consumption and GDP. Evidence for feedback hypothesis was also documented by Osman, Gachino, and Hoque, (2016) in the case of Gulf Corporation Council countries, which include a long-run relationship between electricity and growth (see also Gurgul & Lach, 2012, for Poland; Yoo, 2005, for Korea; Cheng-Lang, Lin, & Chang, 2010, for Taiwan). Abbas and Choudhury (2013) analysed causality at disaggregated level and demonstrated a two-way causal relationship between agricultural electricity consumption and agricultural GDP in India while a unidirectional causality (agricultural GDP to agricultural electricity consumption) was shown for Pakistan. Furthermore, Salahuddin and Alam (2015) demonstrated that internet and mobile use cause both electricity consumption and economic growth while additional causality is also found running from electricity consumption to growth.

Focusing on 17 African economies, Wolde-Rufael (2006) found causality running from both directions for 3 economies, from electricity to growth for 3 economies, from growth to electricity in 6 economies, and no causality for the rest. Akinlo's (2009) results show a unidirectional Granger causality from electricity consumption to GDP in Nigeria (see also Lyke, 2015). A bi-directional causality between electricity and growth was also revealed by Kouakou (2011) in Cote d'Ivoire. More so, a study by Ibrahiem (2015) indicated a cointegrating relationship between economic growth, electricity consumption and foreign direct investment in Egypt as well as evidence for bi-directional causality between electricity consumption and growth. Recently, Adams, Klobodua, and Opoku (2016) investigated the relationship between energy consumption and growth using a panel vector autoregression model of 16 SSA states. Their results suggested a feedback hypothesis for the two variables. Additionally, they found the relationship to be moderated by democracy. Generally, it is possible to find evidence for both bi-directional and unidirectional causal relationship between electricity and growth when applying data for different countries (see Yoo & Kwak, 2010; Yoo, 2006; Chiou-Wei, Zhu, Chen, & Hsueh, 2016).

Other studies scrutinised the growth contribution of electricity based sources (i.e. either renewable or non-renewable source). Using data for 18 Latin American countries, Al-mulali, Fereidouni, and Lee (2014) documented a cointegrating relationship between non-renewable electricity consumption, renewable electricity consumption, labour, total trade and capital. Their Dynamic Ordinary Least Squares (DOLS) estimator indicated that these variables have a long-run positive effect on GDP. Interestingly, renewable energy consumption was found to be more significant than non-renewable energy. Closely related, Dogan (2015) also found renewable electricity consumption (RELC), non-renewable electricity consumption (NRELC), labour and capital to be cointegrated in Turkey (see also Kahia, Aissa, & Charfeddine, 2016 in the case of MENA Net Oil Exporting Countries). Contrary to Al-mulali et al. (2014), Dogan's results show that NRELC can positively impact growth in the long-run while the RELC cannot be significant (with a negative coefficient). They advised the Turkish government to continue encouraging consumption from NRELC for sustainable growth. Based on 9 Black Sea and Balkan countries, Kocak and Sarkgunes' (2017) findings suggested a long-term relationship between renewable energy consumption and growth, whereby energy consumption can positively impact economic growth.

Despite the indispensable role of electricity, it is possible to hardly detect its growth impact. For example, Ozturk and Acaravci's (2011) results implied no cointegration between electricity consumption and economic growth in Iran, Morocco and Syria. Their results entail the absence of electricity-growth relationship in most of the Middle East and North Africa (MENA) countries. Furthermore, limited evidence of electricity-led growth hypothesis was documented by Wolde-Rufael (2014) who examined 15 transition economies.

In view of the above, all the five key infrastructure sectors tend to play a central role in economic development. Most countries or regions stand to reap the benefits of infrastructure provision. Nevertheless, no convergence of findings regarding the actual impact of infrastructure on GDP per capita has happened. Lack of consensus regarding the sign (+/-) of the growth effect of each infrastructure sector and direction of causality is still at large. The current empirical problem is not limited the sign of the effect but the size as well. As mentioned in the first essay, the most critical challenge failure to account properly for the quality developments of each infrastructure service. Consequently, these outstanding issues necessitate further research. The focus of this essay is to furnish policy makers and other groups of interest (such as researchers and advocates for more infrastructure) with separate growth effects emerging from infrastructure quantity and quality developments in both short and long run periods. That said, the findings of the essay should help decision makers in terms of infrastructure investment. Though most evidence is on the side of positive contribution of infrastructure to economic growth, we reveal instances where stock or quality measures of certain infrastructure sectors may not lead to GDP growth or suggesting negative effects in SSA. Probable reasons are provided as to why and how certain infrastructures may lead to poor growth in the regions.

3.3 Methodology and Data

3.3.1 Data

This empirical study considers 42 SSA countries.[26] Annual data for the period 2000-2014 is obtained from numerous sources (see Appendix 1). Gross Domestic Product (GDP) per capita is the dependent variable. Quantity and quality measures of electricity, telecommunication (fixed lines plus mobile), transportation (roads and airports) and water are the focus variables. As discussed in chapter two, only the quality measure of sanitation is available for analysis. The control variables include trade openness, financial depth, human development,

[26] See Appendix 1 for the list of countries. These are the countries considered in the chapter 2.

institutional qualities, inflation and terms of trade. These variables are fully discussed in essay one.

3.3.2 Model

To examine cointegration and long-run infrastructure-growth elasticities, this essay examines the following non-stationary panel model:

$$y_{it} = \alpha_{it} + \beta_1 ele_{it} + \beta_2 tel_{it} + \beta_3 tra_{it} + \beta_4 wat_{it} + \beta_5 san_{it} + \varepsilon_{it} \qquad (3.1)$$

$$\varepsilon_{it} = \rho\varepsilon_{it-1} + \nu_{it} \qquad (3.2)$$

where y_{it} is GDP per capita, α_{it} gives provision for country-specific effects, $ele_{it}, tel_{it}, tra_{it}, wat_{it}, san_{it}$ represent the logarithms of electricity, telecommunication, transportation, water and sanitation infrastructure variables, respectively. We estimate three different models using equation (3.1), that is, stock, quality, and hybrid models. To estimate the short-term growth effects of the infrastructure sectors, we consider the following empirical model:

$$y_{it} = \alpha_{it} + \delta g_{it} + \eta' z_{it} + \varepsilon_{it} \qquad (3.3)$$

$$i = 1,...,N, t = 1,...,T$$

where g_{it} denotes a particular infrastructure measure in logarithm, and z_{it} is the vector of control variables (in logs).[27] In this model only stationary variables are used in order to make proper GMM estimates. This is contrary to the first model (Equation 3.1) whereby non-stationary variables are used as required by the cointegration techniques we have adopted.

As also raised in the previous chapter, identification is often problematic especially in the presence of endogenous variables and correlation between the covariates and the error terms. A bi-directional causality may exist between infrastructure and growth. While, in theory, a full structural model can handle bi-directional causality, its practical implementation poses stringent data requirements (Calderon & Serven, 2010). Consequently, the use of instrumental variable approach is an alternative. External instruments such as demographic indicators can be used as proxy for infrastructure (see Calderon, 2009). These can be used

[27] Note that we do not consider control variables in the first model since our interest is to examine if there is a long-run steady relationship (cointegration) between GDP and the various infrastructure measures.

together with internal instruments (lags) in a GMM framework. Finding reasonable external instruments that can represent each infrastructure sector is a challenge. We already have demographic variables (population with access) as proxies for water and sanitation measures. Thus, to overcome the identification problem, we only rely on internal instruments in a dynamic *system*-GMM framework.

3.3.3 Econometric approach

We apply techniques that are best suited for panel data. Panel tests are generally believed to be more robust than time series tests given additional information to exploit that emerges from cross-sectional dimensions (Burret, Feld, & Kohler, 2014). Panel techniques allow us to control for unobserved heterogeneity among cross sections that would remain unexploited if time series approach is adopted (see Khan & Abbas, 2016). Our study follows a five step panel analysis including testing for (i) cross-section dependence, (ii) unit root (iii) cointegration for the variables that are I(1), (iv) long-run infrastructure-growth effects, and (v) short-run infrastructure effects on growth. Note that the last step is not dependent on the observation of the previous step.

3.3.3.1 Cross-Dependence test

3.3.3.1.1 Rationale

Possible dependability among cross-sections has attracted a great deal of attention in panel data. Our cross-dependence (CD) test is driven by two main concerns. First, the so called ‘first generation’ unit root tests (for example, Levin, Lin & Chu, 2002; Hadri, 2000; Im, Pesaran & Shin, 1995 & 2003) are based on the assumption of cross-sectional independence, which is frequently violated and leads to biased unit root results (see O’Connell, 1998; Cerasa, 2008; Burret et al., 2014). As a result, this study performs CD test prior to unit root testing. Rejecting the hypothesis of cross-section independence makes it credible to rely more on ‘second generation’ type of unit root tests (e.g. Pesaran’s CIPS) that consider cross-dependence of units. Second, the existence of cross-dependence has important policy insights. Based on the variables of interest, it may imply that a substantial change of policies or investments in any SSA country will affect other regional states. Therefore, a country’s decision making should account for external forces.

3.3.3.1.2 CD framework

In a panel setting, assume a model of the following form

$$y_{it} = \theta_i + \delta' x_{it} + \mu_{it} \quad (3.4)$$

$$i = 1,...,N, t = 1,...,T$$

where θ_i denotes time-invariant nuisance parameters, δ' is a $k \times 1$ vector of parameters, x_{it} is a $k \times 1$ vector of time-varying regressors. The δ' coefficients are permitted to vary across i, and u_{it} for each i is assumed to be independent and identically distributed (i.i.d) for all t but may be correlated across units. The key hypotheses are

$$H_0 = \rho_{ij} = \rho_{ji} = corr(\mu_{it}, \mu_{jt}) = 0 \quad (3.5)$$

for all $t, i \neq j$

$$H_1 = \rho_{ij} = \rho_{ji} \neq 0 \quad (3.6)$$

for some $i \neq j$

where ρ_{ij} is a pair-wise correlation coefficient of the residuals and $corr(\mu_{it}, \mu_{jt)}$ is the correlation between any cross-section i and j at time t. The null hypothesis (H_0) is saying no cross-sectional dependence. Therefore, rejecting the H_0 suggests that there is cross-dependence among some of the cross-sections.

The cross-section dependence in this study is based on Pesaran (2004) with the null hypothesis that the cross-sections are independent. This is an alternative approach to the CD test (LM statistic) by Breusch and Pagan (1980) in the context of seemingly unrelated regression estimation (SURE) with N fixed and T approaches infinite. The problem with the LM statistic is that it shows considerable biases when N is large and T is small, which is often the case in empirical applications (Pesaran, 2004). Instead, Pesaran (2004) suggested a different technique as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \quad (3.7)$$

where $CD \approx N(0,1)$ with T large and N under the null hypothesis of no cross-sectional dependence. Thus, Pesaran's CD test overcomes the challenge of the LM test. However, it is worth noting that when T is finite the regular central limit theorems cannot be used in the derivation of the CD statistics (Pesaran, 2012). To overcome this challenge the CD statistic can be written as

$$CD_{NT} = \sqrt{\frac{2}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \sqrt{T}\hat{\rho}_{ij} \tag{3.8}$$

Where $\rho_{ij} = T^{-1}\sum_{t=1}^{T} \xi_{it}\xi_{jt}$ are the scaled residuals.[28]

This study deals with 42 cross-sections (countries) and 15 periods. The presence of cross-section dependence compels the use of Pesaran's CIPS unit root test.

3.3.3.2 Pesaran panel unit root test

3.3.3.2.1 Rationale

Due to the manifestation of unobserved components and common shocks that become part of disturbance terms, an array of studies for panel data concludes that panel data often reveal significant cross-section dependence in the disturbances (De Hoyos & Sarafidis, 2006). As specified in the previous sub-section, cross-section dependence can adversely affect the 'first generation' unit root results, which do not account for cross-dependence. The application of 'second generation' kind of unit root test ensures that we do not reject unnecessarily the existence of a unit root as often do the 'first generation' tests (see Burret et al., 2014). Therefore, our use of Pesaran's cross sectional augmented panel unit root test is driven by the strong evidence of cross-section dependence in terms of the various infrastructure indicators and GDP per capita, which are further tested for cointegration only if these indicators are I(1) as required by Pedroni's cointegration test. This test proved to have satisfactory power and size properties even for relatively small samples (Pesaran, 2007).

3.3.3.2.2 CIPS framework

Pesaran' CIPS unit root tests is one of the 'second generation' tests that takes cross-sectional dependence into consideration. This technique arguments the standard Augmented Dickey Fuller (ADF) regressions with the cross-section averages of first differences and levels of individual series (Pesaran, 2007). Thus, the typical tests for unit root are transformed based on the simple averages of the individual cross-sectionally ADF statistics (CADF), which can

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[28] In this case, $\xi_{it} \frac{e_{it}}{(T^{-1}E_i'E_i)^{1/2}}$, e_{it} denotes ordinary least squares residuals from the individual-specific regressions and $E_i = (e_{i1},...., e_{iT})'$ (see Pesaran, 2012 for detailed illustrations).

further be utilized to have advanced versions of the t-bar tests suggested by Im, Pesaran and Shin (IPS). The CIPS tests is obtainable based on the individual CADF statistics as follows

$$CIPS = N^{-1}\sum_{i=1}^{N} CADF_i \tag{3.9}$$

Equation (3.9) shows that the CIPS test is basically the simple averages of the individual CADF statistics. To illustrate the estimation of the CADF, consider the following model

$$y_{it} = (1-\theta_i)\mu_i + \theta y_{i,t-1} + \mu_{it} \tag{3.10}$$

$i = 1,...N, t = 1,..., T$ and

$$\mu_{it} = \gamma_i f_t + \varepsilon_{it} \tag{3.11}$$

where y_{it} is the observation on the i^{th} cross-sectional unit at time t, f_t represents the unobserved common effect, ε_{it} denote the individual-specific error. We can as well express equations (3.10) and (3.11) as

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \varepsilon_{it} \tag{3.12}$$

Where $\alpha_i = (1-\theta_i)\mu_i$ and $\beta_i = -(1-\theta_i)$. The null hypothesis to be tested is

$$H_0 : \beta_i = 0 \text{ for all } i \tag{3.13}$$

versus the alternative

$$H_0 : \beta_i > 0, i = 1,..., N_1, \beta = 0, i = N_1 + 1,..., N \tag{3.14}$$

The null hypothesis say a series contain a unit root (i.e. $\theta_i = 1$). Pesaran's idea is that of having the cross-section averages of y_{it} (that is, $\bar{y}_t = \frac{1}{N}\sum_{i=1}^{N} y_{it}$ and its lags, $\bar{y}_{t-1}, \bar{y}_{t-2},..., N$ as proxy for the common factor f_t. H_0 in equation (3.14) is now based on the t-ratio of the ordinary least squares (OLS) estimate of β_i for CADF regression of the form

$$\Delta y_{it} = \alpha_i + b_i y_{i,t-1} + c_i \bar{y}_{t-1} + d_i \Delta\bar{y}_t + e_{it} \tag{3.15}$$

The averages of the individual CADF statistics gives the CIPS statistic and equation (3.9) can be written as

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} t_i(N,T) \tag{3.16}$$

The authors tabulated critical values for the various combinations of T and N. The null hypothesis of a unit is rejected if the CIPS statistic value is less than the critical value.

In the presence of serial correlation of the individual disturbance terms, this test can be adjusted by allowing extra suitable lags of $\bar{y}_t$ and $\Delta\bar{y}_{it}$ in the CADF regression (Cerasa, 2008; Pesaran, 2007). Despite the significance of the CIPS test, when the preposition of a single common factor is violated the behaviour of the test will not be satisfactory (Cerasa, 2008). The CIPS test may also lack power in small sample in comparison with the IPS test, therefore, it is imperative to apply CIPS in situation where strong evidence for cross-section dependence exist (see Pesaran, 2007).

3.3.3.3 Cointegration approach

When testing for a long-run relationship among integrated variables, the application of cointegration methods has been conversant in panel data. This also has to do with increased power of test that may emerge from accounting for both time series and cross-sectional dimensions (Persyn & Westerlund, 2008). Wolde-Rufael (2006) argues that cointegration is favoured over the orthodox approaches for two major reasons. First, relationships that are found based on the ordinary regression analysis of time series may turn to be spurious as cross-sectional properties are not taken into account.[29] Second, though ordinary regression can be helpful in determining the correlation between variables, it cannot entail a long-run relationship, neither could it imply any causality among the variables of interest. Cointegration is an approach of circumventing any possible misleading inference of spurious regressions (see, Enders, 2004; Wolde-Rufael, 2006). If the unit root results suggest that the series are I(1), then this essay applies panel cointegration test by Pedroni (1999, 2004) as the main technique to detect if there is a long-run steady relationship between GDP and the stock (and quality) measures of the infrastructure sectors. We also adopt Kao (1999) cointegration test to bolster our initial findings.

[29] In this case, panel regressions tend to be superior as more information is guaranteed from a combination of time series (T) and cross-sectional (N) dimensions. The N dimension also assist to improve the sample size especially when data for some periods is not available.

3.3.3.4 Pedroni cointegration

3.3.3.4.1 Rationale

Contrary to the cointegration tests such as Kao (1999) that treat cross-sectional units as homogenous, Pedroni's (1999, 2004) test controls for heterogeneity among individual panel members and hence an advancement over conventional cointegration methods (Khan & Abbas, 2016). Moreover, with the possibility of reverse causation between infrastructure and economic growth, we employ Pedroni's cointegration test which is strong to bidirectional causality, handles short-term dynamics across nations and heterogeneous cointegrating vectors (see Canning & Pedroni, 2008). Final but not least, this approach provides several statistics for both group mean between-dimension tests and pooled within-dimensions tests.

3.3.3.4.2 Pedroni cointegration framework

Pedroni (1999) constructed several cointegration test statistics that accounts for heterogeneity among cross sectional units. Consider the cointegrating regression of the form

$$y_{it} = \alpha_i + \beta_i I_{1,it},..., \beta_{mi} I_{m,it} + \varepsilon_{it} \quad (3.17)$$

$$i = 1,..., N, t = 1,..., T; m = 1,..., M$$

where N is the number of countries in the panel, T is the number of observations, M denotes the number of regressors (that is, infrastructure variables), y_{it} is GDP per capita and ε_{it} are the residuals. The $I_1,..., I_m$ infrastructure variables are all assumed to be I(1). The coefficients β_s and α_i are allowed to vary across individual members. The seven test statistics by Pedroni are constructed using the residuals from equation (3.17). Four of these statistics are based on the within-dimension (panel cointegration statistics) while the remaining three are for the between-dimension (group cointegration statistics). We do not show how these statistics are calculated but see the original document, that is, Pedroni (1999). The within-dimension statistics are (i) *panel v* (non-parametric variance ratio statistic), (ii) *panel rho* (non-parametric statistic comparable to Phillips and Perron rho-statistic), (iii) *panel PP* (non-parametric statistic comparable to Phillips and Perron t-statistic and (iv) *panel ADF* (parametric statistic comparable to ADF t-statistic). The three group mean statistics are (i) *group rho-statistic*, (ii) *group PP-statistic* and (iii) *group ADF-statistic*, which are analogous to Phillips and Perron rho-statistic, Phillips and Perron t-statistic and ADF t-statistic, respectively.

The null of no cointegration for the within-dimension statistics is

$$H_0 : \gamma = 1 \text{ for all } i \tag{3.18}$$

against the alternative

$$H_1 : (\gamma_i = \gamma) < 1 \text{ for all } i \tag{3.19}$$

The null of no cointegration for the between-dimension statistics is

$$H_0 : \gamma_i = 1 \text{ for all } i \tag{3.20}$$

against the alternative

$$H_1 : \gamma_i < 1 \text{ for all } i \text{ (heterogeneous alternative)} \tag{3.21}$$

In the case of hypothesis (3.21), H_1 does not assume a common value for $\gamma_i = \gamma$. According to Pedroni (2004) this alternative hypothesis should be interpreted as saying a considerable portion of the individuals are cointegrated. The critical values for the statistics are discussed and presented in Pedroni (1999). Basically, for each of the seven statistics, rejecting H_0 suggests that the variables are cointegrated.

3.3.3.5 Kao (Engle-Granger based) cointegration

3.3.3.5.1 Rationale

We apply this approach as a second cointegration test which has a different assumption of homogenous cointegrating vectors. Kao (1999) examines a special case of homogeneously cointegrating vectors but in a situation where the asymptotic equivalency results are violated due to endogeneity of independent variables.

Generally, the residual-based cointegration tests have their caveats. Most importantly, they impose a common-factor restriction which cause them to lose power and as a result often fail to reject the null of no-cointegration even in situations where it is most suggested by theory (Persyn & Westerlund, 2008). Westerlund (2007) developed a four panel cointegration approach that does not impose a common restriction. This study does not apply the Westerlund approach as this has failed to perform on our data structure. Despite the fact, it is our belief that Pedroni's seven statistics are satisfactory to detect cointegration between the variables of interest.

3.3.3.5.2 Kao cointegration framework

This test follows a similar approach as that of Pedroni, however, stipulates homogeneous coefficients and cross-section specific intercepts on the first-stage regressors (Eviews, 2015). To illustrate this approach consider a bivariate case and the model of the form

$$y_{it} = a_i + \beta_i g_{it} + \varepsilon_{it}, \tag{3.22}$$

in which

$$y_{it} = y_{i,t-1} + \mu_{it} \tag{3.23}$$

$$g_{it} = g_{i,t-1} + e_{it} \tag{3.24}$$

$$i = 1,...,N; t = 1,...,T$$

and a_{it} are allowed to vary across i (heterogeneous) and β_{it} (slope) is homogeneous across the individual members. The residuals can further be used by performing the following

$$\varepsilon_{it} = \rho\varepsilon_{i,t-1} + v_{it} \tag{3.25}$$

or the augmented model

$$\varepsilon_{it} = \hat{\rho}\varepsilon_{i,t-1} + \sum_{j=1}^{p}\phi_j \Delta\varepsilon_{i,t-j} + v_{it} \tag{3.26}$$

The null hypothesis to be tested is

$$H_0 : \rho = 1 \qquad (\textit{Suggesting no cointegration}) \tag{3.27}$$

versus the alternative

$$H_1 : \rho < 1 \qquad (\textit{Suggesting cointegration}) \tag{3.28}$$

Based on the Dickey Fuller, Kao presents the following statistics:

$$DF_\rho = \frac{T\sqrt{N}(\hat{\rho}-1) + 3\sqrt{N}}{\sqrt{10.2}} \tag{3.29}$$

$$DF_t = \sqrt{1.25}tp + \sqrt{1.875N} \tag{3.30}$$

$$DF_{\rho}^{*} = \frac{\sqrt{N}T(\hat{\rho}-1)+3\sqrt{N}\hat{\sigma}_{\nu}^{2}/\hat{\sigma}_{0\nu}^{2}}{\sqrt{3+36\hat{\sigma}_{\nu}^{4}/(5\hat{\sigma}_{0\nu}^{4})}} \tag{3.31}$$

$$DF_{t}^{*} = \frac{t\rho+\sqrt{6N}\hat{\sigma}_{\nu}/(2\hat{\sigma}_{0\nu})}{\sqrt{\hat{\sigma}_{0\nu}^{2}/(2\hat{\sigma}_{\nu}^{2})+3\hat{\sigma}_{\nu}^{2}/(10\hat{\sigma}_{0\nu}^{2})}} \tag{3.32}$$

which are $N(0,1)$.[30] Without going deeper, rejecting the null hypothesis implies that the variables are cointegrated.

3.3.3.6 Fully Modified Ordinary Least Squares (FMOLS)

3.3.3.6.1 Rational

Generally, the typical OLS is biased and inefficient in the presence of serial correlation and endogeneity of covariates. As Singh (2010) pointed, the application of an instrumental variable technique to overcome the threat of endogeneity could also be plagued with problems if the instrumental variables fail to meet orthogonality conditions and are autocorrelated. As a result, this gives precedence for the use of FMOLS estimator by Phillips and Hansen (1990). This method uses semi-parametric correction to OLS estimates to eradicate the threats caused by long-run correlation. The FMOLS estimator is essentially unbiased and it has fully efficient mixture normal asymptotics permitting for standard Wald test (Al-mulali, Sab, & Fereidouni, 2012; Eviews, 2015).[31]

Basically, the ability to eliminate serial correlation and endogeneity in the covariates make the FMOLS become prevalent in conventional time series econometrics (Kim, Oh, & Jeong, 2005). Pedroni (2000) shows how the FMOLS can be modified and applied to panel cointegration regression. He proposes two estimators: the group-mean (between-group) FMOLS estimator and the pooled (within-group) panel FMOLS estimator. The main advantage of Pedroni's technique is that, in addition to elimination of endogeneity and serial correlation problems, it accounts for substantial heterogeneity across individual members (Salahuddin, Gow, & Ozturk, 2015; Khan & Abbas, 2016). Thus, the FMOLS by Pedroni is superior to the dynamic OLS (DOLS) method of Kao and Chiang (2000) which does not account for cross-sectional heterogeneity. Pedroni's FMOLS estimator yields asymptotically

[30] A detailed discussion of the statistics in given in the original document by Kao (1999).
[31] The modified t-statistics of the FMOLS are asymptotically normal (Singh, 2010).

unbiased estimates of the long-run elasticities and efficient normally distributed error terms if the variables are cointegrated (Liddle, 2012).

3.3.3.6.2 FMOLS framework

Phillips and Hansen (1990) originally developed a FMOLS that works with variables which are integrated of order one. This study uses the panel FMOLS by Pedroni (2000) in order to account for cross-sectional heterogeneity while eliminating the problems of endogeneity and serial correlation. It is believed that this method offers consistent estimates in small samples (Khan & Abbas, 2016). Using FMOLS to estimate cointegrating vectors in panel data, consider the following model:

$$y_{it} = \alpha_i + \beta_i x_{it} + \varepsilon_{it} \tag{3.33}$$

$$x_{it} = x_{i,t-1} + e_{it}$$

where x_{it} is a vector of infrastructure variables, ε_{it} and e_{it} are the disturbance terms, which are accepted as stationary, and y_{it} is as defined in equation (3.17). The following shows the FMOLS estimator

$$\hat{\beta}^{*}_{FMOLS} = N^{-1}\sum_{i=1}^{N}\left[\left(\sum_{t=1}^{T}(x_{it}-\bar{x}_{it})^2\right)^{-1}\left(\sum_{t=1}^{T}(x_{it}-\bar{x}_{it})w^{*}_{it}-T\hat{y}_i\right)\right] \tag{3.34}$$

where

$$w^{*}_{it} = (x_{it}-\bar{x}_i) - \frac{\hat{C}ov_{21,i}}{\hat{C}ov_{22,i}}\Delta x_{it} \tag{3.35}$$

$$\hat{y}_i = \hat{\Pi}_{21,i} + \hat{C}ov_{21,i} - \frac{\hat{C}ov_{21,i}}{\hat{C}ov_{22,i}}(\hat{\Pi}_{22,i} + \hat{C}ov^{0}_{22,i}) \tag{3.36}$$

Note that $\hat{C}ov_i$ is the long-run covariance matrix, Π_i represents a weighted sum of covariance, and $\hat{y}_i$ handle the serial correlation effect (Khan & Abbas, 2016). The term W is a vector of standard Brownian motion (see Benali, Abdelkafi, & Feki, 2016).

3.3.3.7 System-GMM

The GMM technique is fully discussed in the first chapter, which shows the various advantages of using GMM and how it works. Therefore, this chapter does not give a detailed discussion of the GMM but specifically explain the *system*-GMM by Blundell and Bond, 1998. This is essentially an extension from the *difference*-GMM, which is used in chapter one. Note that in the estimation of equation (2.8) in chapter one, instrumental variables are used to eliminate the problem of endogeneity of regressors whereby the endogenous and predetermined variables in first differences are instrumented with suitable lags of the variables in levels (see also Liang, 2006).

Nevertheless, at times the lagged levels of the independent variables cannot be strong instruments when the variables are persistent over a period of time (Blundell & Bond, 1998). Consequently, a *system*-GMM can be used which allows for a combination of regressions in differences and in levels to develop a more efficient *system estimator* (Arellano & Bover, 1995; Blundell & Bond, 1998; Calderon, 2009; Liang, 2006). In view of the moment conditions for the *difference*-GMM (Equation 2.11), additional moment conditions based on *system*-GMM are as follows:

$$E\left[\begin{pmatrix}\Delta x_{i,t-1}\\ \Delta y_{i,t-1}\end{pmatrix}(\phi_i+\varepsilon_{it})\right]=0 \qquad (3.37)$$

$$\Delta x_{i,t-1}=x_{i,t-1}-x_{i,t-2},\Delta y_{i,t-1}=y_{i,t-1}-y_{i,t-2},$$

where the moment conditions in Equation (3.37) are based on the assumption of zero correlation between the differences of the variables and the country-specific effects. We use the *system*-GMM to estimate the impact of various infrastructure stocks and qualities on economic growth. In particular, the objective is to investigate the short-term growth effects of various infrastructure sector developments. The rationale for the choice of GMM is fully discussed in chapter one. Unlike the *differenced*-GMM, *system*-GMM tend to be robust when the lagged levels have become weak instruments for first differences.

3.4 Results and Discussion

3.4.1 Summary statistics

The summary statistics of the variables are shown in Table 3.1. All variables are normalised by the natural logarithm transformation. Our focus variables are log Gross Domestic Product per capital (LGDP), log stocks of electricity (LELES), telecommunication (LTEL), transport (LTRANSS) and water (LWATS), including their log qualities plus that of sanitation (i.e. LELEQ, LTELQ, LTRANSQ, LWATQ and LSANQ). The control variables are trade openness (LTRA), financial depth (LFDP), institutional quality (LINQ), inflation (LINF), human development (LHD) and terms of trade (LTOT), all in logs.

Table 3. 1: Summary Statistics

Variable	*Obs*	*Mean*	*St.Dev*	*Min*	*Max*	*Skew*	*Kurt*
LGDP	630	6.731	1.106	4.691	9.628	0.717	2.685
LELES	546	11.830	1.489	8.907	15.434	0.275	2.525
LTELS	630	2.739	1.636	-2.976	5.375	-0.658	2.534
LTRANSS	630	0.006	1.283	-2.811	8.148	0.920	5.973
LWATS	630	3.748	0.477	1.999	4.605	-1.337	4.769
LELEQ	546	2.115	0.768	-0.542	3.598	-1.351	4.504
LTELQ	630	1.276	1.665	-3.936	4.605	0.194	2.734
LTRANSQ	630	0.011	1.232	-2.607	2.648	0.191	2.758
LWATQ	630	-0.389	0.242	-1.241	-0.001	-0.436	2.510
LSANQ	630	-1.336	0.641	-2.724	-0.016	0.125	2.010
LTRA	618	4.248	0.452	3.043	5.416	0.213	2.689
LFDEP	597	2.658	0.871	-1.618	5.076	-0.187	4.951
LINQ	630	0.030	1.717	-4.769	4.290	0.113	2.673
LINF	625	2.749	0.574	-3.507	6.259	-1.345	33.61
LHD	630	3.946	0.239	3.254	4.463	-0.121	3.073
LTOT	588	4.668	0.346	3.055	5.564	-0.759	7.238

Note: Estimations based on Stata. All variables are in logs.

Note that the transport infrastructure measures (TRANSS & TRANSQ) are the first principal components that combine roads and airports. Without digging deeper, most importantly is the fact that some variables show excess kurtosis (TRANSS, LWAT, LELEQ, LFDP, LINF and LTOT). It implies, therefore, that these variables are fat tailed. At the same time, there is a mixture of positively and negatively skewed variables.

Often excess kurtosis and skewness are undesirable features that potentially threaten the identification of parameters, especially when the standard OLS is used. These issues are not expected to plague our estimations by applying the *system*-GMM estimator, which does not require any distribution assumptions (see Hansen & West, 2002) and Pedroni's FMOLS estimator which is robust for cointegrating non-stationary variables. The total number of observations (Obs) for each variable should be 630 but other variables have less, thus, having an unbalanced panel. The average, standard deviation, minimum and maximum values for each variable are presented in the table.

3.4.2 Cross-sectional dependence

This study starts by testing the validity of the cross-section independence preposition of the 'first generation' unit root tests using Pesaran's CD test. The estimations are conducted using *Stata 13*. The results of the CD test are shown in Table 3.2 including the correlation coefficients.

Table 3. 2: Pesaran's CD-test

Variables	*CD-test*	*corr*	*abs(corr)*
LGDP	97.140***	0.855	0.856
LELES	26.070***	0.248	0.486
LTELS	101.190***	0.960	0.960
LTRANSS	2.784***	-------	-------
LWATS	29.46***	0.259	0.533
LELEQ	-1.590	-0.015	0.313
LTELQ	42.78***	0.376	0.594
LTRANSQ	9.214***	-------	-------
LWATQ	89.140***	0.847	0.938
LSANQ	71.560***	0.678	0.952
LHIELE	90.930***	0.800	0.818
LHITEL	50.020***	0.440	0.645
LHITRANS	16.210***	0.143	0.417
LHIWAT	48.980***	0.431	0.710
LTRA	9.35***	0.081	0.394
LFDEP	48.32***	0.423	0.589
LHD	84.04***	0.739	0.805
LTOT	15.41***	0.14	0.557
LINF	16.22***	0.144	0.274
LINQ	1.94**	0.017	0.388

Note: xtcd Stata command is used. The test is under the null hypothesis of cross-section independence. The xtcd could not perform the CD test for transport infrastructure thus we apply xtcd2, which test residuals or a variable for weak cross sectional dependence in a panel data.
**** and ** denotes significance at 1% and 5% level.

Except for electricity quality, the CD test statistics for all the variables are significant at the 1% level. Therefore, the null hypothesis of cross-sectional independence is strongly rejected and conclude that cross-section dependence among the SSA states exist. Log hybrid indices of electricity (LHIELE), telecommunication (LHITEL), transport (LHITRANS) and water (LHIWAT) are included.

Econometrically, cross-section dependence implies that the panel stationarity tests and cointegration approaches that consider dependence of cross-section units should be used. Most essentially, cross-section dependence discloses that changes in the variable in one nation affects those in other regional nations. Consequently, when any of the countries in SSA set its strategies it should take into account the policies of other regional states and their external influences. Cross-section dependence in terms of infrastructure development could as well be spearheaded by consolidated effort by the African countries in encouraging infrastructure development. The African Development Bank is playing a fundamental role to spur sustainable economic development in the regional member states, which include the mobilisation and allocation of investment resources. More so, external funding towards infrastructure development in SSA and Africa at large may necessitate this cross-section dependence. For example, of the $74.5 billion towards infrastructure development in 2014, 37% was from foreign external funding and multilateral agencies (Canilao, 2017). Cross-sectional dependence of the telecommunication variables may entail the success of technology and innovation that spread faster among countries. Efforts in these countries (with invaluable support of organisations such as WHO and UNICEF) to achieve MDGs targets for improved water and sanitation may enhance cross-sectional dependency.

Cross-sectional dependence of financial depth and inflation may suggest improved financial integration among other SSA states. For example, other countries are in the Common Monetary Area (South Africa, Lesotho, Namibia, Swaziland), while Zimbabwe has been using multiple currencies since 2009. Thus, financial and monetary policies in one country can affect other countries. Cross-dependence of the trade openness variables may also infer progress in the adoption of trade liberalisation policies in SSA, facilitated by regional blocs such as Southern African Development Community (SADC), Common Market for Eastern and Southern Africa (COMESA) and Economic Community of West African States (ECOWAS), among others.

The results also imply that the institutional quality measures improve or deteriorate together in SSA. Therefore, policy makers should consider external spillovers of institutional quality dynamics across borders, which may facilitate (e.g. good governance, enhanced freedom, political stability - peaceful elections) or undermine (if bad, e.g. political instability in neighbouring states) the domestic economy. African countries are close "brothers" when it comes to weak institutional qualities, which require an enormous progression. Overall, cross-section dependence should be taken serious in both academic research and policy decision making.

3.4.3 Stationarity

Table 3.3 shows the results for unit root tests. We begin by testing for unit root using Im, Pesaran and Shin (IPS) approach, which unlike the Levin, Lin & Chu (LLC) test, it assumes individual unit root process. This is one of the 'first generation' unit root tests with the limitation that they do not consider cross-section dependence. According to Burret et al. (2014), these tests also tend to excessively reject the null hypothesis of a unit root. Thus, we prove this argument by including the IPS in Table 3.3.

In the presence of cross-section dependence (see Table 3.2), our most preferable panel unit root approach is the CIPS test, which is among the 'second generation' techniques. As our key technique, the CIPS test is fully discussed in section 3.3.3. For the IPS, automatic lag selection based on Akaike Information Criterion (AIC) is used, which suggests that the optimal lags of all the variables are less than 1. In terms of the CIPS test, the criterion decision Portmanteau (Q) test for white noise is implemented by Stata and the user set the maximum lags at 2. This maximum lag selection is sound given the optimum lags suggested by the AIC.

In Table 3.3, the IPS suggests that 11 out of 20 variables are stationary in level while the rest contain a unit root. On the other hand, the CIPS test suggests that only 3 out of 20 variables are integrated of order zero while the rest become stationary in the first difference. As Burret et al. (2014) argued, the results imply that the first generation (i.e. IPS) unit root tests tend to over-reject the null hypothesis of a unit root in the presence of cross-section dependence. Only the variables that are I(1) can be considered further for cointegration analysis based on Pedroni and Kao techniques. Accounting for cross-section dependence, the CIPS results imply that we can proceed to test for cointegration between GDP and the various infrastructure measures except for LELEQ and LWATQ.

Table 3. 3: Panel unit root tests

Variable	*Im, Pesaran & Shin (IPS)*		*Pesaran's CIPS*	
	level	1st Diff	Level	1st Diff
LGDP	2.851	-12.104***	-2.425	-3.292***
LELES	1.024	-12.932***	-1.808	-2.837***
LTELS	-4.274***	-5.734***	-2.262	-2.988***
LTRANSS	0.801	-13.689***	-1.436	-3.016***
LWATS	2.359	-12.507***	-1.906	-3656***
LELEQ	-6.750***	-18.164***	-2.547***	-4.141***
LTELQ	-8.882***	-12.599***	-1.809	-2.974***
LTRANSQ	-0.578	-15.350***	-1.997	-3.393***
LWATQ	-86.526***	-12.225***	-2.778***	-2.778***
LSANQ	-78.341***	-2.594***	-2.217	-3.191***
LHIELE	3.194	-12.494***	-1.717	-3.780***
LHITEL	0.213	-8.634***	-1.998	-2.843***
LHITRANS	-1.297*	-17.957***	-1.135	-3.028***
LHIWAT	-2.496***	-11.448***	-1.498	-3426***
LHD	-3.989***	-20.347***	-1.88	-3.069***
LTOT	-1.4658	-13.6616	-2.232	-3.17***
LINQ	-2.752***	-23.435***	-1.508	-3.262***
LTRA	-3.028***	-16.822***	-0.824	-5.233***
LFDP	1.903	-12.708***	-0.605	-1.531*
LINF	-12.078***	-19.679***	-2.927***	-6.731***

Note: Stata estimates. Tests performed including a constant without trend. Stata xtunitroot ips and xtcips commands used. The CIPS test could not perform unit root tests for three other control variables (LTRA, LFDP, LINF) due to the nature of missing observations on them. However, CADF test another version by Pesaran is performed. CIPS and CADF tests are analogue (see Section 3) but CIPS seems more sensitive to the balance of the panel. The CIPS' Critical Value at 1% is -2.44 and H_0 is rejected when the CIPS statistic is less than Critical value.
*** and * denote significance at 1% and 10% level.

3.4.4 Cointegration testing

The results based on Pedroni and Kao cointegration tests are presented in Tables 3.4 and 3.5, respectively. In these tables, Case I involves the cointegration between GDP and the infrastructure stock variables, Case II is for GDP and infrastructure quality variables, and Case III is for GDP and the hybrid infrastructure variables. Other quality variables are integrated of order zero and hence are excluded from our cointegration tests. All estimations are performed including an intercept with automatic lag selection based on AIC. In Table 3.4, except for panel v, panel rho and group rho, the remaining four panel statistics are significant (mostly at 1% level) and hence rejecting the null hypothesis of no cointegration. This observation holds in all cases. Note that panel-ADF and group-ADF statistics are believed to possess superior sample properties than the other five (see Pedroni, 1999; Lee, 2005). Kao ADF cointegration test (Table 3.5) buttresses the evidence of cointegration between the variables of interest.

The presence of cointegration implies that there is a long-run equilibrium relationship between GDP and the stocks of electricity, telecommunication, transport and water (Case I). The same applies in terms of the variables in the remaining cases. Generally, infrastructure development and economic growth move together in the long-run. This is of paramount importance to policy makers in SSA as it entails that every infrastructure investment made is accompanied by changes in GDP levels in the long-run. Nevertheless, the nature of the cointegrating relationship is not known, at least at this stage. To be more helpful to policy makers, the next sub-section reveals the exact nature of the long-run relationship.

Table 3. 4: Pedroni cointegration test

Statistics	*Case I (stock variables)*	*Case II (quality variables)*	*Case III (hybrid variables)*
Panel v	-0.892971	0.621431	-1.542532
Panel rho	3.483963	2.006819	3.870013
Panel PP	-6.925221***	-1.951424***	-1.764296**
Panel ADF	-7.964***	-3.880366***	-2.350***
Group rho	6.428943	5.384727	7.050875
Group PP	-11.38473***	-1.674917**	-4.657924***
Group ADF	-9.265***	-5.002354***	-4.631***
Cointegrating Variables	*LGDP, LELES, LTELS, LTRANSS, LWATS*	*LGDP, LTELQ, LTRANSQ, LSANQ*	*LGDP, LHIELE, LHITEL, LHITRANS, LHIWAT*

Note: Estimations based on Eviews with individual intercept included with Newey-West automatic bandwidth selection and Bartlett kernel. Automatic lag length selection based on AIC. H_0: No cointegration.
*** and ** denote significant at 1% and 5% level.

Table 3. 5: Kao cointegration test

Variables	*ADF-statistic*
Case I: LGDP, LELES, LTELS, LTRANSS, LWATS	-6.139***
Case II: LGDP, LTELQ, LTRANSQ, LSANQ	-3.768***
Case III: LGDP, LHIELE, LHITEL, LHITRANS, LHIWAT	-3.520***

Note: H_0: No cointegration.
*** denotes significant at 1% level.

3.4.5 Long-term elasticities

3.4.5.1 Interpretation

In the presence of cointegration, we estimate the long-term infrastructure growth elasticities using the FMOLS estimator proposed by Pedroni (2000). The pooled estimations are performed including an intercept. Table 3.6 presents the results of the long-run growth elasticities with respect to various infrastructure variables. Our results suggest that a 1% increase in electricity generation capacity will increase GDP per capita by 0.17% in the long-term. This shows the importance of electricity in production and other economic activities. However, the coefficient might be lesser due to substantial unmet demand for electricity in

SSA. The International Energy Agency's (2014) report indicated that since 2000 demand for electricity in SSA rose by 35% to reach 352 TWh in 2012. In the same period (2000-2012), SSA's grid-based power generation capacity increased from 68 gigawatts (GW) to 90 GW with generation from coal accounting for 45% of the total, hydro-generation (22%), oil (17%), gas (14%), nuclear (2%) and other renewables (below 1%). The deficiency of electricity cause people to consume less than they require.

Table 3. 6: Long-run growth effects - FMOLS

Stock variables		Quality variables		Hybrid variables	
Variable	*Coefficient*	*Variable*	*Coefficient*	*Variable*	*Coefficient*
LELES	0.174***	LTELQ	0.033***	LHIELE	-0.009129***
LTELS	0.251***	LTRANSQ	0.131***	LHITEL	0.025398***
LTRANSS	-0.086***	LSANQ	2.809***	LHITRAN	0.006877***
LWATS	0.003			LHIWAT	0.602845***
R^2	0.975728	R^2	0.948070	R^2	0.929343
SE	0.184437	SE	0.268792	SE	0.305297
S^2	14.76335	S^2	37.06390	S^2	50.51771
Obs	480	Obs	558	Obs	588

Note: Eviews software used. The long-run covariance estimates are based on Bartlett kernel, Newey-West automatic bandwidth with Newey-West automatic lag length applied. First-stage residuals use heterogeneous long-run coefficients. Coefficient covariance computed using sandwich method. SE is the standard error of regression and S^2 is the long-run variance.
*** denotes significant at 1% level.

The most striking result is the negative growth effect suggested by transportation stock. A percentage increase in the stock of roads and airports lessens GDP per capita by 0.09% in the long-term. This outcome is completely the opposite of our theoretical expectation that an economy can benefit from its stock of road and airport networks. Empirically, it is not much of a surprise; Tripathi and Gautam (2010) found similar evidence in the case of India. Most relevantly, our negative coefficient of the transport sector confirms the findings by Canning and Pedroni (2008) who reported pervasively negative long-run effects of transport infrastructure (kilometres of paved roads) on economic growth among African countries. They pointed that African economies as a group may tend to over-invest in roads such that when additional construction is carried out, the drain on resources from other investments overwhelm the positive impact of road networks, thus leading to long-run negative effects.

Though this might be possible, we believe the term "over-invest" requires caution in our analysis. It does not suggest the SSA countries have invested enormously in roads and airports. Rather, given their level of resources when these countries invest in road and airport constructions there will be a huge drain of public funds and significant sacrifices of other investments while the economic benefits from such construction will not surpass their opportunity costs, in the long-term. It is our belief that the key problem in most SSA countries is lack of conducive environment *(which promote vibrant economic activity & create jobs)* that ensures most productive utilisation of the transportation infrastructure system. It is only in favourable environments that transportation infrastructure can create economic benefits above the cost of constructing roads & airports, including any potential growth "curse" from carbon dioxide CO2 emissions. It is vital to contemplate Canning and Pedroni's (2004:19) observation that, "there is a growth maximizing level of infrastructure above which the diversion of resources from other productive uses outweighs the gain from having more infrastructure." It is below such a level that construction of additional infrastructure increases growth in the long-run whereas investment above the maximisation level diminishes the long-run growth.

Despite the negative transportation stock effect, our results suggest a positive growth effect (0.131) coming from the improved quality of roads and airports. Therefore, enhanced transportation quality will have significant economic benefits in the long-run. 'Paveways' raises efficiency in the use of transportation system which improves productivity.[32] Additionally, paveways are durable which allow for the use of infrastructure for long and hence minimise the cost of persistent maintenance (e.g. repairing dust roads after every rain season). Accordingly, the quality of transport infrastructure pays off in the long-run.

The long-run growth elasticity of telecommunication stock implies that a 1% increase in telephone and mobile phone subscriptions leads to 0.25% rise in economic growth. This coefficient is higher than the average 0.06% estimated by Canning and Pedroni (2008) in the case of 25 African countries using number of telephones. The growth impact of telecommunication sector is expected to advance with the growing use of mobile phones and technology as long as these innovations can augment productivity. Telecommunication is one of the key solutions to distance barrier. The significant growth contribution of telecommunication over 2000-2014 may also be attributed to the success of private participation in this particular sector. Moreover, public fixed line providers (e.g. Telkom in South Africa, Netone in Zimbabwe) have raised their focus towards mobile and data facilities. Tributes can be given to telecommunication policies that seek to enhance competition in telecommunication sectors of SSA countries. Market structures have ranged

[32] Paveways in this study describes paved roads and airports' paved runways, which are used in the measure of transportation quality.

from state-ownership to joint ventures or private-ownership and from monopoly to competition (see Minges, 1999).

Telecommunication quality shows a positive but weak long-run growth impact (0.033). This might reflect poor quality of the telecom sector in most SSA states as represented by lower levels of information technology, graphically illustrated in Figure 3.1 (see Appendix 3). Besides, weak growth effects from telecommunication may imply some unproductive use of the emerging mobile advances. Despite several people having access to mobile internet or data services and the use of these tools as marketing tools, the majority may use their devices for unrelated business social interactions (e.g. via Whatsapp, Facebook, Instagram, Twitter) which barely make any economic input. Among the stock variables, water shows no significant effect on economic growth in SSA. Note that our proxy for water stock is access to agricultural water in rural communities. Thus, the results imply that the provision of this agricultural water have had no meaningful growth contribution in most regional countries over the period 2000-2014. One explanation is that the provision of water for agricultures is still low to make a significant growth contribution. This reasoning is based on the fact that access to water for agriculture was approximately 42% in 2007, reaching about 54% in 2014 (see Figure 3.7). Another explanation is that water alone is not sufficient as the farmers may require other input such as fertilizers, tractors, pesticides and so on. According to Cooper et al. (2008), substantial agricultural investment by a wide range of stakeholders will be needed for the agricultural sector to meet food security needs of Africa. When it comes to the infrastructures that are available to rural population, it is imperative to think also of the measurement related limitations that may influence the results. For example, the agricultural water and roads may play a central role in rural communities but a question remains whether the rural economy is fully reflected in the GDP measure.

The coefficient for sanitation is too huge to be credible. The results suggest that improvement in the level of sanitation stock will increase economic growth level by more than double in the long-run. This coefficient should be interpreted with caution.[33] Despite the reservation, as the number of people with access to improved sanitation facilities increases, it will generate significant economic and social benefits to the society and hence increase GDP per capita. Jerome (2011) indicated that sanitation (& water) are associated with health, employment, education and income outcome, which are other Millennium Development Goals (MDG).

[33] It might be a statistical phenomenon.

Hutton (2012) finds sanitation to have the largest benefits in SSA as well as East Asia and South Asia with key contributions coming from health, particularly the value of saved lives. Our results may suggest that sanitation's economic benefits exceed the cost of having improved sanitation by relatively great magnitude compared to the cost-benefit structures of electricity, telecommunication and transportation.

Finally, except for electricity, all hybrid indices are positive. More precisely, the elasticities for the combined (stock and quality) effect of electricity (-0.009), telecommunication (0.025) and transportation (0.007) with respect to growth are small. However, our estimations show that these elasticities are significant and hence should carry vital growth implications. LHIWAT is the only infrastructure variable with a huge long-run growth effect (0.603). Consequently, the combination of providing water for agriculture and improved drinking water will substantially raise SSA's economic growth in the long-run.

3.4.6 Short-term dynamics

Tables 3.7, 3.8 and 3.9 report the results of the dynamic *system*-GMM performed using Stata. The short-term dynamics are essential in this kind of analysis to show the immediate impact infrastructure investment on GDP growth. They also inform policy makers on the types of infrastructure sectors that yield the most benefits in a short space of time. The lags of the variables are used as instruments with five set as maximum lags. In terms of diagnostic tests, we report the second-order serial correlation which is tested using Arellano-Bond test. The results suggest no autocorrelation. The Sargan test of overidentifying restrictions also indicates that the applied instruments are valid. Thus, ensuring the models have passed specification tests. The negative constants entail that when all the explanatory variables are set at zero, SSA will experience negative growth rates, thus, the variables are fundamental growth determinants.

3.4.6.1 Interpretation

In general, the short-run infrastructure growth effects are relatively low compared to the long-run effects. Using dynamic system GMM, changes in GDP represent economic growth. We explain the results of Table 3.7 (stock) and 3.8 (quality) together. A percentage increase electricity stock increases economic growth by 0.09% while electricity quality reduces growth by 0.05% in the short run. A number of factors are linked to the weak contribution of electricity stock in SSA. As previously mentioned, electricity shortage is the major obstacle in SSA and hence does not contribute as much especially in the short-term. The power outages that are common in Africa are also linked to shortage of electricity. Andersen and Dalgaard (2013) demonstrated how power outages could cause substantial growth drag in SSA. They show that approximately a 0.4% decline in GDP per capita is as a result of one log point change in the number of outages.

Table 3. 7: Stock effect - dynamic system-GMM

	Model 1	Model 2	Model 3	Model 4
Independent variables	*(Electricity)*	*(Telecom)*	*(Transport)*	*(Water)*
LELES	0.092***	----	----	----
LTELS	----	0.045***	----	----
LTRANSS	----	----	-0.013***	----
LWATS	----	----	----	-0.067***
Control variables				
LGDP (-1)	0.835***	0.774***	0.890***	0.921***
LTRA	0.106***	0.160***	0.118***	0.139***
LFDP	-0.089***	-0.167***	-0.097***	-0.103***
LINQ	0.057***	0.081***	0.047***	0.045***
LINF	-0.030***	-0.034***	-0.036***	-0.034***
LHD	0.374***	0.497***	0.415***	0.240***
LTOT	0.358***	0.321***	0.285***	0.271***
Constant	-3.197***	-2.155***	-2.314***	-1.588***
Obs	479	514	514	514
No. of Countries	42	42	42	42
Diagnostic tests				
(1) abond-2nd order	-1.138	-0.600	-1.048	-1.154
(P-value)	(0.255)	(0.549)	(0.295)	(0.2485)
(2) Sargan-chi2	40.875	39.691	41.061	40.403
(P-value)	(0.922)	(0.984)	(1.000)	(1.000)

Note: LELES, LTELS, LTRANSS and LWATS are the logs for the stocks of electricity, telecommunication, transport and water, respectively. LTRA, LFDP, LINQ, LINF, LHD and LTOT represent the logs of trade openness, financial depth, institutional quality, inflation, human development and terms of trade, respectively. Arellano-Bover/Blundell-Bond estimations using Stata command xtdpdsys. Lag variables are used as instruments. Sargan test of overidentifying restrictions has the null hypothesis that overidentifying restrictions are valid. Arellano-Bond test for autocorrelation has the null hypothesis of no autocorrelation.
***, **, * denote significance at 1%, 5% and 10% level.

Cook, Campbell, Brown, and Ratner, (2015) mentioned several ways in which electricity gaps hinder regional economic growth. These include ability to lower production and commerce, undermining human resource development, and elevating the use of polluting biomass energy such as charcoal and wool. We believe the problem of pollution is even worse when electricity generated from polluting energy sources does not yield economic benefits above the cost of having a friendly environment. Accordingly, the electricity crisis and CO2 emissions from polluting sources are threats to productivity in SSA. Unproductive use of the available energy may also lead to weak growth impact.

The negative growth impact of electricity quality in SSA is not surprising given the high electricity transmission and distribution losses (see Figure 3.2). In so far as electricity quality is concerned, Calderon's (2009) results also imply negative growth effects in certain African regions such as Southern Africa and Central Africa. Insufficient and ageing power plants which are poorly maintained is problematic. The International Energy Agency (2014) states that the stock of electricity available to users is significantly less than the level suggested by installed capacity of which poor maintenance is one of the reasons. Transmission and distribution losses lessen the final electricity supply by 20% in other SSA states (International Energy Agency, 2014). They also mentioned unreliable fuel supply especially for gas, and inefficient grid operations as other factors.

Table 3. 8: Quality effect - dynamic system-GMM

Independent variables	Model 6 *(Electricity)*	Model 7 *(Telecom)*	Model 8 *(Transport)*	Model 9 *(Water)*	Model 10 *(Sanitation)*
LELEQ	-0.054***				
LTELQ		0.043***			
LTRANSQ			0.002		
LWATQ				0.115	
LSANQ					0.109**
Control variables					
LGDP (-1)	0.829***	0.857***	0.859***	0.850***	0.853***
LTRA	0.146***	0.115***	0.122***	0.058*	0.110***
LFDP	-0.116***	-0.160***	-0.134***	-0.093***	-0.125***
LINQ	0.065***	0.053***	0.058***	0.064***	0.057***
LINF	-0.028***	-0.033***	-0.034***	-0.026***	-0.032***
LHD	0.690***	0.441***	0.606***	0.392***	0.478***
LTOT	0.368***	0.351***	0.364***	0.405***	0.371***
Constant	-3.355***	-2.388***	-3.156***	-2.257***	-2.464***
Obs	479	514	514	514	514
Countries	42	42	42	42	42
Diagnostic tests					
(1) abond-2nd order	-1.222	-0.705	-0.782	-0.813	-0.836
(P-value)	(0.222)	(0.481)	(0.435)	(0.416)	(0.403)
(2) Sargan-chi2	39.605	39.184	40.053	40.317	40.548
(P-value)	(0.942)	(0.987)	(0.983)	(1.000)	(0.980)

Note: LELEQ, LTELQ, LTRANSQ, LWATQ and LSANQ are the logs for the qualities of electricity, telecommunication, transport, water and sanitation, respectively. See Table 3.7 for the rest of footnotes.

Among the findings, telecommunication stock and quality have positive impacts on growth in the short-run. The contribution to economic growth is weak just like the other infrastructures. As previously argued, this might be linked to unproductive use of telephones and mobile phones as the number of subscriptions increases. For instance, Rohman and Bohlin's (2014) results indicated a greater coefficient multiplier of telecommunication in the 1980s as compared to the 21st century (particularly, 2008), with technological coefficient weakens as the epicentre of telecommunication output. They pinpointed the utilisation of cellular in much less business activities than that of the telephone era in the past as a possible explanation. It is likely that the market structure of the telecommunication sector in SSA is not competitive enough to ensure efficiency in service provision. Market structure can define the inefficiencies emanating from the telecom companies, in which competition promotes innovation (Jerbashian, 2015). Furthermore, power interruptions that are common in SSA can adversely affect the performance of telecommunication (see Malakata 2015; Ewusi-Mensah, 2012).

As in the long-run, transportation stock still imply a negative growth elasticity (-0.013) in the short run while transportation quality imply a positive impact though not significant. We have already discussed the possible reasons for negative growth impact from transport. Underutilisation of transportation infrastructure makes economic and social benefits fall beneath the economic cost of construction. Even in areas with road network, the issue of transportation cost is another issue SSA, which is critical especially in rural areas. African people face the problem of lack of cheap transport (Mission, 2014). Rural people walk long distances to get access to means of transport (e.g. buses, taxis) thus hindering their ability to frequently visit market places. For transport sector quality, not only the ratio of paved roads matters but the prevalent of road potholes even on paved roads is upsetting in most SSA countries. For example, in February 2017, President Mugabe declares Harare road network a state of disaster given potholes in combination with rains making some of them essentially impassable (Muzulu, 2017).

The negative transportation growth effect may not entirely entail that all countries in SSA are not reaping the benefits from transportation sector. These elasticities may vary across different states. This view is derived from previous studies that examined more than one region such as Yu et al. (2012) who demonstrated that transport investment yields less economic returns in the lagging regions of China, thus contradicting other studies (e.g. Demurger, 2001) which argue them to have higher returns than the developed regions. Lee (2010) demonstrated evidence of this variability and argued that the negative elasticities in other states show that the benefits of extra mile road construction does not cover the cost of maintenance.

Besides unproductive use of transport infrastructure, we also emphasise the idea that roads and airports development may take valuable resources away from competing production inputs such as land, private capital and human capital (see also Lee, 2010). As a result, a country's potential output growth is reduced. For instance, valuable resources can be taken away from agriculture (in form of loss of land, less investment in fertilizers, tractors, irrigation equipment) which has been one of Africa's key sectors, leading to poor harvest and output growth. Taking away resources from education can lower potential output growth especially in the long-run. But bear in mind that education, agriculture, mining, and other key activities require good transportation network. Consequently, the interpretation of transportation growth elasticities should go beyond and above the statistical coefficients. Rather, in short, it should be viewed also in the context of "*agglomeration economics.*"[34]

Water stock shows a negative growth effect in the short-run. Therefore, provision of water for agriculture to the rural population exerts negative pressure on growth in the short-run. It may indicate a scenario whereby the people who receive this infrastructure from the government can lack some necessary skills and other complementary agricultural inputs. As a results, several water projects will experience losses especially in the short-term. It is similar to a situation where the government has provided irrigation facilities to farmers while expecting them to payback after each harvest, but the farmers fail to payback due to poor harvests. While the quality of water suggests a positive growth contribution, the coefficient is statistically insignificant. Consequently, improvement in water quality since 2000 has not generated any meaningful benefits in the short-run. It is our belief that when considering relative percentage of persons who still remain without access to safe drinking water, no short-term vital growth contributions from improved water access has been recognised in most SSA countries. The population without access to safe drinking water is prone to water borne diseases and other health issues that result in economic losses.

In the World Health Organization 2012 report, Hutton (2012) indicated that the impact of short supply of drinking water was part of the reasons for economic losses (between 0.5% and 4.3% proportion of GDP) among regions, in which SSA experienced the largest blow. In most SSA countries, water problems are exacerbated by several factors, including ageing water infrastructure, poor supply of technical skills, non-payment of water bills, poor planning & maintenance at municipal level (see Stone, 2016 in the case of South Africa). Generally, countries are facing water quality crisis because of rapid industrilisation,

[34] The key challenge, however, is to measure the externalities from transportation infrastructure in the entire connected area.

urbanisation, and unregulated discharge of contaminated water, among other factors (Corcoran et al., 2010).

Furthermore, the results suggested that a 1% increase in sanitation quality increases economic growth by 11 basis points in the short-run. Thus, increase in the number of people with access to improved sanitation facilities only generate minor economic benefits in the short-term but it will be relatively large in the long-term. While some progress in terms of people with access to improved sanitation happen in most SSA states, the gains (such as good health & reduced healthcare expenses, prolonged lifespan, and reduction of working days lost due to illness) still have minimal short-run growth impact. The quality effect of sanitation is also weak due to large proportion of people who do not have access to improve sanitation facilities in the region. Calculating from our data of 42 SSA nations, we demonstrated that the percentage of persons with access to good sanitation was on average 29% in 2000, 32% in 2007 and reached 35% in 2014 (see Figure 3.1). It is a small progress with implied consequences stemming from the majority of persons without access to improved sanitation. Doing nothing is costly, the representative economy loses potential returns while incurring health expenses. UNDESA (2014) asserts that each $1 invested in sanitation gets a $5.50 return by keeping people health and productive.

Moving to hybrid indices, Table 3.9 shows the results of the joint effects of infrastructure stock and quality. All the hybrid coefficients are positive and significant except for water. While an increase in the transportation stock does not necessarily yield positive benefits, the whole infrastructure system produces positive returns. The same applies with water whose sign turned from negative to positive though not significant. Generally, the combined infrastructure stock and quality effects show economic benefits in the short-run but smaller in sizes. One possible explanation of the poor combined effects is poor state of the infrastructure stocks which are also in short supply. Therefore, the combination of insufficient and inefficiencies in the provision of infrastructure leads to small but significant benefits in the short-run. For example, excessive electricity transmission and distribution losses worsen the supply of electricity from the existing capacities; poor telecom services (e.g. network connection problems) inhibit the use telecommunication by subscribers. Again, the proportion of population with no access to improved water and sanitation leads to increased health expenses and economic losses. When stock and quality features are combined, the hybrid effects now imply that the growth contributions of electricity and telecommunication stocks tend to be exaggerated while for transport and water seem underestimated. Unlike the linear aggregator used to construct the hybrid indices in chapter two, this essay used product aggregator to construct the hybrid indices. Therefore, the quality features may moderate the relationship between infrastructure stock and economic growth.

Table 3. 9: Hybrid effect - dynamic system-GMM

	Model 11	Model 12	Model 13	Model 14
Independent variables	*(HI electricity)*	*(HI Telecom)*	*(HI Trans)*	*(HI Water)*
LHIELE	0.001*	----	----	----
LHITEL	----	0.004***	----	----
LHITRAN	----	----	0.007***	----
LHIWAT	----	----	----	0.014
Control variables				
LGDP(-1)	0.891***	0.851***	0.856***	0.854***
LTRA	0.171***	0.108***	0.115***	0.125***
LFDP	-0.080***	-0.142***	-0.131***	-0.132***
LINQ	0.036***	0.058***	0.057***	0.058***
LINF	-0.027***	-0.034***	-0.034***	-0.034***
LHD	0.367***	0.592***	0.607***	0.555**
LTOT	0.246***	0.367***	0.369***	0.373***
Constant	-2.267***	-2.996***	-3.145***	-2.961***
Obs	514	514	514	514
No. of Countries	42	42	42	42
Diagnostic tests				
(1) abond-2nd order	-1.205	-0.728	-7.767	-0.801
(P-value)	(0.228)	(0.467)	(0.443)	(0.423)
(2) Sargan-chi2	39.293	69.227	40.305	40.428
(P-value)	(1.000)	(0.986)	(0.981)	(0.981)

Note: See Table 3.7 footnotes.

Given the nature of infrastructure, the short-term dynamics provide an important insight that the impact of infrastructure tend to be lesser in the short-run yet it is relatively high in the long-run. The absolute sizes of the coefficients are generally larger in the long-run. This suggest the existence of time lags before the full impact of infrastructure on economic growth becomes more sizable. However, the short-run coefficient of telecommunication quality is slightly larger than the long-run coefficient.

Finally, the results of the control variables are briefly discussed. The results are almost similar across the three tables (Tables 3.7, 3.8, 3.9). The inflation sign is negative across all models as expected. It implies that an increase in the average price level reduces economic growth in SSA by adversely affect consumer demand (see also Kodongo & Ojah, 2016). Weak monetary and financial policies are among the reasons for high inflation levels in some of the countries, for example, Zimbabwe that experienced a world-record hyperinflation in 2008. Financial depth suggests a negative growth effect in SSA; this result was also documented by Chakamera and Alagidede (2016) using a *difference*-GMM approach.

According to Kodongo and Ojah (2016), it seems that African economies have not achieved a threshold level of financial development that would enable incremental economic activity. They added it could be that credit supply to private sector (mainly to individual borrowers) finances consumption instead of investment activities. Dahou, Omar, & Pfister (2009) highlighted weak capital markets, failure of banking sector to play its intermediation role, lack of innovative financial instruments, and inadequate regulatory framework as key obstacles in several African states. Capital markets appear to be small and fragmented. Nevertheless, SSA countries have been making some progress in past decades, including innovative financial services based on mobile telephone system (IMF, 2016). The IMF report mentioned that Pan-African banks assume an essential role in boosting financial development but they also pose risks, mostly linked to inadequate supervisory oversight.

More so, human development tend to have the most growth contribution in SSA. This suggest the fundamental contribution of educational development which is a key component of the human development measure. In terms of progress, SSA reaped the largest benefits in secondary education participation in comparison to other regions between 1999 and 2012 (THE AFRICA-AMERICA INSTITURE, 2015). This report further indicated that educational returns in SSA are highest in the world (21% increase in GDP) and an annual increase in average tertiary education level rises yearly GDP in Africa by 0.39%. Education or human development in broad sense allows for good employment opportunities, enhances quality of life, promotes innovation, improves productivity and ultimately triggers economic growth. Despite the benefits and the progress towards education for all in SSA, several children are finding it hard to attend secondary schools near their homes and may ended up having limited access to secondary education (THE AFRICA-AMERICA INSTITURE, 2015). Many parents are failing to adequately educate their children because of poverty in most SSA countries.

Based on the coefficients across all models, openness to trade could benefit SSA in the range between 0.06% and 0.17% of annual increase in economic growth. Thus, trade liberalisation gains SSA though not substantially. Due to other factors such as competitiveness on the international market, international relations (being under economic/or targeted sanctions e.g. Zimbabwe), political stability and, sound financial and monetary system, the gains of trade openness are often different among individual countries. Manwa and Wijeweera's (2016) suggested that South Africa benefited from its trade liberation strategies compared to Namibia, Lesotho, Botswana and Swaziland. This study beliefs that the weak contribution from trade liberation policies may also be linked to the terms of trade (TOT) in SSA, which have not really developed much mainly as a result of relying on the trading primary commodities. Despite the suggested positive contribution of TOT, the IMF (2016) argues that the sharp fall in commodities prices cause serious strains on several SSA countries, with oil exporting economies (e.g. Nigeria, Angola) encounter challenging economic conditions, so do non-energy commodity exporting countries such as South Africa, Ghana and Zambia. In addition, countries such as Zimbabwe, Malawi and Ethiopia are facing serious drought. Basically, due to smaller value of primary products, commodity shocks and fluctuating prices, SSA countries could not realise the full potential growth contribution of TOT.

Institutional quality development shows a positive (but very smaller) growth contribution in SSA. This shows the importance of improving political stability and absence of violence/terrorism, governance, freedom, and personal safety, which are captured in our measure for institutional quality. Sound institutional qualities create a conducive investment environment that attracts foreign investment and enhances productivity of local investments (by avoiding unnecessary disturbances caused by strikes and demonstrations), and ultimately improves economic growth. We do not realize enormous growth contributions probably because the institutional qualities in SSA are on average poor (see Barry & Tacneng, 2014). Disputed elections, violence and loss of lives have been common in Africa, Gambia and Kenya being the latest examples. Political fragility has also been associated with a number of military coups in several SSA countries (for example, DRC, Cote d'Ivoire, Chad, Guinea, Niger, and Mali) in the 21st century (see Barka & Ncube, 2012).

3.4.7 Key Policy Implications

Our results reveal a number of implications. First, the level of infrastructure quality in SSA tend to moderate the nexus between the existing infrastructure stocks and GDP per capita. This implication is drawn from the absolute effects of the hybrid indices that are essentially lower than the infrastructure stock effects. The hybrid indices in this essay were constructed (*stock index* × *quality index* = *hybrid index*) with the logic that the quality features of infrastructure may act as weight that improves (or impedes) the growth contribution of the existing infrastructure stocks if the quality level is better (or poor). The hybrid results of this essay implies that the poor quality of infrastructure stocks in SSA basically hinder the potential benefits of the infrastructure sectors. Improvement in the quality of existing infrastructure stocks may raise the growth contribution of various infrastructure sectors. It seems plausible for researchers to consider also the application of hybrid indices, which allow a simultaneous capture of both quantity and quality features for each infrastructure sector.

Second, the observation that the infrastructure quality effects are generally weaker than the quantity effects and that they hinder the benefits obtainable from various infrastructure sectors (as argued above), implies that policy makers should increase the proportion of annual infrastructure funding towards the improvement of the existing infrastructures and other necessary innovations. Under such circumstances, the infrastructure quantity in each sector will be able to effectively contribute to economic growth given the additive effect from enhanced quality. We have already revealed in our results that, for instance, paved roads and airport runways can contribute significantly in the long-run.

Irrespective of the importance of infrastructure quality, the issue of the qualitative effects that are generally smaller than the quantitative effects may imply something different. We cannot ignore the implication that an additional infrastructure in a region where the shortage of infrastructure is severe (as in SSA) can be of great value and possibly producing relatively great marginal impacts than in places with enhanced infrastructure. What it means is that, for instance, having additional subscribers of telecommunication may produce vital benefits than the issues of connectivity and waiting time in a region where most people have no access to telecommunication. We believe that in developed regions where infrastructure shortages are less of a problem, enhancing the quality of the infrastructure may produce higher marginal economic growth effects than marginal effects of from additional infrastructure.

The fourth implication drawn from hybrid effects being lower than stock effects has to do with methodological approach, which is an important insight to both policy makers and researchers. This outcome may say something about the application and possible performance of different aggregators. In particular, we applied both a product aggregator (in this chapter) and a linear aggregator (in chapter two) to construct the hybrid indices that capture the combined impacts of both infrastructure stock and quality. The use of a linear aggregator is something that has not been closely interrogated in the literature (see Alvarez et al., 2006). The implication from the linear aggregator is that the explicit capture or accountability of infrastructure quality features brings additional effects such that the hybrid effects will be greater that the stock effects alone (see previous chapter). On the contrary, the product aggregator implies that when quality features are captured, the hybrid impact will be lesser than the stock effects alone. Despite the fact, these two aggregators are important and we believe their central policy suggestion is one, that is, improvement of infrastructure quality in SSA matters. More precisely, a linear aggregator as in chapter two is plausible when the variables to combine have same measurement scale and the new indices may reveal a better statistical distribution. What the linear aggregator says is that improved infrastructure quality brings extra effects to the contribution of the entire infrastructure system. A product aggregator brings in the idea of potential moderation by which the infrastructure quality attributes may moderate the contribution of the existing infrastructure stocks to GDP per capita. Either way, while fighting the shortage of infrastructure in SSA, policy makers should not neglect the importance of quality. Infrastructure quality may improve with technology and innovation or deteriorate due to poor maintenance, both with bearing on economic performance.

Fifth, our results that access to agricultural water for the rural population exerts a negative pressure on economic growth in the short-run while its long-run growth effects are not statistically significant may imply that the provision of water for agriculture (or irrigation) alone cannot stimulate agricultural productivity in rural areas if farmers lack other key resources such as skill, fertilizers, pesticides, among others inputs. Aside, we believe that the poor performance of agricultural water for the rural population might be a measurement-related problem. For instance, roads and water for agriculture in rural areas can yield important benefits but the GDP measure may not adequately reflect or capture the rural economy. Under such circumstances the actual contribution of infrastructure to economic growth will be undermined. This is a possibility that policy makers should consider. Additionally, SSA should continue increasing the number of people with access to improved water sources. The countries should know the economic losses posed by the population without access to improved water. This population is prone to waterborne diseases, leading to economic costs in terms of healthcare expenses, loss of working days due to sickness and loss of productivity. It is crucial to spread improved water sources across residential areas. Planners must make sure that the boreholes are strategically located especially in rural areas in order to shorten the distance travelled. Persistent maintenance of the improved water sources is fundamental as well. In rural areas community-based management could be effective. With water treatment becoming a challenge in countries such as Zimbabwe, we endorse the use of borehole system in urban areas (Zimbabwe has already put boreholes in cities and towns though maintenance is still wanting).

A sixth key implication of this study is drawn from the cross-section dependency among SSA countries in terms of the infrastructure measures (see Table 3.2). It is important for policy makers to consider this cross-section dependence when formulating their infrastructure investment policies. Except for electricity quality, changes in other infrastructure variables in one country tend to impact similar variables in other regional countries. This kind of cross-dependence may entail possible infrastructure spillover effects across SSA countries. In the presence of cross-section dependence and implied spillovers, countries can benefit from each other's infrastructure. At times in the presence of cross-section dependence, other policies are best made at regional level than country. Possible cross-dependency in this chapter inspires a critical examination of infrastructure spillovers in chapter five, with vital policy inferences of the spillovers discussed.

Furthermore, our results may suggest that the current trend of rising mobile services is not productively taken advantage of, while it advances unrelated business use of social media through mobile internet. This is based on the telecommunication stock effects that are weak, especially in the short-run despite massive improvements in the number of subscriptions by 2014 (roughly 86 per 100 persons in 2014, while it was 6 in 2000), mostly from mobile (see Figure 3.3). Minor benefits are also obtainable from telecommunication quality. Telecom quality improvements are expected to generate higher returns especially in the long-run when the new innovations are used beneficially in areas such as education and learning, and marketing, among other vital uses. Apart from the productive use of the new telecommunication technologies, the quality of the telecommunication sector in SSA is still low, which might be one of the reasons for the minor growth effects. Private participation in the telecommunication sector may improve performance. Poor legal framework, degree of state intervention and weak regulation levels obstruct the measures that are set to improve competition and attracting investments in the telecommunication sector of developing economies (Paleologos & Polemis, 2013). Moreover, the respective governments should note that the common power outages in SSA may impact negatively on the performance of the telecommunication sector (see Malakata, 2015).

The negative coefficient for transport stock in both long-run and short-run has other vital implications. SSA economies may tend to underutilise roads and airports for productive purposes thus failing to yield greater economic benefits over and above the cost of constructing these infrastructures together with the costs of pollution from transportation sector. A greater proportion of inefficient and mostly second hand vehicles in most SSA countries may intensify the pollution levels. Deng (2013) also raises the issue of conducive environment, urging that productivity depends on the economy's capacity in allowing development, including an effective utilisation of transport infrastructure, proper human capital and incentive strategies. Policy makers should ensure favourable environments (e.g. with high economic activity, low unemployment, less pollution from old cars) that may augment the productive use of roads and airports. In line with Canning and Pedroni (2008), we also believe that the construction of these transport infrastructures may drain public funding from other potential investments, which overwhelm the benefits of having additional roads and airports, such that the net impact becomes negative. Despite the negative growth effects of transport stock, our evidence suggest that improving the state of transport infrastructure (i.e. roads and airports) will positively impact growth in the long-run though the effect could be insignificant in the short-run. Thus, policy makers should take note of the time lags before investment in paveways start making significant growth impacts. To ensure sustainable growth, SSA countries should persistently maintain their roads and airports. Most importantly, transport infrastructure could bring several benefits in the agglomerated area through network dynamic externalities, which are difficult to accurately measure.[35] Overall, transportation infrastructure investment is worth pursuing.

Additionally, SSA countries should prioritise funding the power sector, which proved to contribute positively to economic growth in both short-run and long-run when the supply of electricity increases. Despite the positive growth effects, electricity has not fully benefited SSA because of enormous energy gaps (demand > supply). This problem is aggravated by the poor state of electricity sector as demonstrated by the general rise in average electricity transmission and distribution losses. Accordingly, electricity quality developments suggest negative growth effects in SSA. Policy wise, electricity conservation strategies that reduces the supply of electricity (e.g. load shedding) could hurt economic growth. On the other hand, it is important for the respective economies to diversify their electricity sources rather than relying on the traditional sources of coal and hydro. Universal electrification may require speeding up other electricity sources like the solar system and bioenergy in SSA (see also Ramamurthi, Fernandes, Nielsen, & Nunes, 2016). Shifting towards renewable energy sources is fundamental for the sake of long-term sustainability. It is an excellent opportunity as noted by the International Energy Agency (2014) that the African continent is basically

[35] In such cases, policy makers have to move beyond the estimated growth coefficients when planning to invest in transport sector.

endowed with abundant renewable power potential. Other researches (e.g. Al-mulali et al., 2014) indicated that the improved use of renewable energy can have greater contribution to growth than non-renewable. Due to inadequate grid-based power supply and outages in SSA, the use of solar energy is better than fuel back-up generators which are expensive. Minimising electricity transmission and distribution losses is also key to ensure efficiency and increased end user-power utilisation at reduced prices in SSA.

In general, the existing infrastructures are in short supply and poorly maintained due to wider financing gaps in most SSA states. Unreliable electricity supply, crumbling roads, poor telecommunication services and inadequate provision of safe water and sanitation undermine economic growth in SSA (see Hove, Ngwerume, & Muchemwa, 2013). Another explanation is that the existing infrastructures are underutilised due to low levels of economic activity (with high unemployment rates) in most SSA countries. As such, the environments in which public infrastructure funds are pumped into matter. Policy makers in SSA should make great efforts in creating favourable environments that can foster economic development. Strong evidence of cointegration between the various infrastructure measures and GDP per capita shows the existence of a long-run stead-state relationship, which is highly crucial for investment commitments in both infrastructure quantities and qualities.

Other implications of the results based on control variables are fully discussed in chapter one. Our results indicate that price stability is necessary as high inflation can harm economic growth. SSA countries are strongly argued to continue boosting human development, which tend to have enormous gains. Efforts towards meeting universal education (the key driver for human development) in the continent are warranted. Improving health, which is part of human development is also a necessity. More so, SSA economies stand to gain further from TOT if they would reduce their heavy reliance on exportation of primary commodities, which have less value than finished products. Enhancing institutional qualities in SSA is highly required as well. Institutional qualities are very poor in the region. For instance, most SSA countries often experience violence and disputes during election periods. Freedom of expression is not yet present in several SSA countries. Some benefits are attainable from trade openness, which has mostly been as a result of both regional integration and specialisation. Economic integration has been facilitated by regional communities such as SADC, COMESA, EAC and ECOWAS. Specialisation in commodities (e.g. minerals, agricultural produce) and exporting to the Europe Union has been common through various multilateral and bilateral trade agreement. Recently, however, China has become another major trading partner of the African states. The negative growth effect of financial depth shows the poor state of financial system in SSA and hence weak financial intermediation. The majority of people also fail to have access to loans due to lack of collateral security (see Dahou et al., 2009). Dahou and others also mentioned that interest rate spreads reveal the high cost of credit, while at the same time capital markets remain underdeveloped in Africa. It is vital for the representative governments to create investment opportunities in domestic capital markets for both foreign and local investors, which may include favourable laws regarding foreign ownership and institutional qualities.[36]

The respective governments can gain more from improving sanitation facilities, especially in the long-run. The short-run benefits of improved sanitation tend to be weak. One explanation is that SSA countries on average have made limited progress to improve sanitation since 2000 as indicted in Figure 3.1. This should worry the representative countries, which must then raise the proportion of public funding towards the sanitation sector.

3.5 Conclusion

The projected economic growth contributions of the existing infrastructure stocks in SSA may be over-estimated if the quality characteristics of such infrastructures are not fully captured in the analysis. The emerging consensus is that increased infrastructure supply drives economic growth. Nevertheless, little is known regarding the long-run and short-run economic growth effects of both quantitative and qualitative measures of the various infrastructure sectors (for example, electricity, telecommunication, transportation and water). As discussed in the introduction we also contribute to the literature by examining the short-term and long-term growth effect of each infrastructure sector from the hybrid indices perspective. This is step from Loayza and Odawara (2010) who implemented the indices of the same nature but based on aggregate indices that combined key infrastructure sectors (transport, electricity, telecommunication) and focused on short-term effects in GMM framework. A hybrid index provide more information by simultaneously accounting for both quantity and quality effects of existing infrastructures. This index may be interpreted as an effective contribution of a particular infrastructure sector to economic growth. Moreover, it bring the idea of the state (or quality) of infrastructure being able to moderate the relationship between infrastructure stock and economic growth. In this study, we investigate both long-

[36] In 2008, Zimbabwe passed an Indigenisation and Economic Empowerment Act that pushes foreign firms to transfer at least 51% of share ownership to black Zimbabweans. This policy is believed to cause foreign investors to shun Zimbabwe.

run and short run impacts of each single infrastructure sector with water included as well, employing data for 42 SSA economies over the period 2000-2014. We begin by investigating cross-sectional dependence using Pesaran's CD test. Pedroni and Kao cointegration tests are used to examine the existence of a long-run equilibrium relationship between GDP per capita and the various infrastructure variables while the FMOLS estimator reveals the long-run infrastructure growth elasticities. The short-run effects are estimated using the dynamic *system*-GMM.

The CD test indicates strong cross-section dependency between the SSA countries in terms of GDP and all the infrastructure measures except for electricity quality. Dependence between countries also exist in the case of other key growth factors (i.e. trade openness, financial depth, human development, term of trade, inflation and institutional quality). Thus, changes of each variable in one of the countries tend to affect other regional countries. Policy makers should consider this dependency when formulating their domestic policies with regard to these variables. We found evidence of cointegrating relationship between the various infrastructure measures and economic growth. Our FMOLS estimator shows that developments in the stocks of electricity and telecommunication can positively impact growth in the long-run. Increases in transport stock (quality) suggest a negative (positive) growth effect in the long-run. The negative growth effects from transportation sector may suggest that roadways and airport runways are not fully and productively utilised to generate economic benefits above the cost of constructing these infrastructures. Construction of these transport infrastructures may drain substantial government funds which could have been invested in other key economic activities like education. In the long-run, the quality effects of telecommunication and sanitation are positive.

The *system*-GMM also suggest that developments in transportation stock have negative growth contribution while transportation quality does not have significant impact in the short-run. While electricity stock contributes positively to growth, developments in the quality of electricity exerts negative effects on growth in SSA. As illustrated in Figure 3.2 in the Appendix, we also observe deterioration in the quality of electricity sector in SSA over the 13 year period.[37] Thus, high levels of electricity transmission and distribution losses in SSA are hurting economic growth. Telecommunication stock and quality show positive growth effects

[37] While we applied the inverse of the ratio of electricity transmission & distribution losses (RETDL) such that the higher the value (lower losses) the better the quality, it is worth noting that even the use of RETDL in the system GMM does not change the results. This is vital for the clarity of our interpretation with regard to the negative coefficient of the electricity quality indicator. Overall, the rising RETDL tend to reduce GDP growth.

in the short-run though the impacts are weak. Provision of agricultural water suggests a negative effect on growth in the short-run while the coefficient for improved drinking water is positive but not significant. Moreover, sanitation quality has positive growth effect in the short-run. The weak growth effect from sanitation are not surprising given the greater proportion of people who remain without access to improved sanitation in SSA. Except for water, the hybrid (or interaction) coefficients across the infrastructure sectors are positive and significant but smaller in magnitudes as compared to the stock effects. Generally, we cannot negate the possibility that the quality features may moderate the relationship between infrastructure stock and GDP per capita. Poor state of the existing infrastructures tend to reduce the effectiveness of the existing infrastructure stocks in general.

In view of the findings, it is plausible to consider hybrid indices in addition to stock and quality measures of infrastructure when analysing the infrastructure-growth relationship. Hybrid measures allow for extra information regarding potential moderation effect of the infrastructure quality. The existing infrastructure stocks will not fully contribute to growth if the qualities are poor. As far as this paper goes, we conclude by saying, "*Because infrastructure investments in SSA have tended to have weak growth effects and even negative effects in cases such as transportation and water stocks, the drive for infrastructure investment has to be carefully planned depending on country specific needs*."

CHAPTER FOUR

ELECTRICITY CRISIS AND THE EFFECT OF CO_2 EMISSIONS ON INFRASTRUCTURE-GROWTH NEXUS IN SUB SAHARAN AFRICA

4.1 Introduction

Sub Saharan Africa (SSA) is a region for over 950 million people but also with the poorest access to electricity in the world (Avila, Carvallo, Shaw, & Kammen, 2017). The World Development Indicators reveal that CO2 emissions from electricity and heat production (CO2EM), and the ratio of electricity transmission and distribution losses (RETDL) have been rising in SSA over the past decades, implying deterioration in efficiency of the power sector. Consequently, poor electricity access is believed to remain the key obstacle to most businesses and economic growth in several SSA countries (Lemma, Massa, Scott, & Willem te Velde, 2016), while potential threats from greenhouse gases is associated with substantial negative impact in SSA given the persistent rise in CO2EM in the region (Gao & Zhang, 2014). CO2 emissions cause environmental problems and to mitigate their consequences, many nations have signed the Kyoto Protocol and pledged to lessen their emissions (Esso & Keho, 2016).

Recently, with increased focus on the Sustainable Development Goals (SDGs), studies on the impact of electricity consumption and CO2 emissions on economic growth remain vital to inspire energy policy and academic research. Interest in the potential nexus between electricity consumption, CO2 emissions and growth is traced back to the 1970s when scholars begun to notice the probable connection between these variables (Mezghani & Haddad, 2017). Several studies have empirically tested the environmental Kuznets curve (EKC) that hypothesizes environmental quality and economic growth nexus. The EKC suggests that environmental degradation initially increases and then declines as economic growth continues to rise. Since then, plenty of literature investigated the cointegration between electricity, CO2 emissions and growth (for example, Gao & Zhang, 2014; Asongu, Montasser, & Toumi, 2015; Ahmad et al., 2016), and/or the direction of causality between these variables (for example, Cowan et al., 2014; Esso & Keho, 2016). Generally, most research findings show evidence of cointegration between electricity, CO2 emissions and economic growth.

Despite considerable amount of extant studies, firstly, accounting for electricity quality is still lacking and remains a serious gap in the empirical literature. Secondly, measuring both the nature and size of the influence of electricity-related CO2 emissions on the growth contribution of electricity stock (quantity) and quality is another aspect that has not been properly interrogated in the literature. Given these gaps, this essay investigates the economic growth effects of both electricity stock and quality. In terms of our contribution, while most existing studies have investigated the connection between electricity stock (mostly, electricity consumption), CO2 emissions and economic growth (for instance, Salahuddin et al., 2015; Saidi & Hammami, 2015; Salahuddin et al., 2016; Bouznit & Pablo-Romero, 2016; Mezghani & Haddad, 2017), to the best of our knowledge, we are unaware of studies that examine the nature and size of CO2EM's influence on the growth contributions of both electricity stock and quality. This essay assesses the impacts of electricity stock and quality before and after accounting for electricity-related emissions in order to measure the influence of these CO2 emissions. We develop a CO2 emission index that takes the initial year 1990 as base year and then traces the changes in the electricity-related emissions up to 2014. Addressing these major concerns in our view will help illuminate trajectories of energy policy in SSA, especially in the light of the serious shortage of electricity and high levels of CO2 emissions from electricity and heat production. Another vital contribution that emerges from our results is that electricity-related CO2 emissions can diminish the positive economic growth contribution of electricity stock and worsens the negative impact of electricity quality on growth in SSA. From a policy standpoint, we argue that the use of carbon capture technologies (with help of subsidy) could be superior to carbon taxes to lessen the adverse effects of emissions on electricity. In particular, such carbon capture technologies may reduce the effects of emissions without necessarily discouraging the production of electricity, which is still at low levels in SSA. Where carbon taxes are applicable, it is might be useful to account for the impact of the emissions on electricity sector in the structure of a carbon pricing. In both cases, a subsidy is vital to ensure that the cost of carbon technologies or carbon tax burden is not severely passed on to the end users of electricity in terms of high prices.

The rest of the study is organised as follows: Section 2 gives a brief literature survey. Section 3 provides an overview of the electricity shortage and efficiency in SSA. Section 4 presents our approach for the influence of electricity-related CO2 emissions on the growth contributions of electricity stock and quality. Section 5 discusses the key findings and implications of results. Finally, the concluding remarks are provided in section 6.

4.2 Brief review of literature

It is imperative to highlight briefly the Environmental Kuznets Curve (EKC) hypothesis that involves the connection between economic growth and environmental quality. We cannot go into detail since the validation of the EKC is not the concern of this study. The concept of the EKC emerged from the work of Grossman and Krueger (1991) on the environmental impacts of a North American Free Trade Agreement (NAFTA). The EKC was named after Kuznets (1955) who postulated an inverted U relationship between income inequality and economic development (see also Stern, 2003).

The EKC hypothesizes the relationship between growth in per capita income and environmental degradation which is believed to be inverted U-shaped. The notion behind this theory is that in the early stages of development when primary production is the key, there are plenty of natural resources and partial generation of waste due to less economic activity (Kaika & Zervas, 2013). As economic development progresses with industrilisation taking place, there is significant depletion of resources and accumulation of wastes. A positive link between economic growth and environmental degradation occurs in this phase. However, based on this theory, further economic development is expected to overcome environmental degradation that took place in the initial stages of economic growth and hence producing an inverted U-shaped relationship between economic growth and environmental degradation. In other words, at higher levels of economic development (which is associated with enforcement of environmental regulations, environmental awareness, higher environmental expenditures and improved technology), environmental degradation declines (see Panayotou, 1993). The implication of the EKC hypothesis is that economic development is not a threat to global sustainability (Stern, Common, & Barbier, 1996). In other words, if this inverted U-shaped curve holds, then instead of being an environmental risk (as claimed by environmentalists), economic development would be the means to ultimate environmental improvement (see Stern, 2004).

Since the inception of the EKC concept, quite a number of empirical studies have investigated the validity of this curve. While others (for instance, Pao & Tsai, 2010; Lau, Choong, & Eng, 2014; Gao & Zhang, 2014; Farhani & Shahbaz, 2014; Bouznit & Pablo-Romero, 2016; Al-Mulali, Solarin, & Ozturk, 2016) found the validity of this hypothesis, some (for instance, Stern et al., 1996; Vincent, 1997; Coondoo & Dinda, 2008; Ozturk & Al-

Mulali, 2015; Lacheheb, Rahim, & Sirag, 2015) could not find evidence for the inverted U-shaped relationship between pollutants and income.

Electricity and heat production being among the key sources of CO2 emissions, a body of empirical studies investigated the relationships between electricity, CO2 emissions and growth. Among the recent literature, using the autoregressive distributed lag model and vector error correction model, Ahmad et al. (2016) revealed the existence of a long-run cointegrating relationship between energy consumption, CO2 emissions and economic growth, and their results validate the Kuznets curve. Moreover, they found feedback effects between CO2 emissions and growth, and a positive nexus between energy and CO2 emissions. Salahuddin et al. (2015) examined the link between CO2 emissions, electricity consumption, economic growth and financial development in the Gulf Cooperation Council (GCC). Their results suggested that economic growth and electricity consumption are positively related with CO2 emissions while financial development negatively impact CO2 emissions. They also found evidence for causality from electricity to CO2 emissions, and a two-way causal link between growth and CO2 emissions.

In Saudi Arabia, Mezghani and Haddad (2017) found that huge volatility of electricity consumption tend to have negative impacts on oil GDP and CO2 emissions while it positively impact the non-oil GDP. Additionally, low and high volatility of oil GDP were found to have positive effects on CO2 emissions and electricity consumption. More so, the results of Apergis and Payne (2010) suggested a positive relationship between energy consumption and CO2 emissions, with output showing the EKC hypothesis in the long-run. This includes a one way causality from electricity consumption to real output. Kim and Baek (2011) demonstrated that a rise in energy consumption can damage environment in the long-run. Analysing the Turkish power sector, Atilgan and Azapagic's (2016) findings indicated that fossil fuels are accountable for roughly 88-99.9% of environmental effect related to electricity generation. From economic assessment, their results suggested capital costs of US$69.3billion for 49524 MW of installed capacity in 2010, by which hydro, coal and gas contributed 43%, 31% and 22%, respectively.

Furthermore, Cowan et al. (2014) investigated the connection between CO2 emissions, electricity consumption and growth in BRICS economies. In terms of electricity-growth relationship, they found evidence for the conservation hypothesis in South Africa, feedback hypothesis in Russia and neutral hypothesis in India, China and Brazil. For the CO2 emissions and GDP connection, mixed outcomes were shown, that is, GDP to CO_2 emissions (South Africa), CO_2 emissions to GDP (Brazil), feedback hypothesis (Russia) and no Granger causality (China and India). In the African context, Bouznit and Pablo-Romero (2016) confirmed the validity of the EKC in Algeria, however, with a turning point attained for a very huge GDP level, suggesting that economic growth in the country continues to increase CO_2 emissions. Furthermore, there was evidence that increased electricity consumption can raise CO_2 emissions. The inverted U-shaped hypothesis was also documented in Kais and Sami's (2016) work. In a number of SSA countries, Esso and Keho (2016) found power consumption and growth to be associated with rise in pollution in the long-run.

Based on 30 Chinese provinces, an analysis by Ding and Li (2017) suggested that economic development factors are the greatest drivers for regional emissions compared to structural change factors, energy intensity and social transition. Moreover, urbanisation was found to contribute to emissions via changes in energy use characteristics of business sectors, transportation and urban households, among other factors. Rue du Can, Price, & Zwickel (2015) indicated that when allocating CO_2 emissions based on end-user sectors, the share of buildings sector rises the most from 9% (direct emissions alone) to 31% (including indirect emissions), showing the great share of electricity and heat utilised by this sector.

Finding suitable strategies to reduce CO_2 emissions is another key issue. Li, Wang, Zhang, and Kou (2014) found carbon pricing to be an effective measure for lowering CO_2 emissions in China, in which the reduction ranges from 6.8% to 11.2% in the short-run. They also mentioned that in the long and mid-term, the effective policy is to target carbon revenue with competitive price of electricity. Wu, Wang, Pu, and Qi (2016) demonstrated that amending the structure of energy to utilize renewable energy and recycling solid waste can substantially lower CO_2 emissions.

In sight of the above, most researchers tend to examine evidence of cointegration and causality between electricity consumption, CO_2 emissions and economic growth. Plenty of the studies found evidence of cointegration between these variables, implying a long-run relationship. Evidence for the actual direction of causality between electricity consumption and economic growth is mixed in the extant literature. Some studies found the validity of EKC hypothesis in their analyses, suggesting a decline in emissions at higher levels of economic growth. In spite of several work done in this field, the literature has not interrogated and address the extent to which CO_2 emissions may alter the signs and sizes of both electricity stock and quality's effects on GDP per capita. Consequently, this essay brings in knowledge from this other angle, which is expected to be useful for policy making.

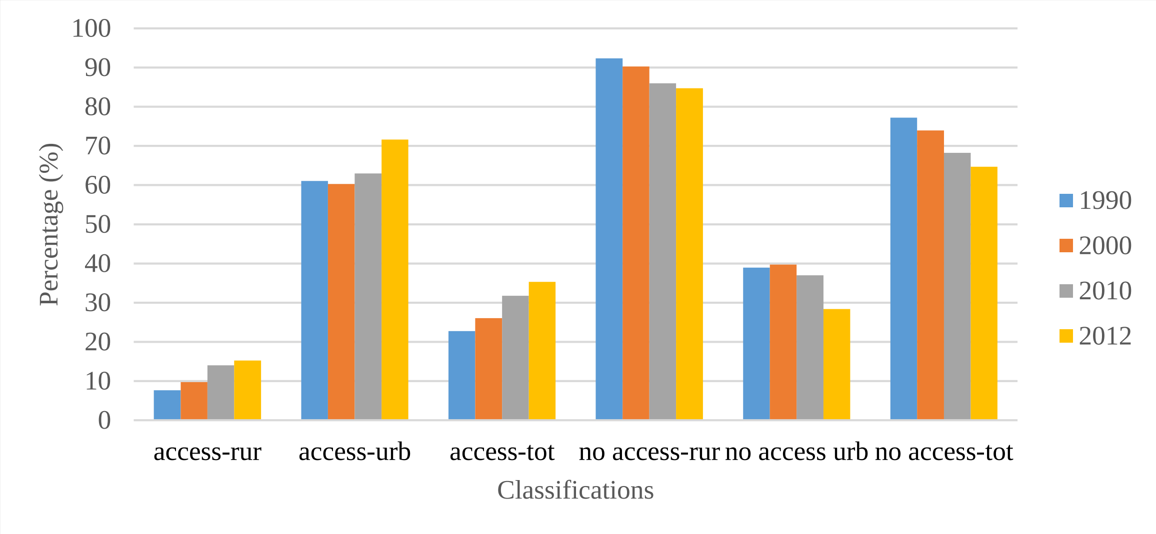
4.3 Overview of electricity shortage and efficiency in SSA

Among the infrastructure problems, the shortage of electricity is a major hindrance to firms' growth and household welfare in SSA. This has also been aggravated by poor quality in the production and provision of electricity as demonstrated by the high ratio of electricity transmission and distribution losses, which tend to exert negative pressure on economic growth (see Calderon, 2009; Chakamera & Alagidede, 2017). More so, CO_2 emissions from electricity and heat production can be problematic to SSA's potential growth. Prior to our investigation of the influences of CO_2 emissions on electricity sector performance, we provide an overview regarding the extent of electricity shortage, effectiveness and efficiency (based on CO_2 emissions from electricity, and transmission and distribution losses) in electricity provision in SSA as compared to other regions.

4.3.1 The extent of electricity gaps

Irrespective of considerable rise in the population with access to electricity in SSA, approximately 530 million persons remain without electricity in 2014, very far from the desirable progress (International Energy Agency, 2014). Given the data available to us, we use the percentage of people with access to electricity as a proxy of any region's electricity supply. On the demand side, we assume that the total population of a region is the proxy for electricity demand. Consequently, using the World Development Indicators by the Wold Bank, the population without access to electricity represent the supply gap.

It is clear from Figure 4.1 that since the 1990s the majority of the population in SSA remain without access to electricity. Roughly 77% of the total population had no access to electricity in 1990, this percentage slightly fell to approximately 65% in 2012. The bigger proportion of those without access to electricity are in rural areas, which slightly decreases from 92% of rural population in 1990 to 85% in 2012. Approximately 28% of urban population also remained with no electricity in 2012. Only 35% of the population in SSA had access to electricity in 2012, most of them reside in urban areas.



Note: access-rur, access-urb, access-tot stand for percentage of population with access to electricity in rural areas, urban areas and total, respectively. no access-rur, no access-urb, no access-tot stand for percentage of population without access to electricity in rural areas, urban areas and total, respectively.

Figure 4. 1: Access to electricity in SSA

Data source: Author's constructs based on World Development Indicators.

Compared with other regions, SSA has the lowest percentage of total population with access to electricity as indicted on Figure 4.2a. While only 35% of SSA population had access to electricity by 2012, Middle East & North Africa (MENA), South Asia (S.Asia), Latin America & Caribbean (LA&Car) had roughly 96%, 78%, 96%, respectively. Compared to these regions and until recently, SSA automatically has a relative big proportion of its population with no access to electricity. In the figure, North America (N.Amer) and the Euro Area proved to be giants with almost everyone having access to electricity (100%) since the 1990s. Additionally, Figure 4.2a shows that access to electricity in SSA is far below the middle income (M.Inco) and world benchmarks. The gap between SSA and the world benchmark slightly narrows from approximately 52% to 49% between 1990 and 2012 while that against the middle income group slightly widened from 51% to 53% in the same time period. Furthermore, SSA's population with access to electricity is slightly above the low income (L.Inco) group. However, some of the countries in the low income group are within SSA.

In addition, a significant number of urban residents still remain without electricity in SSA as compared to other regions. In SSA, the proportion of urban population with access to electricity increased from roughly 61% in 1990 to 72% by 2012 whereas in the MENA, S.Asia, LA&Car it has been generally above 95% since 1990 (see Figure 4.2b). Also in this case, the proportion of urban population with access to electricity in SSA is below the middle income and world levels. However, SSA only manages to narrow the gap against the middle income level from roughly 33% in 1990 to 26% in 2012, while that against the world was narrowed from 33% to 25% by 2012. As in Figure 4.2a, SSA's performance is also above the low income group.

Figure 4. 2: Access to electricity regional comparison

Data source: Author's constructs based on World Development Indicators.

Figure 4.2c shows that the problem of electricity is more critical in the rural areas of SSA than other regions. Since 1990 approximately over 70% of rural population has access to electricity in MENA, over 60% in LA&Car, only rose above 60% in S.Asia as from 2010, and roughly 100% in North America and the Euro Area. Unfortunately in SSA, access to electricity in rural areas only rose from approximately 8% in the 1990s to 15% by 2012. Thus, the majority of rural residents in SSA have no access to electricity compared to these other regions. Moreover, in terms of access to electricity in rural areas, the gaps between SSA and the middle income and world benchmarks tend to widen with SSA lagging behind. In particular, the gap against the middle income group widened from 55% in 1990 to 63% in 2012 while compared to the world levels it stretches from 53% to 56%. This may also has to do with faster population growth than adjustment in electricity supply in SSA.

Final in this sub-section, Figure 4.2d reveals the electricity gaps with respect to kilowatt hour (kWh) per capita consumption in SSA as compared to other regions. In SSA, electricity consumption per capita rose from approximately 324 kWh in 1971 to 511 kWh in 2000 but then declined to 488 kWh in 2013. The region's power consumption per capita has been lesser than that of Latin America & Caribbean, North America and Euro area since the 1970s. In 2013 electricity consumption per capita was roughly 2118 kWh in Latin America & Caribbean, 13241 kWh in North America, and 6491 kWh in Euro area. Power consumption in MENA was only lesser than SSA in 1971 but continues to rise substantially above SSA in the subsequent years, reaching roughly 2880 kWh by 2013. Per capita power consumption for South Asia only begun to exceed that of SSA in 2010. Therefore, the relative small proportion of population with access to electricity in SSA essentially consumed more kWh per capita than South Asia in 1990s and early 2000s. Moreover, SSA's electricity consumption was above the middle income level before the 1990s.

4.3.2 The degree of electricity sector efficiency

This section discusses the changes in CO2 emissions from electricity and heat production, and the electricity transmission and distribution losses (ETDL). As in the previous chapters, the ratio of electricity transmission and distribution losses (RETDL) is used as a proxy for electricity quality. Rise in the RETDL shows deterioration in electricity quality. Also in this chapter, a rise in CO2 emissions shows low efficiency of the electricity sector. High efficiency minimises both emissions and ETDL. SSA recorded higher ETDL than MENA in 1971 and 1980 but the losses fell slightly below the MENA levels in the subsequent years (see Figure 4.3). Moreover, ETDL in SSA have been better than those experienced by South Asia and Latin America and Caribbean. Also in the past five decades, SSA's ETDL stay below the low income benchmark while it rose above the middle income level as from 2010. The Euro area, followed by North America have minimal ETDL compared to the other regions.

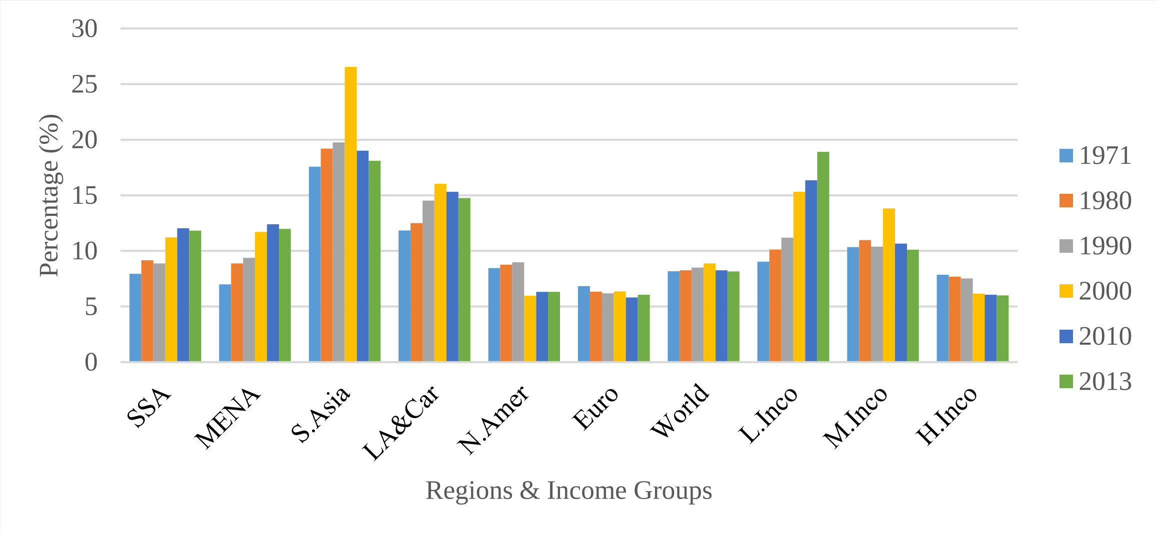


Figure 4. 3: Electricity power transm & distr losses

Data source: Author's constructs based on World Development Indicators.

In Figure 4.4a, SSA remains on top of all other regions in terms of CO2 emissions from electricity and heat production since 1971. This is as a percentage of total fuel combustion. Thus, SSA experiences relatively high CO2 emissions than other regions despite consuming relatively small kWh per capita as indicated in Figure 4.2d. The CO2 emissions from electricity and heat production in SSA increased from 37% of total fuel combustion in 1971 to 53% in 2013. The emission levels are higher than the benchmarks of all the income groups (low, middle and high). On average, Latin America and Caribbean produces lesser CO2 emissions than even North America, Euro Area, South Asia and MENA.

Looking at other sources of CO2 emissions from the energy sector, SSA shows the smallest emissions from gaseous fuel consumption (see Figure 4.4b). In particular, SSA's gaseous fuel emissions are lesser than those of other regions but higher than the low income benchmark since the 1980s. North America has been experiencing the most gaseous CO2 emissions before the 1980s. MENA has recently become the major emitter of CO2 emissions from gas. In Figure 4.4c, SSA's CO2 emissions from liquid fuel consumption generally fell from 30%

in 1971 to 24% in 2000 but climbed again to reach 31% by 2013. However, these emissions from liquid fuel have been below the levels of MENA, Latin America and Caribbean, North America and Euro area since 1971. Also in terms of liquid fuel emissions, the levels of SSA remain smaller than the low income levels throughout the years. Latin America & Caribbean recorded the highest CO2 emissions from liquid fuel consumption over the past decades.

Figure 4. 4: CO2 emissions

Data source: Author's constructs based on World Development Indicators.

Figure 4.4d exhibits CO2 emissions from solid fuel consumption. SSA's solid fuel emissions rose from approximately 57% to 65% between 1971 and 1990 but declined to about 53% in 2013. In comparison to other regions, solid fuel emissions in SSA have been above those produced in the MENA, Latin America and Caribbean, North America and Euro regions since the 1970s. Solid fuel emissions are highest in both SSA and South Asia, in the range between 53% and 63%. High consumption of electricity from coal sources in these two regions (see Figure 4.5b) is the key explanation for highest solid fuel emissions.

4.3.3 Key electricity power sources

According to the International Energy Agency (2014), despite the poor energy supply in SSA, the region is rich in energy resources. Using the World Bank data, Table 4.1 presents the proportions of electricity production from various sources in SSA. In the years shown, coal has always been the major source of electricity production in SSA though its contribution decreases from roughly 67% in 1971 to 54% in 2013. The second main source is hydro, which contributed 18% of total electricity in 1971, 16% in 1990 and 20% in 2013. Only smaller percentages of electricity has been generated from oil and gas sources over the past years. The percentage from gas has been rising. The proportion of electricity production from nuclear is small as well and apparently South Africa has been the only country producing from nuclear. Other sources encompass generation from bioenergy, wind, geothermal and solar. Wind energy to date has been very narrow compared to hydro; solar also has played a minor role while geothermal making up a small proportion of power supply in Africa (International Energy Agency, 2014).

Table 4. 1: Key power sources

	Period					
Source	1971	1980	1990	2000	2010	2013
Coal	67.28%	62.87%	64.21%	62.00%	56.89%	53.66%
Hydro	17.74%	21.29%	16.45%	17.16%	19.87%	20.46%
Gas	0.14%	1.99%	2.94%	3.85%	6.72%	7.90%
Oil	3.74%	2.84%	2.18%	2.37%	2.65%	3.44%
Nuclear	0.00%	0.00%	3.35%	4.06%	2.79%	3.11%

Notes: Full names of the variables - Electricity production from coal sources (% of total); Electricity production from hydroelectric sources (% of total); Electricity production from natural gas sources (% of total); Electricity production from oil sources (% of total); Electricity production from nuclear sources (% of total).

Source: World Bank Group: Word Development Indicators (WDI).

In terms of hydroelectricity proportion (Figure 4.5a), SSA was below MENA only in 1971 but rose above afterward. SSA also exceeded South Asia's hydro ratio in the millennium era, and that of North America and Europe since 1980. The Latin American and Caribbean region has the highest percentage of total electricity from hydro and hence mainly hydroelectric driven. Remarkably, the share of hydro generally tend to decline in MENA, North America, South Asia and Euro over the years, may be with wider exploitation of other sources. Middle income group’s share of hydro power has exceeded the high income group since 1980.

Figure 4. 5: Electricity production from hydro, coal, gas & oil

Source: Author’s constructs based on World Development Indicators.

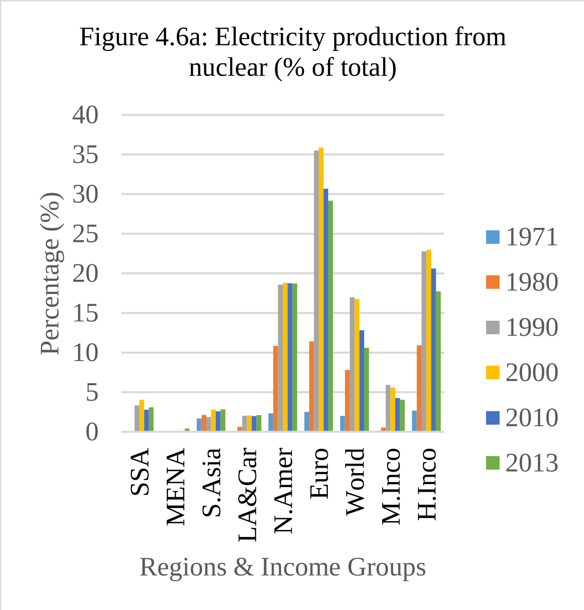
Figure 4.5b shows that SSA relies more on coal than MENA, Latin America and Caribbean, North America, Euro area. The ratio has been above the middle and high income levels since the 1970s. Moreover, the share of electricity from coal in South Asia climbed above all other regions in 2010 and 2013. Basically, SSA and South Asia are more coal electric centred and this explains why these two regions have highest proportion of CO_2 emissions from solid fuel consumption (see Figure 4.4d). Note that several African economies have coal reserves but South Africa has the most reserves (World Coal Association, 2012). In addition, it is believed that several southern African countries have substantial coal reserves that have not been properly exploited.

Meanwhile, SSA has a very small portion of total electricity (below 10%) from natural gas (see Figure 4.5c). This proportion is far below all other regions as well as the levels of middle and high income groups. MENA has had a greater share of gaseous electricity than all other regions since 1971 and the share substantially increased to 65% by 2013 from 15% in 1971. Thus, natural gas has increasingly become the epicentre of MENA's energy, which in turn describes this region's recent majority CO_2 emissions from gaseous sources (see Figure 4.4b). According to the US EIA (2013), SSA contains 221.6 trillion cubic feet of verified natural gas reserves.

In Figure 4.5d, SSA has the smallest proportion of total electricity production from oil (below 4%) over the past decades. On the other hand, MENA has a larger share of energy from oil than other regions. This also has to do with the respective economies' natural endowment of oil resources. However, the share of electricity from oil sources in MENA tend to decline while that of gas rises over the past decades. Nigeria and Angola are the largest producers in SSA. The region has roughly 62.6 billion barrels of crude oil reserves, while Central and South America has 5 times this figure, and Middle East has 3 times this figure (US EIA, 2013).

Furthermore, the proportion of electricity generation from nuclear in SSA has been very small (around 3%) as from 1990 (see Figure 4.6a). The ratio of electricity from nuclear sources in MENA has been zero, recorded 0.4% in 2013. Among the regions, the Euro area has been the one with relatively large proportion of electricity from nuclear, followed by North America. South Africa is the sole SSA country with active nuclear energy plants while there is also interest from other SSA countries to consider nuclear generation (Avila et al., 2017). Avila and others also mentioned that nuclear is a low-carbon resource though it may also have its own environmental, economic, and public safety threats.

Figure 4.6b shows a general trend of increased proportion of electricity production from renewable sources excluding hydro. This is also linked to increased awareness regarding the need for sustainable electricity sources as non-renewable sources such as coal and oil cannot be replenished. Unfortunately, SSA's electricity production from renewable sources, excluding of hydro (as % of total) was still below 1% by 2013. The proportion is even worse in MENA, which has proven to have greater proportions from gas and oil. Increased share of renewable energy has been substantial in the Euro area, reaching 16% by 2013 while North America which is among advanced regions only recorded approximately 6% in 2013. In general, enormous efforts are required across all regions to boost the share of energy from renewable sources given no region attained even 20% by 2013.



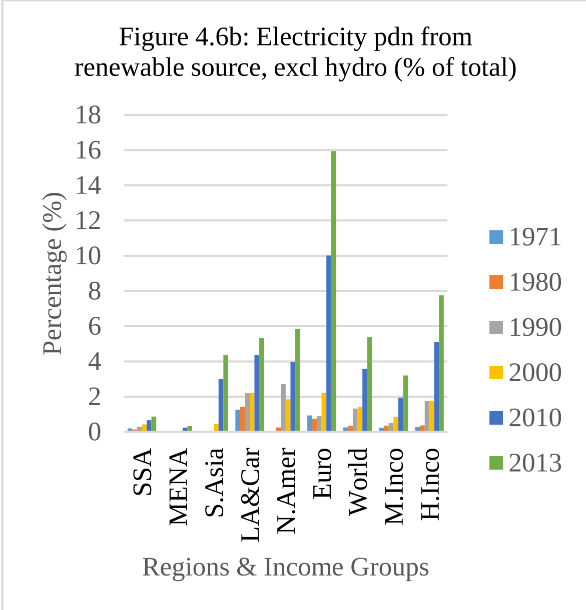


Figure 4. 6: Electricity production from nuclear & renewable sources

Source: Author's constructs based on World Development Indicators.

Figure 4.7 shows fossil fuel energy consumption. MENA has been the highest fossil fuel consumer, followed by North America, Europe, Latin America and Caribbean, and then South Asia. SSA has essentially been the lowest consumer of fossil fuel energy (below 40%). The fossil fuel consumption of SSA falls below world, middle income and high income benchmarks.

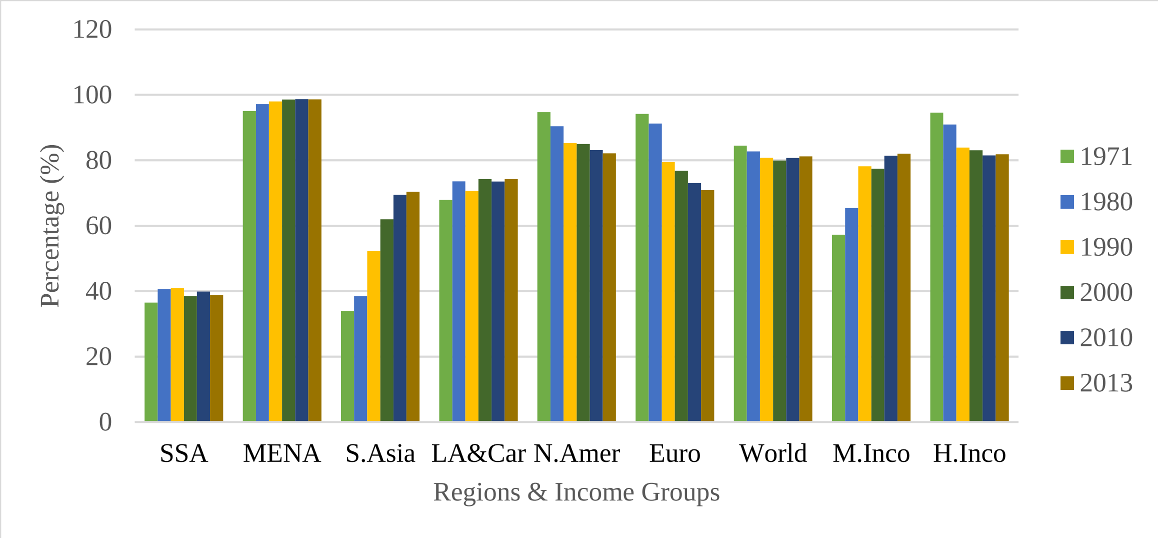


Figure 4. 7: Fossil fuel energy consumption

Source: Author's constructs based on World Development Indicators.

4.3.4 The influence of CO2 emissions on electricity growth contribution

This section examines the economic growth contribution of electricity infrastructure (quantity and quality) in SSA while accounting for CO2 emissions from electricity and heat production. The fundamental idea is to reveal the nature and magnitudes of CO2 emissions' influence on electricity growth contribution. First, we formulate an electricity-related CO2 emission index which takes 1990 as the base year and then traces the changes in CO2 emissions in the subsequent years. Second, the CO2 emission index is used to develop two more indices, namely, the modified electricity consumption (MELEC) and the modified RETDL (MRETDL). The two new indices are the stock and quality measures of electricity after accounting for CO2 emissions through multiplication of the stock and quality indices by the CO2 index. We multiply electricity consumption with the CO2 emission index in order to see how CO2 emissions from electricity and heat production affect the growth contribution of electricity. MRETDL can be interpreted as a measure of any country's effectiveness and efficiency in the provision of electricity by checking both the electricity-related CO2 emissions and distribution losses experienced. We assume that CO2 emissions may have an additive effect on electricity contribution when huge power consumption generates enormous economic returns enough to counter the negative externalities of emissions, otherwise the electricity growth effect is supressed. After incorporating emissions, our results will give an insight whether emissions may moderate the relationship between electricity and GDP per capita. The above are the motives for incorporating emissions to the measures of electricity stock and quality.

4.3.5 Economic growth progression

This section provides a snapshot of how economic growth in SSA has changed in the last decades compared to MENA, middle income and high income levels. This is indicated in Figure 4.8. SSA's GDP per capita increased from approximately US$202 in 1971 to US$1784 in 2013. This is below MENA whose per capita GDP rose from US$328 in 1971 to US$8714 by 2013.

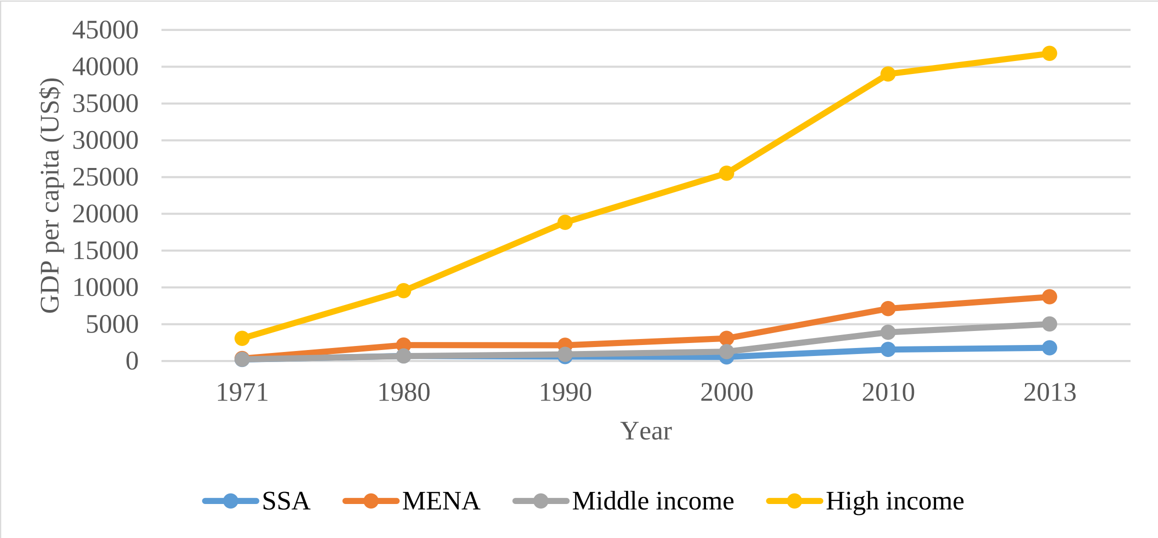


Figure 4. 8: GDP per capita

Data source: World Development Indicators.

While the growth rate of MENA is above that of the middle income group, SSA is at the very bottom. Based on the 2013 statistics, the difference between SSA's growth and MENA was US$6930 while that against the middle income was US$3229 with SSA tailing behind. The difference is substantial, which shows an enormous ground to be covered if catch-up is to happen.

4.4. Brief comparison of the SSA countries in our sample.

We illustrate the extent of electricity access and efficiency for the 18 SSA countries that are analysed in this study. The study focuses only on these countries as they have most of the data available to make comparison. In Appendix 4, Figures 3.8 - 3.11 show the magnitudes of electricity shortage in most SSA economies. Electricity consumption is relatively high in South Africa, followed by the likes of Mauritius, Gabon, Zambia and Zimbabwe (Figure 3.11). Interestingly, the percentage of population with access to electricity is however higher in Mauritius than South Africa (see Figures 3.8 - 3.10). It implies that the distribution of electricity is more equitable in Mauritius than other SSA countries. In the area of efficiency, the electricity distribution losses are better in South Africa but it produces the most CO2 emissions as a percentage of total fuel combustion. We refer to Appendix 4 for more comparison between the various individual countries.

4.4.1 Data issues

The World Bank Group is the source of the data used in this essay, particularly from the World Development Indicators (WDI). The data is for 18 SSA countries over the period 1990-2013.[38] The selection of countries is purely based on data availability for both the time frame in question and the variables of interest. Our electricity stock is represented by electricity power consumption *(kWh per capita)*, and electricity quality is based on electricity power transmission and distribution losses *(% of output) (ETDL)*. The magnitude of ETDL somehow shows the level of efficiency in the transmission and distribution of power. Our interest is on CO2 emissions from electricity and heat production, total *(% of total fuel combustion)* as the third focus variable. The dependent variable is GDP per capita *(current US$)*. In terms of control variables, this study considers (i) Domestic credit to private sector *(% of GDP)* as proxy for financial depth, (ii) Inflation, consumer prices *(annual %)* as proxy for price stability, and (iii) Trade *(% of GDP)* as a proxy for trade openness. Urban population *(% of total)* is also obtained and used as an instrumental variable in 2SLS. All these are from WDI. We also include a coastal dummy (*i.e. 1 if a country is not landlocked and 0 otherwise*) as a fourth control variable. This is based on the possibility that coastal countries may have an advantage in terms of infrastructure gains.

4.4.2 Model and Identification

To examine the relationship between electricity and growth while accounting for the electricity-related CO2 emissions, we consider the following empirical model:

$$\ln gdp_{it} = \alpha_i + \beta_{it} \ln electr_{it} + \phi'_{it} \ln Z_{it} + \gamma_t + \varepsilon_{it} \tag{4.1}$$

(i) $electr = ELEC$

(ii) $electr = RETDL$

[38] Angola, Cameroon, Congo Republic, Cote d'Ivoire, DRC, Ethiopia, Gabon, Ghana, Kenya, Mauritius, Mozambique, Nigeria, Senegal, South Africa, Tanzania, Togo, Zambia, and Zimbabwe.

$(iii)\ electr = MELEC$

$(iv)\ electr = MRETDL$

where all variables are in natural logarithms and $electr$ stands for electricity measure. Based on equation (4.1), different models are estimated by changing only the electricity variable, that is, electricity stock (represented by electricity consumption – ELEC), electricity quality (represented by ratio of electricity transmission and distribution losses - RETDL), modified ELEC (MELEC) and the modified RETDL (MRETDL). Note that MELEC and MRETDL are electricity stock and quality measures that accounts for CO2 emissions. Z is a set of control variables, ε is the disturbance term, and the parameters α , γ stand for intercept and trend included in the models.

Identification problem may arise due to potential endogeneity between electricity infrastructure and economic growth. Infrastructure may also be correlated with other growth determinants and subject to reverse causality. A suitable identification technique is required. Therefore, to overcome this problem we apply the two stage least squares (2SLS) technique, which allows for the use of instrumental variables (see also Wan & Zhang, 2017). Ideally, the instruments will be correlated with the endogenous variable but not correlated with the disturbance terms. However, caution should be taken when applying this approach for weak instruments may affect the estimates. To ensure the validity of our instruments we perform weak instrument test across all models.

4.4.3 Cross-section dependence (CD) test

As discussed in the previous chapter, it is plausible to perform CD test prior to unit root testing because the ‘first generation’ unit root tests that assume cross-section independence can produce biased estimates when dependency exist among cross sections (see Cerasa, 2008). Moreover, cross-section dependence may suggest key policy implications vital for decision making at both national and regional levels. It becomes crucial to consider external factors when the regional countries show dependency amongst themselves, and this buttress certain policies being made at the regional level. In the view of the above, we run cross section dependence test developed by Pesaran (2004). This approach is fully discussed in chapter two. The presence of cross-section dependence necessitates the application of Pesaran’s CIPS unit root test which accounts for cross-sectional dependency.

4.4.4 Pesaran CIPS unit root test

As fully discussed in chapter two, the CIPS unit root test is vital for a number of reasons. Unlike the ‘first generation’ unit root tests, the CIPS accounts for cross section dependence. Moreover, the ‘first generation’ unit root approaches may tend to over-reject the null hypothesis of a unit root in the presence of cross-section dependence (see Burret et al., 2014). Additionally, several studies reached a conclusion that panel data usually exhibit substantial cross-section dependence in the disturbances due to manifestation of unobserved components and common shocks that make part of disturbance terms (De Hoyos & Sarafidis, 2006). This is just a recap of the discussion in the previous essay, thus, this chapter does not go into detail regarding the CIPS framework.

4.4.5 Two Stage Least Squares (2SLS)

Following Bun and Windmeijer (2011), we begin by providing the basic notion behind the 2SLS, which is based on instrumental variables (IV). Assume a model with one endogenous regressor (x_i) and j instruments (z):

$$y_i = \beta_i x_i + \varepsilon_i \tag{4.2}$$

$$x_i = \beta_i' z_i + \varepsilon_i \tag{4.3}$$

$$i = 1,\dots,n$$

A 2SLS estimator of β is estimated as follows:

$$2sls\hat{\beta} = \frac{x'Z(Z'Z)^{-1}Z'y}{x'Z(Z'Z)^{-1}Zx} = \beta + \frac{x'Z(Z'Z)^{-1}Z'\varepsilon}{x'Z(Z'Z)^{-1}Zx} \tag{4.4}$$

Where x is a vector $(x_1,\dots,x_n)'$, y is a vector $(y_1,\dots,y_m)'$ and ε is a vector $(\varepsilon_1,\dots,\varepsilon_n)$.

In this essay, electricity is the endogenous regressor and principal variable in equation (4.1). In order to handle the endogeneity problem, the 2SLS approach first regresses electricity (endogeneity variable) on all explanatory variables in equation (4.1) (i.e. Z) and on the probable instrumental variables excluded from that equation. We consider lagged values of urban population (% of total) as an instrument for the electricity infrastructure. Lagged values of this instrument are found in this essay to be relatively robust compared to the current values. The use of demographic indicators as external instruments for infrastructure variables is also found in other studies such as Calderon (2009) and Calderon and Serven, 2010.[39] They considered current and lagged values of population density and urban population. Their application of demographic measures was also motivated by other scholars (for example, Canning, 1998; Roller & Waverman, 2001) who demonstrated that much of the variations in infrastructure quantities are described by demographic factors, including urbanization and population density. Among other studies, Karanfil and Li (2014) found urbanization to be a key factor of electricity consumption. To ensure that our estimations are not contaminated by poor instruments, we perform weak instrument test. Having discussed the instrumental issue, the first stage model is as follows:

$$\ln electr_{it} = \lambda_0 + \lambda_1 \ln ubnpop_{it} + \lambda_{it}' \ln Z_{it} + e_{it} \tag{4.5}$$

where $ubnpop_{it}$ denotes urban population (% of total). In the second stage, the following regression model is estimated:

$$\ln gdp_{it} + \alpha_i + \beta_{it}\hat{E}_{it} + \phi_{it}' \ln Z_{it} + \gamma_t + \nu_{it}$$

$$\ln gdp_{it} = \alpha_i + \beta_{it}\hat{E}_{it} + \phi_{it}' \ln Z_{it} + \gamma_t + \nu_{it} \tag{4.6}$$

where $\hat{E}$ denotes the fitted values from the first stage regression model and $\nu \equiv \{\varepsilon + \beta(electr\hat{E})\}$ (see also Angrist & Imbens, 1995). The 2SLS thus can be viewed as an instrumental variable (IV) estimator where instruments are Z and $\hat{E}$.

4.5 Key findings and discussion

4.5.1 Summary regarding extent of energy crisis, efficiency and key sources

Analysing the WDIs, the population without access to electricity in SSA slightly declines from roughly 77% in 1990 to 65% in 2012. The majority of those with no access to electricity are the rural folks, approximately 85% of rural population in 2012. We also observe that SSA has the lowest access to electricity in comparison to other regions. For instance, only 35% of total population in SSA had access to electricity in 2012 while the MENA had 96% in the same year. In terms of electricity consumption in 2013, it was roughly 488kWh per capita, far less than 2880kWh in MENA. In this section our comparison is restricted to just SSA versus MENA given other African countries within the MENA group.

[39] The chosen instrument(s) should pass weak instrument test because weak instruments cause the 2SLS estimator to be inconsistent with large standard errors.

In the area of efficiency, electricity power transmission and distribution losses (% of output) have generally been rising in SSA over the past decades. Compared to other regions, SSA is not the one with the highest distribution losses; it has been below South Asia and Latin America and Caribbean from 1971 and below the MENA since the 1990s. In addition, since the 1970s SSA has experienced higher levels of CO_2 emissions from electricity and heat production (% of total fuel combustion) than all other regions. Solid fuel consumption has been the major cause of these emissions. The World Development Indicators show that in MENA greater proportions of CO_2 emissions are from gas and liquid fuels.

As for the sources of electricity, coal has been the major source of electricity production in SSA. South Africa has the most coal reserves and solely a SSA country with active nuclear power plants. While the MENA region is less dependent on coal, its electricity is mainly from natural gas and oil sources. More so, SSA has greater hydro electricity production than MENA. Proportion of hydropower in MENA fell substantially since 1971 (when it was above SSA level) as the region increased its focus on oil and gas sources. Electricity production from renewable sources (excluding hydro) is still very low in SSA, and it is even lowest in MENA.

This analysis reveals the extreme shortage of electricity in SSA, the poor efficiency associated with electricity transmission and distribution losses and highest levels of CO_2 emissions from energy and heat production. The challenges to SSA's electricity development include financing, technical issues and policy mechanisms to advance electricity sector (Avila et al., 2017). The authors attributed high transmission and distribution losses to lack of systematic planning for the energy sector. Additionally, other factors such as unreliable rainfall patterns and extended droughts can adversely affect hydropower, leading to more outages. There has been an involvement of independent power producers (IPP) in SSA to help solve the electricity problem. Involvement of the Chinese oil companies in African power sector has been expanding, however, China is not side-lining Western or United States firms or taking over African power sector as popularly portrayed in media (Cooke & Goldwyn, 2015). Cooke and others also maintain that the African continent is an attractive destination in terms of gas and oil investments due to factors such as proximity to the Asian market and being still underdeveloped.

4.5.2 Electricity-growth relationship and the influence of CO2 emissions

4.5.2.1 Summary statistics

Table 4.2 displays the descriptive statistics for the data. All variables are in natural logarithms. Even though our variables show evidence of skewness, all focus variables, which are logarithms of gross domestic product per capita (LGDP), electricity consumption (LELEC), ratio of electricity transmission and distribution losses (LRETDL) and CO2 emission index (LCO2INDEX) have kurtosis less than the threshold of 3. Consequently, these variables are not fat tailed.

Table 4. 2: Summary statistics

Variable	*Obs*	*Average*	*Std.Dev*	*Min*	*Max*	*Skew*	*Kurt*
LGDP	432	6.662	1.094	4.612	9.353	0.562	2.543
LELEC	432	5.428	1.244	3.075	8.529	0.675	2.979
LRETDL	432	-2.744	1.646	-6.600	0.480	-0.569	2.500
LCO2INDEX	432	0.193	0.155	0.000	0.541	0.423	2.038
LFDP	407	2.677	0.995	-1.618	5.076	-0.230	4.744
LTRA	422	4.153	0.569	1.412	5.187	-1.568	7.122
LINF	431	3.263	1.074	-1.159	10.103	2.746	15.171

Note: Data for 18 SSA countries considered over the period 1990-2013. The LCO2INDEX is the log of electricity-related carbon emission index, formed using the starting year (1990) as a base year and hence trace changes in these emissions from 1990 to 2013.

On the contrary, logarithms of inflation (LINFL), trade openness (LTRA) and financial depth (LFDEP), which are control variables are fat tailed. Excess kurtosis and skewness violate the normality assumption of the data process and may lead to biased estimates especially when the standard OLS technique is used. However, our 2SLS estimator based on the instrumental variable approach overcomes potential problems that may emanate from non-normality. The table also presents the average, standard deviations, maximum and minimum values of the variables. The inflation variable has the highest maximum value indicating that some representative economies recorded extreme levels of inflation in certain periods.

4.5.2.2 Cross-section dependence

Pesaran’s CD test results are indicated in Table 4.3. Except for logs of electricity quality variables (LRETDL and LMRETDL) and the LCO2INDEX, the CD statistics for the rest of the variables are statistically significant at the 1% level and hence the null hypothesis of cross-section independence is rejected in terms of the variables in question.

Table 4. 3: Cross-Section (CD) Dependence test

Variable	*CD-test*	*corr*	*abs(corr)*
LGDP	46.36***	0.765	0.768
LELEC	17.23***	0.284	0.529
LMELEC	14.01***	0.231	0.468
LRETDL	-0.39	-0.006	0.405
LMRETDL	-0.53	-0.009	0.399
LCO2INDEX	-0.55	-0.009	0.47
LUBNPOP	39.82***	0.657	0.87
LFDP	14.25***	0.246	0.405
LTRA	11.92***	0.199	0.378
LINF	15.67***	0.259	0.342

Notes: Under the null hypothesis of cross-section independence. LUBNPOP is urban population (% of total). LMELEC=LELEC x LCO2INDEX; LMRETDL = LRETDL x LCO2INDEX (thus, both stock and quality variables account for electricity-related CO2 emissions.

From a policy perspective, cross-section dependence implies that changes in the variable of interest in one country will affect a similar variable in other regional states. For instance, when electricity consumption (or GDP) increases in South Africa, the consumption of electricity (or GDP) in other countries within SSA is affected as well. This could give credence to the idea of having certain policies for electricity (or economic growth) advancement to be taken at the regional level than individual states. Furthermore, cross-section dependence of electricity consumption might represent implied spillovers from this infrastructure among regional countries. Thus, the representative countries tend to gain from each other's development. However, on the downside, it shows that negative shocks can easily pass among the regional countries. For instance, electricity infrastructure crisis in one country can affect electricity consumption in other countries especially if the affected economy has been an exporter of electricity to the neighbouring countries. Policy wise, it is imperative to consider this cross-section dependence when formulating domestic policies to account for potential external influences.

Econometrically, strong evidence of dependency among SSA countries for a number of variables entails the importance of applying 'second generation' kind of unit root tests that account for cross-section dependence. In this case, Pesaran's CIPS unit root test is implemented as one of the 'second generation' unit root tests.

4.5.2.3 Unit root

Table 4.4 exhibits the unit root results based on Pesaran's (2007) CIPS test, which is robust and plausible in sight of dependency among cross-sections. We consider both estimations with constant only and constant plus trend in order to exploit potential hidden data features. Consequently, comparisons are made and decide on the models that best fit the data.

Table 4. 4: Pesaran unit root test

	Constant		Constant & Trend	
Variable	*Level*	*1st Diff*	*Level*	*1st Diff*
LGDP	-2.587***	-5.169***	-3.302***	-5.230***
LELEC	-2.315**	-4.541***	-2.826**	-4.562***
LMELEC	-2.309**	-4.638***	-2.754**	-4.830***
LRETDL	-1.541	-4.568***	-2.241	-4.495***
LMRETDL	-1.520	-4.563***	-2.251	-4.546***
LCO2INDEX	-2.472***	-4.941***	-2.701**	-5.004***
LUBNPOP	-2.115*	-1.089	-2.713**	-4.501***
LFDP	-4.795***	-7.707***	-2.289***	-5.691***
LTRA	-2.646***	-5.881***	-0.883	-3.634***
LINF	-4.808***	-14.864***	-6.024***	-13.189***

Note: Dynamic lags criterion decision is based on Portmanteau (Q) test for white noise with maximum lag set at 4. LUBNPOP is the first lag values of urban population as a percentage of total population. For LTRA, LFDP, LINF the CADF test (another version by Pesaran) is performed since CIPS couldn't perform due to the nature of missing observations. Constant: Critical values (level of significance) are -2.07 (10%), -2.15 (5%) & -2.32 (1%). Constant plus Trend: Critical values (level of significance) are -2.58 (10%), -2.67 (5%) & -2.83 (1%).
H0: homogeneous non-stationary, rejected when Statistic < Critical value.

It is clear that across all tests (both constant and constant plus trend), most variables (LGDP, LELEC, LMELEC, LCO2INDEX, LUBNPOP, LTRA and LINF) are stationary in level except for LRETDL, LMRETDL and LTRA. However, the CIPS test with constant only also suggests that LTRA is stationary in level. Working with stationary variables avoids the likelihood of producing spurious results.

4.5.2.4 Electricity growth effects

In Table 4.5, electricity stock measures (i.e. LELEC and LMELEC) are the instrumented variables, the instrument is the lagged log of urban population as a percentage of total population (LUBNPOP) as discussed fully in the previous section. We do the same in Table 4.6 but in this case, electricity quality measures (i.e. LRETDL and LMRETDL) are the instrumented variables. Our choice of this demographic factor as an instrument to our stock and quality measures of electricity infrastructure is not random. We have tried a number of population variables that include total population, population density and urban population growth rate but found LUBNPOP to be plausible from both the size of correlation with electricity measures and its performance in the regressions. For preliminary checks, the correlation coefficients between LUBNPOP versus LELEC, LMELEC, LRETDL and LMRETDL are 0.62, 0.63, -0.50 & -0.48, respectively. The positive correlations implies that electricity consumption tend to increase as the percentage of urban population increases. The negative correlations entail that the ratio of electricity transmission and distribution losses tend to decline as the population increasingly become urbanised. This might be as a result of short distributional distances, contrary to a sparsely populated region or country, thus, urbanisation assist in overcoming geographical obstacles.

LUBNPOP thus enters in the first stage of each regression. As discussed in section 4.4, the fitted values from the first stage regression automatically appear in the final regression model and hence instrumenting the endogenous variable (electricity measure). Using a similar instrument in these related models ensures that the changes in growth effects are restricted to: (i) the infrastructure variable (i.e. stock or quality) and (ii) the influence of CO2 emissions on electricity impact.

This essay considers a just-identified model, that is, single endogenous variable and single instrument. In terms of specification tests for a just-identified model, the success of an instrumental variable approach (IV) demands answering two key questions: (i) are the variables endogenous and (ii) are the instruments weak or not? Across all the models (Tables 4.5 and 4.6), both the Durbin Chi2 and Wu-Hausaman statistics are highly significant and hence rejecting the null hypothesis that the variables are exogenous. As a result we are correct to treat electricity infrastructure measures as endogenous. Moreover, the F-statistics across all models are significant and hence rejecting the null hypothesis of weak instruments. Consequently, the problem of weak instruments does not affect our estimates. We therefore proceed to discuss the electricity growth impact results.

4.5.2.4.1 Stock effects

Table 4.5 presents the major findings on the growth effects of electricity stock, along with specification tests. As discussed in the previous sub-section, our specification tests suggest that the models are adequate. Electricity stock is represented by the electricity consumption per capita. Model 1 (that includes only the constant) and Model 3 (for constant plus trend) focus on the growth contribution of electricity consumption in SSA before accounting for CO2 emissions from electricity sector. To achieve the key objective of this paper, we further examine the influence of CO2 emissions on the economic growth impact of electricity consumption, which is demonstrated in models 2 and 4, including constant only and constant plus trend, respectively.

A number of striking findings are shown in Table 4.5. First, all electricity infrastructure variables have the expected sign and significant at the 1% level. Thus, the positive impact of electricity on growth remains even after controlling for CO2 emissions from electricity and heat production. Based on the results from the two cases, the growth contribution of electricity consumption is in the range between 0.68% and 0.79%. The positive impact of electricity consumption on economic growth confirms the results of other previous studies (for instance, Akinlo, 2008; Arouri, Youssef, M'Henni, & Rault, 2014) that examined African economies.

Table 4. 5: Electricity Stock

	Case 1: Constant		Case 2: Constant and Trend	
Variable	*Model 1*	*Model 2*	*Model 3*	*Model 4*
LELEC	0.789***	----	0.744***	----
	[0.050]	----	[0.048]	----
LMELEC	----	0.723***	----	0.680***
	----	[0.045]	----	[0.043]
LTRA	0.082	0.115	0.029	0.058
	[0.081]	[0.077]	[0.082]	[0.079]
LFDP	-0.128***	-0.165***	-0.219	-0.185
	[0.049]	[0.049]	[0.144]	[0.141]
LINF	-0.275***	-0.288***	-0.198***	-0.199***
	[0.040]	[0.038]	[0.038]	[0.037]
COASTAL DUMMY	0.730***	0.659***	0.733***	0.675***
	[0.115]	[0.110]	[0.113]	[0.109]
CONSTANT	2.649***	2.925***	2.140***	2.285***
	[0.309]	[0.298]	[0.290]	[0.280]
TREND	----	----	0.033***	0.032***
	----	----	[0.005]	[0.005]
Obs	385	385	382	382
R-squared	0.653	0.677	0.688	0.704
Root MSE	0.654	0 .630	0.619	0.604
Post-estimation checks				
(1) First-stage regression key statistics				
Adjusted R-squared	0.712	0.749	0.4656	0.4633
Partial R-squared	0.501	0.539	0.3542	0.357
(2) Endogeneity tests				
Durbin (score) chi2	28.219	19.584	16.642	14.687
	(0.000)	(0.000)	(0.000)	(0.000)
Wu-Hausman F	29.897	20.259	17.035	14.955
	(0.000)	(0.000)	(0.000)	(0.000)
(3) Weak instruments test				
F - statistic	80.566	443.569	205.663	208.478
	(0.000)	(0.000)	(0.000)	(0.000)

Note: 2SLS estimates based on Stata 13. Electricity stock measures are endogenous variables (i.e. LELEC and LMELEC). Endogeneity tests have the null hypothesis that the variables are exogenous. The weak instrument test has the null hypothesis that the instruments are weak. [ ] and ( ) represent standard errors and p-values, respectively.
*** denotes significant at 1% level

The results reveal the importance of energy use in production processes; it enhances the efficiency of production inputs (see Jumbe, 2004). Electricity also complements other public infrastructures such as telecommunication, transportation, health and education.

Second, the growth effects of electricity consumption decline when CO2 emissions are accounted for as presented by the coefficients of LMELEC being smaller than those of LELEC. Being initially in the range 0.74 % (Case 2) - 0.79% (Case 1), the contribution falls to somewhere between 0.68% (Case 2) and 0.72% (Case 1) after accounting for the CO2 emissions. Consequently, CO2 emissions reduce the growth contribution of electricity stock by roughly between 0.06% and 0.07%. It implies that electricity-related CO2 emissions can adversely affect the effective growth impact of the current electricity consumption in SSA. The relationship between electricity stock and economic growth, thus, should also be analysed thoughtfully with environmental effects in mind. The CO2 emissions from electricity add to excess CO2 which become pollutants with adverse effects on environment, including negative impact on water, health and agricultural production (Ahmad et al., 2016). As long-term consequences, CO2 emissions released to the atmosphere lead to ocean acidification, ozone layer depletion, global warming, climate change and altering plant growth. As a result, the costs that are associated with rising CO2 emissions from electricity production can exert negative pressure on GDP growth by impeding the potential growth effect of electricity consumption.

Third, the models that account for CO2 emissions (i.e. Model 2 & 4) have lower standard errors (SE) for the individual coefficients, together with higher R^2 and lower Root MSE than those that do not capture emissions (Model 1 & 3).[40] The comparison here is made for Model 1 versus Model 2 and Model 3 versus Model 4. Furthermore, for the first stage regression statistics, Models 2 and 4 have higher Partial R^2 than their counterparts (Models 1 & 3). Partial R^2 measures the correlation between the endogenous variable (electricity measure) and the instrument (LUBNPOP) after restricted the effects the exogenous independent variables. We therefore conclude that accounting for CO2 emissions in nexus between electricity stock and growth improves our models.

Fourth, the models that include both constant and trend (Models 3 & 4) have most of their individual coefficients with lower SE, higher R^2 and lower Root MSE than the equivalent models 1 & 2. In this case, models 4 and 2 are compared against each other while Model 3 is versus Model 1. The conclusion is that the models that include both constant and trend (Case 2) tend to have the best fit. We are right therefore to include deterministic trend, which

[40] Root MSE shows the standard error for the estimated model.

improves our estimations. The results of the control variables in Table 4.5 are not very different from those in Table 4.6 and these results are discussed in the next sub-section.

4.5.2.4.2 Quality effects

Table 4.6 presents the impact of electricity quality before accounting for CO2 emissions and after controlling for emissions. All the models pass specification test as previously discussed. A number of key results are shown in table.

Table 4. 6: Electricity Quality

	Case 1: Constant		Case 2: Constant and Trend	
Variable	*Model 5*	*Model 6*	*Model 7*	*Model 8*
LRETDL	-0.606***	----	-0.567***	----
	[0.048]	----	[0.044]	----
LMRETDL	----	-0.651***	----	-0.610***
	----	[0.055]	----	[0.050]
LTRA	0.418***	0.413***	0.346***	0.343***
	[0.089]	[0.094]	[0.087]	[0.091]
LFDP	-0.062	-0.024	-0.448***	-0.495***
	[0.058]	[0.059]	[0.176]	[0.185]
LINF	-0.360***	-0.354***	-0.300***	-0.307***
	[0.051]	[0.053]	[0.045]	[0.047]
COASTAL DUMMY	0.850***	0.924***	0.819***	0.879***
	[0.145]	[0.155]	[0.139]	[0.148]
CONSTANT	3.867***	3.711***	3.486***	3.460***
	[0.395]	[0.413]	[0.327]	[0.344]
TREND	----	----	0.039***	0.040***
	----	----	[0.006]	[0.007]
Obs	385	385	382	382
R-squared	0.462	0.404	0.542	0.494
Root MSE	[0.814]	[0.857]	[0.751]	[0.789]
Post-estimation checks				
(1) First-stage regression key statistics				
Adjusted R-squared	0.526	0.475	0.347	0.334
Partial R-squared	0.372	0.337	0.306	0.291
(2) Endogeneity tests				
Durbin (score) chi2	69.914	78.027	36.805	42.667
	(0.000)	(0.000)	(0.000)	(0.000)
Wu-Hausman F	83.874	96.080	39.876	47.026
	(0.000)	(0.000)	(0.000)	(0.000)
(3) Weak instruments test				
F - statistic	224.714	192.554	165.355	153.506
	(0.000)	(0.000)	(0.000)	(0.000)

Note: Electricity quality measures are endogenous variables (i.e. LRETDL & LMRETDL). See Table 4.5 footnotes.

First, our electricity quality measures (LRETDL and LMRETDL) have negative and significant coefficients. A percentage increase in the ratio of electricity transmission and distribution losses reduces economic growth in the range between -0.57% and -0.65%.

Consequently, deterioration in the quality of electricity in most SSA states is adversely affecting GDP per capita. The implied negative growth effects from electricity quality in SSA were also demonstrated in the chapter two using a different technique (see also Calderon, 2009). Electricity transmission and distribution losses (ETDL) are among the factors that lower electricity access in SSA. Poloamina and Umoh (2013) mention that ETDL do not only lessen power consumption but also lead to loss of revenue in SSA. Avila et al. (2017) asserts that the system losses in SSA comprise of technical losses from weakly maintained transmission and distribution networks, including commercial losses from poor revenue collection. Another explanation is that Africa is dominated by costly small-scale power systems that lead to greater transmission and distribution costs, mostly from power losses (Castellano, Kendall, Nikomarov, & Swemmer, 2015). Small power plants lack necessary economies of scale in the production, transmission and distribution of electricity (see AfDB, 2013).

Second, the negative growth effects of electricity quality are intensified once the CO2 emissions are taken into consideration. The negative effects may increase to reach approximately -0.65%. It implies that CO2 emissions from electricity production further hinder the electricity quality growth effects. This is expected given the adverse effects of CO2 emissions we have previously noticed. Therefore, combining the negative effects of electricity distribution losses and CO2 emissions can worsen the negative pressure on GDP growth.

Third, unlike the electricity stock regressions, the models that do not account for CO2 emissions (Models 5 & 7) have lower SE for individual coefficients as well as higher R^2 and lower Root MSE than their counterparts that account for CO2 emissions (Models 6 & 8). Note that we compare models 5 versus 6, and 7 versus 8. Fourth, like the stock models, the quality models that include constant and trend (Models 7 & 8) have relatively small SE for individual coefficients, together with higher R^2 and small Root MSE than their counterparts that excludes deterministic trend (Models 5 & 6). In this case, comparisons are made for models 5 versus 7 and then models 6 versus 8. We reach the final conclusion that including deterministic trend tend to improve our model fit as suggested by rise in R^2 and decrease in standard errors. Note that the standard errors (SE) for individual coefficients can be referred to as SE of the estimates. SE is an important statistic that shows the average distance that the observed values lie from the regression line. Consequently, it tells how wrong the estimated coefficient is on average. The smaller the SE the better the estimated coefficient as it shows better precision of the prediction.

Based on the results across all models (both Tables 4.5 and 4.6), an increase in inflation levels reduces economic growth (roughly in the range between -0.19% and -0.36%) in SSA as theoretically expected. The negative coefficient of inflation confirms the commonly accepted hypothesis that inflation is harmful to economic growth and is largely consistent with the literature (see Baharumshah, Slesman, & Woharc, 2016). This is one of the reasons why inflation targeting has become a key monetary policy regime as most countries are cautious of the detrimental effects of price instability on economic activity and ultimately economic growth. Zimbabwe is one of the SSA states that experienced world records of inflation levels in 2008 that had pushed the country into de facto dollarisation. Nguyen, Dridi, Unsal, and Williams (2017) demonstrated that exchange rate, monetary variable shocks and domestic supply shocks have been the core drivers of inflation in SSA in the past 25 years but their impact has declined recently. Nevertheless, demand pressure and global shocks have become the key inflation drivers in the past decade.

Moreover, the trade openness coefficients for all quality models are positive (in the range between 0.34% and 0.42%) and highly significant but those for stock models are not significant. Thus, in line with conventional wisdom, there exist a growth enhancing effect of trade openness in SSA countries since 1990. As mentioned earlier, trade liberation has been facilitated by both integration and specialisation. Various regional communities in Africa (for example, SADC, ECOWAS, COMESA, ECCAS, EAC, among others) play an essential role in the process of integration among member states, with trade agreements being among the key components of these regional blocs. SSA countries heavily specialise in primary commodities such as mineral and agricultural products that are exported mostly to Europe, and also facilitated through various multilateral and bilateral trade agreements. However, the connection between trade openness and growth may not be linear in SSA as demonstrated in Zahonogo's (2017) recent work.[41]

Financial depth coefficients across all models are negative and four out of eight models are significant at the 1% level. The level of financial development in SSA implies negative growth effects. This observation was also observed by Chakamera and Alagidede (2017) in a

[41] A threshold may exist below which large openness is beneficial to growth and above which the trade liberalisation growth effect falls.

Generalized Method of Moments framework (see also Gries, Kraft, & Meierrieks, 2009; Kodongo & Ojah, 2016). As mentioned in the previous essay, possibly a good ratio of the credit provided especially to individuals (mainly as unsecured personal loans) is used to finance consumption instead of investment (Kodongo & Ojah, 2016). Financial and banking systems of SSA are essentially fragile and hence cannot effectively ensure a sound allocation of investment funds. The absence of efficient and deep financial markets hinders both economic growth and poverty alleviation in SSA (Gulde, Pattillo, Christensen, Carey, & Wagh, 2006).

Another concern is that coastal countries may have an advantage in terms of infrastructure gains as compared to landlocked countries. The coastal dummy shows a positive and robust impact on economic growth (see also Ran, 2005). Coastal economies may yield greater benefits from their superior access to transportation network with the external markets than the inland economies. The trend coefficients are not only significant but also improve our models. Finally, the constants have high positive and significant coefficients, which may suggest growth effects explained by other factors (e.g. total factor productivity -TFP) rather than those considered in this study.

The results demonstrated in this study hold even under the GMM framework. For instance, we have indicated this by analysing the models with constant (Case I in Tables 4.5 and 4.6) using GMM and reported the results in the Appendix 1, Table A.2. In Table A2, the results of models 1 & 2 are almost similar to those by the 2SLS in Table 4.5 models 1 & 2. Similarly, the results of models 3 & 4 are almost similar to those by the 2SLS in Table 4.6 models 5 & 6. This support Wooldridge (2001) that there would be no difference between the 2SLS and GMM in the case of just-identified.

4.5.2.5 Implication of key results

The findings of this paper provide crucial implications for policy making that are drawn from the extent to which electricity-related CO2 emissions can alter the economic growth effects of both electricity stock and quality, the degree of electricity shortages and efficiency in SSA.

From a policy perspective, it could be relevant to consider also the sizes of CO2 emissions' influence on the growth effects of electricity stock and quality in the calculations of carbon taxes (carbon pricing); as nations increase focus on SDGs strategies. We demonstrated that CO2 emissions from electricity production reduce the contribution of electricity sector to

GDP per capita. Countries are mostly heterogeneous in terms of electricity growth effects and the impact of emissions. Some countries might be in a phase where CO_2 emissions from electricity entail minimal negative effects on the electricity growth contribution, in the opinion of EKC hypothesis.[42] Therefore, where carbon pricing is applicable, considering both the sizes of CO_2 emissions and their influence on electricity-growth contribution seems plausible. It ensures a carbon pricing approach that is designed to minimise emissions without excessively discouraging the benefits from electricity sector.[43] The problem is worse if CO_2 emissions from electricity production reduce the positive contribution of electricity in huge proportions, which may require a reasonable carbon penalty. Additionally, resources that are equivalent to the potential growth loss implied by rising emissions can be used in efforts that are meant to create a friendly environment. However, policy makers should bear in mind that stringent environmental standards on emissions may have substantial implications on power production (International Energy Agency, 2014). The power sector should consider better combinations of power sources that minimise environmental degradation while making significant contribution to economic growth.

Positive growth effects of electricity consumption warrants the importance of electricity infrastructure. However, we believe that SSA's electricity sector may attain its economic growth potential when the critical power shortages are reduced. Appropriate planning and substantial investment is highly needed to promote economic development. Given financial challenges experienced by most SSA countries, policy makers should consider independent power producers (IPP) to work side by side with government parastatals in the production and provision of electricity. The IPP will make extra funds available to increase the total kWh of electricity generated in a country, which may form diverse sources of energy. Though the participation of IPP is necessary to address the problem of electricity shortage, the government should still ensure appropriate regulations. Among other factors, the regulations will cover areas such as CO_2 emissions from electricity production and the price of electricity paid by the end-users. In addition, though SSA countries may exercise exportation and importation of electricity among themselves, the problem here is that when major exporters experience some negative electricity shocks this will negatively impact other regional

[42] The EKC hypothesis suggests a phase where CO_2 emissions will be a threat to economic growth and another phase where high economic growth can help reducing the CO_2 emissions.

[43] Though theoretically sound, it might be difficult in practice to measure with accuracy the influence of electricity-related CO_2 emissions on the growth contribution of the energy sector. However, from a policy making position, it helps to penalise each sector of the economy according to the size of emissions and its growth contribution.

countries. Transfer of shocks is confirmed by the evidence of strong cross-section dependence among SSA economies in terms of electricity stock variables. Recently, Zimbabwe has been relying on electricity from Eskom, South Africa. If Eskom reduces its power export to Zimbabwe (say when Zimbabwe has accumulated a huge debt), Zimbabwe will encounter severe load shedding.[44] Consequently, efforts should be made for each country to boost its electricity production.

Furthermore, the respective governments in SSA need to improve the efficiency of the energy sector to minimise the ratio of electricity transmission and distribution losses, which imply negative growth effects. While small-scale power plants (e.g. solar, small-scale hydropower) can improve the supply of electricity even in remote areas as off-grid systems, they lack economies of scale to reduce generation costs and losses. To enhance efficiency in the transmission and distribution of energy, proper planning and implementation, skilled personnel, adequate research and development are among the key factors. Appropriate measures to deal with electricity pilferage (which is part of ETDL as non-technical loss) are also essential in SSA. Large power plants are also believed to be cost-effective unlike the small-scale power systems that dominate Africa (see AfDB, 2013).

Moreover, the greater proportion of people without access to electricity may represent an opportunity to be exploited when these people become future consumers of energy, especially in productive activities such as agriculture in rural areas. Increased access to electricity can also help alleviate the unemployment challenge in SSA as others would become self-employed in various small business projects (e.g. barbershops and saloons, poultry, carpentry, internet cafe, among others). It is important for the countries in SSA to increase small-scale off-grid systems in a decentralised manner to reduce the percentage of population without access to electricity, especially in rural communities. This can reduce reliance on centralised grid systems that hardly reach the rural areas. It is also important to ensure affordable electricity prices. Electricity prices in SSA are among the highest in the world.

The fact that electricity power generation from renewable sources (excluding hydro) is still very low in SSA (second lowest from MENA), it should be a major concern for respective governments, and appropriate policies to promote renewable energy production are called for. Solar energy has not assumed a major role in Africa but its gaining ground (International

[44] There has been threats by Eskom to disconnect its power to Zimbabwe due millions of unpaid debt, and the Zimbabwean Reserve Bank had to intervene and pay a certain proportion of the debt (fin24, 2017).

Energy Agency, 2014). Despite the fact, the region is endowed with abundant renewable resources. Africa at large has more than 20% of world's hydro resources and a number of countries in the continent experience long hours of sunshine with considerable radiation to be utilised, including wind resources mainly along the Western, Northern and Southern African coastlines (AfDB, 2009). The risk of climatic change, however, is an obstacles to the renewable sources such as hydro, wind and solar (see Avila et al., 2017). This study argues policy makers to invest considerably in solar systems, which has both the advantage of being renewable and clean source of energy.

Because of large coal reserves in SSA, the countries should also continue exploiting this endowment. We have already discussed earlier that SSA is greatly dependent on electricity production from coal. The use of coal brings some key advantages including its wide distribution, reliability, affordability and being the least subsidised (see World Coal Association, 2012). The World Coal Association also applauded its convertibility to liquid fuel (coal liquefaction) as has been in South Africa since 1955. Nevertheless, coal sources have been the greatest emitters of CO_2 emissions and hence there should be suitable policies designed to minimise these emissions. We support the recommendation by the World Coal Association (2012) that policy makers should seek to improve the efficiency of most aged and inefficient coal plants as well as considering CO_2 capture and storage technologies that handle CO_2 emissions not only from coal but the entire electricity sector. When applying CO_2 capture and storage technologies, and/or carbon taxes, this study argues that it may be useful for policy makers to consider a reasonable subsidy from government to the power producers. The subsidy will ensure that the cost burdens that are related to CO_2 capture technologies and carbon taxes are not entirely borne by the end-users of electricity in terms of high charges.

Based on control variables, the positive coastal effect may imply that coastal economies gains from their favourable transport infrastructure connection with external markets, which might translate to becoming favourable investment destinations (see also Ran, 2005). Again in support of the findings in previous chapters, SSA countries tend to benefit from trade openness in general. The regional communities and various bilateral and multilateral trade agreements help in the process towards trade openness in SSA. Given that inflation has had negative effects in SSA since 1990, inflation targeting may remain one of the key approaches to ensure price stability. However, it also demands discipline and less political pressure to avoid a "time inconsistency" problem that arises when policy makers adopt discretionary monetary policies (for example, expansionary monetary policy) based on favourable short-term outcomes (for instance, increased investment) but neglecting the undesirable long-term effects (for example, high inflation). More so, financial development in SSA is poor. Banks and stock markets in the region are weak in terms of facilitating investment funds while a significant proportion of credit especially to individual borrowers is used for consumption than investment purposes. Bolstering financial sector may require substantial effort from the respective governments to attract investment in this sector, including proper supervision.

4.6 Concluding remarks

We investigate the relationship between electricity stock (electricity consumption) and quality (RETDL) in 18 SSA countries over the period 1990-2013. Earlier studies have been focusing mostly on cointegration (or relationships) and/or direction of causality between electricity quantity measure (usually, electricity consumption), CO2 emissions and economic growth but have been failing to properly interrogate the extent to which emissions can alter the economic impacts of both electricity stock and quality. The CO2 emissions versus electricity quality link has been the most relevant missing aspect in the earlier studies. The investigation in this essay is done before and after accounting for electricity-related CO2 emissions to detect the influence of these emissions on the growth contribution of both electricity stock and quality. Our results show evidence of cross-section dependence among SSA economies in terms of LGDP, LELEC, LMELEC, LINF, LTRA, LFDP and LUBNPOP but not for LRETDL, LMRETDL and LCO2EM. Electricity consumption shows positive growth contribution in SSA and this contribution declines when the effects of CO2 emissions are accounted for. Electricity quality developments (as represented by change in the RETDL) suggest negative growth effects in SSA. The negative growth effects will be worse once the CO2 emissions are taken into consideration. Consequently, CO2 emissions from electricity and heat production reduce the growth effects from electricity stock and quality. Furthermore, accounting for CO2 emissions tend to improve the adequacy of our regression models. Also in terms of model choice, the models that include constant plus trend have the best fit for our data. Inclusion of deterministic trend enhances the electricity - growth nexus.

Most importantly, it is concluded in this study that SSA countries require substantial funds to address both the critical shortage of electricity and enhancing efficiency of the energy sector. We recommend the representative countries to increase the participation of independent power producers rather than relying on the public sector. Attracting adequate investment (especially from external sources) in the power sector may also demand improvement of institutional quality in SSA, including "ease of doing business" indicators and reduction of corruption. While carbon pricing (or taxes) may help in lowering CO2 emissions and their adverse influence on growth contribution of electricity sector, this strategy may further worsen electricity crisis in SSA, especially when no provision for subsidy has been made. The use of carbon capture and storage technologies might be better but a subsidy might also be vital, especially when the costs of such technologies are sizable. A detailed cost and benefit analysis (CBA) is needed when choosing the best strategy to improve environmental quality with caution on each strategy's impact on electricity production and ultimately economic growth.

CHAPTER FIVE

SPATIAL SPILLOVER EFFECTS OF AGGREGATE INFRASTRUCTURE STOCK AND QUALITY

5.1 Introduction

Spatial spillover effects from infrastructure raises important policy inferences about the effectiveness and efficiency of infrastructure investments. Since the seminal work of Aschauer (1989) there has been an incredible interest on the economic impact of public infrastructure from the empirical perspective. Besides the role of infrastructure in stimulating domestic economic activity, it is commonly accepted that a country's infrastructure gives impetus to the development of the surrounding countries. The economic growth literature shows that fast-growing economies cluster together and hence location matters (Alvarez et al., 2006). It is the importance of proximity that many studies often quantify the infrastructure spillover effects using a neighbour weighting criterion (focusing on areas that share borders). Spillovers may happen beyond common borders, therefore, distance and trade based weights are other considerations that have been exploited.

Domestic infrastructures may generate economic benefits in the areas of location as well as positive or negative spillovers to other areas (Moreno & Lopez-Bazo, 2007). Thus, while infrastructure spillovers from other areas may have benefits (see Pereira & Roca-Sagales, 2003), the impact of these spillovers to an area could be negative (for example, Sloboda & Yao, 2008; Zhang, 2008 & 2013). Negative spillovers may occur when sound infrastructure development in a region draws production factors (human and physical capital) away from the regions with poor infrastructure. Thus, infrastructure can create a competitive advantage. This is due to relocation of economic factors and firms to areas with greater accessibility from strong transport and telecommunication networks (Condeco-Melhorado, Tillema, de Jong, & Koopal, 2014), reliable energy supply, improved water and sanitation. Omitting these spillover effects would cause systematic bias regarding the effective growth impact of infrastructure.

Most studies (for example, Fedderke & Garlick, 2008; Loayza & Odawara, 2010; Chakamera & Alagidede, 2017) assessed the economic impact of local infrastructure on economic growth yet analysis of infrastructure spillovers among regional countries especially in SSA is still thin. Those who investigated spillovers have focused on the spillovers from individual infrastructure types (mostly transport and telecommunication). More so, failure to account for infrastructure quality remains a serious problem.

In view of the empirical gaps above, our contributions to the body of literature are: First, the application of aggregate infrastructure indices to model spillovers across SSA states. This does not mean that the aggregate infrastructure measures are superior to single infrastructure sector measures. However, as discussed in the chapter one, it is also interesting to have knowledge of the spillover effects that emerge from the overall infrastructure system of an economy. One will be able to say the infrastructure of country A as whole can generate important spillovers that can impact country B's economic development. While some single infrastructures may suggest positive as other suggest negative spillovers, the aggregate measures provide us a summary of spillovers effects from entire infrastructure system. Second, unlike the common literature, we do not only consider the quantity of infrastructure but also the spillovers associated with aggregate infrastructure quality. Thus, apart from spillovers from infrastructure stocks, it is crucial to understand the spillovers that emerge from quality development. Third, an important contribution drawn from our findings is the different dynamics under which infrastructure spillovers may occur between aggregate infrastructure stock and quality. It is suggested in this essay that the development of foreign infrastructure stock may exert a negative pressure on domestic economic development. However, the development of foreign aggregate infrastructure quality tends to stimulate domestic economic development. The explanations are provided under the implication section. To the best of our knowledge, it is novel in this study to inspect spillover effects of aggregate infrastructure stock and quality in a panel vector autoregressive (VAR) framework. Evidence of spillover effects (positive and negative) have key policy implications, which include ensuring optimal infrastructure investments and cost-sharing among SSA countries. The kind of infrastructure spillover analysed in this study is therefore timely and imperious.

This essay expounds the nature and magnitudes of aggregate infrastructure (stock and quality) spillover effects in Sub Saharan Africa (SSA). *We hypothesise that the aggregate infrastructure stock and quality of a country may produce positive or negative spillover effects on other regional countries.* Following the original works of Love and Zicchino (2006) and Abrigo and Love (2016), a panel VAR approach that does the estimations in a generalized method of moments (GMM) framework is implemented to test for the existence of spillovers.

The remainder of the essay proceeds as follows: Section 2 provides a brief survey of the related literature. The methodology of the study is presented in section 3. Section 4 discusses the results and key policy implications. Finally, section 5 provides concludes the essay.

5.2 Brief literature survey

The provision of adequate infrastructure is fundamental to the viability of every economy. It may enter as an input of production (Barro, 1990; Ayogu, 1994). Public infrastructure complements other private inputs of production. Since Aschauer (1989), plenty of empirical literature have examined the nexus between infrastructure and growth. Among these studies, the importance of spillovers from infrastructure development has consistently received much attention. Infrastructure (mostly economic infrastructure) possess network and scale effects, whose role is not only limited to the enhancement of local production processes but also influencing the surrounding areas via spillovers, which can either be positive or negative (see Li et al., 2017). Dembour and Wauthy (2009) pointed that as much as spatial externalities are concerned, if regions are genuinely contiguous then physical location in one area than another does not matter. Theoretically, the development of infrastructures such as good transport network, power plants and telecommunication promotes development in the surrounding areas. There will be direct use of transportation infrastructure (for example, highways, seaports, railways and airports) by other countries during trade, electricity can be imported while advanced telecommunication technology in a country can be transferred and adopted in other regions.

Substantial empirical work exists in terms of spillovers from transport infrastructure. Recently, Li et al. (2017) assessed the returns of road infrastructure investment in China. Their results suggested roughly 11% rate of return per annum from productivity gains, somewhat as a result of positive spillovers. Their findings did not support the idea that China's road investment is excessive. Moreover, the importance of road infrastructure spillovers among municipalities in the Dutch province was documented by Condeco-Melhorado et al. (2014). They estimated the benefits of extra road links in forms of monetary gains and travel time savings. In the case of Spanish provinces, Arbues, Banos, and Mayor (2015) investigated spillovers of roadways, airports, seaports and railways. While they found road infrastructure to have positive impacts on the area of location and neighbouring provinces, the other transportation modes showed no significant effects on average. Furthermore, investigating the effects of transport infrastructure on agricultural output across

44 states in the United States (US), Tong, Yu, Cho, Jensen, & Ugarte's (2013) results indicated that road disbursement in a particular state would have a direct positive contribution to its own agricultural output and spillover effects on other neighbouring states. Another incredible observation of their study was the variability of spillover effects based on the spatial weight matrix applied in the model.

In the case of Mexico, Duran-Fernandez and Santos (2014) found roads to have a positive and significant effect on regional variations in productivity. Their findings suggested that the unexplained output per worker at regional level was associated with regional variables. Interestingly, they also documented that not all elements of the road system have similar effects. Yoshino and Abidhadjaev (2017) investigated the impact of Uzbekistan's TBK railway connection and their results indicated positive effects in the regions crisscrossed by the railway but the effects were statistically significant only in the medium and long periods, while negative effects were recorded for the outlying regions in the short term. In addition, Zhang (2008) found transport infrastructure spillovers to be largely positive, however, negative spillovers were established with population density spatial weights matrix model.

Bouwmeester and Scholtens (2017) examined cross-border spillover effects associated with investment expenditure of 5 Western European economies using a multi-regional input-output model. They found evidence for spillovers, which were distributed unevenly among the economies. In particular, the effect of gas infrastructure on both domestic values added and cross-border leakages was found to differ greatly among the countries. In the case of Spanish provinces, Alvarez, Barbero, and Zofío (2016) analysed the growth effects of imported capital stock connected to the utilisation of infrastructures in neighbouring areas. Their results confirmed the hypothesis that the imported capital has a positive impact on production. Furthermore, Peng and Hong (2013) investigated spillovers at sectoral level in China. They found economic growth in a sector to be explained by spillover effects among sectors that are connected via flows of commodities, with economic distance assuming a major role in stimulating productivity than spatial distance. Additionally, their results suggested the significance of infrastructure spillovers in enhancing labour productivity in related sectors and that agglomeration diseconomies of scale may partly be lowered by infrastructure investment.

In so far as the role of infrastructure spillovers on productivity is concerned, Owyong and Thangavelu (2001) also reported positive spillovers from the US public capital to Canada's productivity. More so, positive effects of public infrastructure on regional productivity of neighbouring regions were demonstrated by Bronzini and Piselli (2009) in the case of Italian regions. They also found evidence of a one-way causality from public infrastructure to productivity. Wang (2014) showed that growth is strictly endogenous in the presence of considerable public infrastructure spillovers. Despite the importance of spillovers, the development of infrastructure may also lead to congestion spillover effects. Gudmundsson, Paleari, and Redondi, (2014) found evidence of congestion spillovers not only to the nearest airports within multiple airport regions (MARs) but also to the airports that are distant outside the MARs. In particular, the spillovers of intercontinental flights impact demand patterns, new flight offerings and flight influences in the United Kingdom and secondary airports within and outside the London MAR.

In the African context, Richaud, Sekkat, and Varoudakis, (1999) investigated growth spillovers among African countries and the importance of infrastructure in their transmission. Their findings revealed the role of infrastructure development in lifting the profitability of both domestic and foreign investment. Most importantly, they argued that infrastructure investment at national level can be sub-optimal in the presence of spillovers. Furthermore, Roberts and Deichmann (2009) examined the growth spillover effects of telecommunication and transport infrastructure. Their results suggested heterogeneous growth spillovers, which were more robust among the OECD nations while basically absent in SSA. More so, evidence was found for strong interaction between infrastructure and being a landlocked state, implying spillovers being dependent on the ways in which spillover effects can spread (infrastructure endowments being central). In Roberts and Deichmann (2011) negative and positive values were linked to the infrastructures that are low or high, respectively. When Equatorial Guinea was excluded from the sample of several states (including non-African), there were no significant interaction effects involving spillover.

Regarding the mixed outcomes of the infrastructure-growth nexus, Elburz et al.'s (2017) meta-analysis revealed that studies which take into consideration interprovincial, interregional and interstate relations have high probability of obtaining negative effects, giving an idea concerning the spillovers of these investments. Likewise, the kinds of infrastructure, time frame, methodology, geographical scale, and types of infrastructure measure can affect the results of the primary studies.

From the foregoing, substantial empirical evidence exist in support of positive spatial spillover effects from infrastructure. Therefore, infrastructure development in a region (or province) can facilitate economic development in the surrounding regions (or provinces). If the spillovers are always positive then it might be logical that the country originators of spillovers would seek for ways to internalise the effects. In this scenario, policy makers at both national and regional levels may focus on finding appropriate cost sharing arrangements among beneficiaries and hence not discouraging the positive spillovers. However, some studies have demonstrated evidence of negative spillovers from infrastructure while others could not find the existence of spillovers. It becomes even harder for policy purposes, when different results are documented for the same infrastructure, same period and same geographical area. Besides the mixed outcomes, it seems most studies examined spillovers from transport infrastructure. Lack of knowledge regarding spillover effects from the perspective of aggregate infrastructure stock and quality is the major research gap. Failure to account for infrastructure quality has been the most critical challenge. Consequently, this essay seeks to address these problems by employing the aggregate measures of both infrastructure stock and quality. The aggregates carry information of four infrastructure sectors (electricity, transport, telecommunication and water).

5.3 Methodology and Data

5.3.1 Data

This study considers stock and quality measures of electricity, telecommunication, road, airport and water infrastructures for a panel of 39 SSA countries over the period 2000-2014.[45] These variables are discussed in chapter one. In this essay sanitation is dropped because we want to have variables with both quantitative and qualitative measures. Our interest is not on the individual infrastructure types per se but rather on their aggregate impact. Subsequently, principal component analysis (PCA) is used to cluster the different types of infrastructure stock measures, thus, developing an aggregate infrastructure stock index (AIS) for each country. The same is applicable in terms of aggregate infrastructure quality index (AIQ). This study calls the AIS and AIQ for any country i domestic aggregate infrastructure stock (DAIS) and domestic aggregate infrastructure quality (DAIQ), respectively. From the perspective of any country i, the combination of the AIS variables of other regional countries

[45] Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Chad, Comoros, Congo Republic, Cote d'Ivoire, Democratic Republic of Congo, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome & Principe, Senegal, Seychelles, Sierra Leone, South Africa, Swaziland, Tanzania, Togo, Uganda, Zambia and Zimbabwe.

creates a foreign aggregate infrastructure stock (FAIS) variable that enters into country i's output function. The same holds in the development of a foreign aggregate infrastructure quality (FAIQ). Accordingly, FAIS and FAIQ are the central variables used to assess the spillover effects of aggregate infrastructure endowments of other countries. Notice that the calculation of FAIS and FAIQ involves the use of weights that are based on proximity, which matters in the dynamics of spillovers across regions (see sub-section 3.2.1 about the use of weights).

5.3.2 Econometric Approach

5.3.2.1 Model

This study proposes an output function of the following form

$$gdp_{it} = f(dais_{it}, daiq_{it}, fais_{jt}^{wij} faiq_{jt}^{wij}) \qquad (5.1)$$

$$i = 1,..., N; t = 1,..., T$$

where $dais_{it}$ is the domestic aggregate infrastructure stock and $daiq_{it}$ is the domestic aggregate infrastructure quality. Added to the output function of any country i are the foreign aggregate infrastructure stock ($fais_{it}^{wij}$) and foreign aggregate infrastructure quality ($faiq_{it}^{wij}$) variables of any other regional country j, and w_{ij} is the weight for any pair of countries i and j. We assume that foreign infrastructures of other regional countries have an effect on the growth performance of the domestic country.

The choice of a weight matrix is vital in this kind of analysis. Most studies applied a neighbour weighting matrix whereby a weight of 1 is attached to countries that share boarders and 0 otherwise. Adjacent countries are believed to have more influence to each other's growth through spillovers across borders. This criterion, however, has a problem of attaching same weights to the neighbouring countries while in fact others can be more important (Condeco-Melhorado et al., 2014). More so, it excludes several other regional countries that do not share similar borders though they may have significant spillovers. The distance-based weighting criterion is an alternative that can be used to include all countries within a region or sample. This approach gives more weight to the countries that are closer to each other.

Recently, a trade-based weighting matrix has been of interest. Unlike the proximity (neighbours and distance) criteria's implied assumption that the closer the regions the greater the spillover effects, the later views the level of trade as another channel through which regions can benefit from each other's infrastructure development. However, the challenge with bilateral trade-based weight matrix especially in Africa is the high degree of informal trade that remain unrecorded. Moreover, formal bilateral trading data for some pairs of SSA countries or years is difficult to find. Thus, in this study the distance weighting criterion is applied in the development of foreign infrastructure variables. The weights are computed based on percentage distance (*1/D*100*) where D is the distance between capital cities. The numerator is 1 such that the closer the capital cities the greater the percentage weight. Given equation (5.1), we estimate the following empirical panel model for any country i :

$$gdp_{it} = \alpha_0 + \beta'_{it} ldais_{it} + \phi'_{it} ldaiq_{it} + \lambda'_{it} \sum_{j=1}^{N} w_{ij} lfais_{jt} + \psi'_{it} \sum_{j=1}^{N} w_{ij} lfaiq_{jt} + u_{it} \qquad (5.2)$$

where α_0 is an intercept, u_{it} is the disturbance term, N denotes the number of countries, l denotes the logs of the variables defined in equation (5.1) and $\beta, \phi, \lambda \,\&\, \psi$ are parameters to be estimated. Alvarez et al. (2006) talks about effective stock of public capital that combines both domestic and foreign infrastructure. Consequently, we consider another empirical model for effective infrastructure stock and quality as follows:

$$gdp = \alpha_0 + \beta'_{it} leais_{it} + \phi'_{it} leaiq_{it} + \mu_{it} \qquad (5.3)$$

$$leais^{e}_{it} = ldais_{it} * \sum_{i=1}^{N} w_{ij}\, fais_{jt} \qquad (5.4)$$

$$leaiq^{e}_{it} = ldaiq_{it} * \sum_{i=1}^{N} w_{ij}\, faiq_{jt} \qquad (5.5)$$

where $leais_{it}$ is the effective aggregate infrastructure stock, $leaiq_{it}$ is the effective aggregate infrastructure quality, $ldais$ and $ldaiq$ are the within-country infrastructure aggregates while $lfais$ and $lfaiq$ are the foreign infrastructure. As shown in equations (5.4) and (5.5), we apply a product combination but one may also consider a linear aggregator to develop the effective infrastructure variables as shown in Alvarez et al. (2006). A linear aggregator has been used in chapter two to develop hybrid indices. The merit of our product combination is that one may also think of the foreign infrastructures as potential moderators that improve the infrastructure-growth nexus when captured.[46]

5.3.2.2 Panel VAR

While equations (5.1) to (5.3) show our central objective whether GDP growth is dependent on domestic and foreign infrastructure, the panel VAR model checks for reverse causality as well. There might be reverse causality from GDP growth to infrastructure development. In terms of domestic infrastructure, we have indicated in chapter two and three some empirical studies that found support for a positive effect of infrastructure (or various infrastructure sectors) on economic growth. As discussed earlier, the main reason being that public infrastructures may act as additional inputs of production or complement private capital, which in turn impact the national output. In other words, businesses do not only depend on their own capital, technology and labour but also on the complimentary infrastructure that include telecommunication, electricity, transportation, sanitation and water (see Owyong and Thangavelu, 2001). With regard to the role of foreign infrastructure, national GDP may also be affected by the foreign infrastructure development through spatial spillovers (see for example, Richaud et al., 1999; Roberts and Deichmann, 2009; Alvarez et al., 2016). The broad issue and relevance of spillover effects is also based on the observation that countries often do well when their neighbours are doing well (see Roberts and Deichmann, 2009). Roberts and Deichmann (2009) gave the example of the industrial evolution in England that spread in the continent like contagion-like process and the "East Asian miracle". Alvarez et al. (2016) demonstrated the importance of imported capital stock that represent spillovers obtainable from the utilisation of roads located not only in neighbouring locations but non-adjacent locations as well. These infrastructures such as local and foreign road networks and telecommunication systems are used in trade flows and as ways for accessing markets.

On the aspect of potential reverse causality, we indicated in the previous chapters a number of studies that demonstrated a bi-directional causal relationship between infrastructure and economic growth. A VAR model can be used in order to allow for this possible feedback effect. Specifically, this study employs the panel VAR approach focusing mainly on the impact of both domestic and foreign infrastructure on economic growth.

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[46] This might be judged when one has conducted moderation analysis or checking the changes in R-squared when the foreign variables are captured in the model. However, our panel VAR approach does not show R-squared but we might have a clue from the standard errors, which are relatively low in Equation (5.2) i.e. model B. Despite the fact, Equation (5.1) remains extremely important as it is the one that reveals spillover effects.

We apply the panel VAR approach by Love and Zicchino (2006) and Abrigo and Love (2016) that runs in a GMM framework.

5.3.2.2.1 Rationale

Panel VAR is one the robust techniques that can be used to examine the nature and degree of spillovers (see Koop & Korobilis, 2016). Among the merits, one does not need to worry about endogenous variables as the approach treats all variables as endogenous and interdependent but exogenous variables can be included (Canova & Ciccarelli, 2013). Moreover, panel VAR's estimations and inference are conducted in a GMM framework, which is one of the best approach that overcomes the problem of endogeneity. It permits for an efficient estimation of coefficients in a system with endogenous variables. Allowing the lagged variables from each country to influence other countries is another advantage. Furthermore, the panel VAR technique also estimate the impulse response functions (IRF) that reveal the time path of each variable after a shock to other variables in the system.

5.3.2.2.2 P-VAR framework

This study considers a panel VAR for any country p described by the following system of linear equations:

$$y_{it} = \eta_1 y_{t-1} + ... + \eta_p y_{t-p} + \gamma_i + \varepsilon_{it} \qquad (5.6)$$

$$i = \{1,2,..., N\} \quad t = \{1,2,...T\}$$

where y_{it} is a $1 \times k$ vector of endogenous variables, $\eta_{1,...,}\eta_p$ is a $k \times k$ matrix of parameters to be estimated, p denotes the number of lags included, γ_i and ε_{it} are $1 \times k$ vectors of dependent variable-specific fixed effects and error terms, respectively. The disturbances are assumed to have the following features: $E(\varepsilon_{it}) = 0$, $E[\varepsilon'_{it}\varepsilon_{it}] = \Sigma$ and $E[\varepsilon'_{it}\varepsilon_{is}] = 0$ for all $t > s$.

Estimating equation (5.6) with standard method such as ordinary least squares (OLS) would yield biased estimates due to the presence of lagged dependent variables on the right hand side of the system of equations. As a remedy, the panel VAR is designed to run in a GMM framework, which was developed by Arellano and Bond (1991) and further modified by Arellano and Bover (1995) and Blundell and Bond (1998). Therefore, based on Abrigo and Love (2016) the transformed panel VAR of equation is as follows:

$$Y_{iy}^{*} = \bar{Y}_{it} A + \varepsilon_{it}^{*} \tag{5.7}$$

$$Y_{it}^{*} = [y_{it}^{1*} y_{it}^{2*} \ldots y_{it}^{k-1*} y_{it}^{k*}]$$

$$\bar{Y}_{it}^{*} = [Y_{it-1}^{*} Y_{it-2}^{*} \ldots Y_{it-p+1}^{*} Y_{it-p}^{*} X_{it}^{*}]$$

$$\varepsilon_{it}^{*} = [\varepsilon_{it}^{1*} \varepsilon_{it}^{2*} \ldots \varepsilon_{it}^{k-1*} \varepsilon_{it}^{k*}]$$

$$A' = [A_1' A_2' \ldots A_{p-1}' A_p' B']$$

where the asterisk (*) represents transformation of the original variable, for instance, if x_{it} is the original variable, the first difference transformation suggests that $x_{it}^{*} = (x_{it} - \bar{x}_{it})$. The forward moving orthogonal deviation is $x_{it}^{*} = (x_{it} - \bar{x}_{it})\sqrt{T_{it} / (T_{it} + 1)}$.

One of the key aspects of the panel VAR is model selection. This involves the choice of appropriate lags. The procedure is done based on the Andrews and Lu (2001) consistent moment and model selection (MMSC) for GMM. The criteria choose a pair of vectors (m, q m) that minimises:

$$MMSC_{BIC,n}(k,m,q) = J_n(k^2 m, k^2 q) - (|q| - |m| k^2 \ln n \tag{5.8}$$

$$MMSC_{AIC,n}(k,m,q) = J_n(k^2 m, k^2 q) - 2k^2(|q| - |m|) \tag{5.9}$$

$$MMSC_{HQIC,n}(m,q) = J_n(k^2 m, k^2 q) - Rk^2(|q| - |m|)\ln n \quad R > 2 \tag{5.10}$$

where $J_n(k,m,q)$ represents the J-statistic of over-identifying restriction for a k-variate panel VAR of order m and moment conditions given q lags of dependent variables with n sample size. The other aspect of the panel VAR is estimation of impulse response. The impulse response function Φ_i may be estimated by rewriting the model as an infinite vector of moving average (VMA), that is

$$\Phi_i = \begin{cases} I_k, i = 0 \\ \sum_{j=1}^{i} \Phi_{t-j} \eta_j, i = 1,2,\ldots \end{cases} \tag{5.11}$$

where Φ_i denotes the VMA parameters. We believe the panel VAR approach with its post-estimation considerations (i.e. panel Granger causality test, stability condition test, and impulse response test) is most appropriate in this essay.

5.4 Results

5.4.1 PCA outcomes

Table 5.1 presents the PCA results for both stock and quality variables of infrastructure.

Table 5. 1: Eigenvalues

	Eigenvalue	Proportion	Cumulative
Panel A: PCA for infrastructure stock			
PC1	2.277	0.456	0.456
PC2	1.162	0.232	0.688
PC3	0.788	0.158	0.846
PC4	0.539	0.108	0.953
PC5	0.234	0.047	1.000
Panel B: PCA for infrastructure quality			
PC1	2.390	0.478	0.478
PC2	1.111	0.222	0.700
PC3	0.763	0.153	0.853
PC4	0.472	0.094	0.947
PC5	0.265	0.053	1.000

Notes: Eviews 9 estimates. PC denotes principal component. The fourth column is the cumulative proportion.

A common criterion is to retain the principle components (PCs) with eigenvalues greater or equal to unit. Applying this criterion would mean retaining the first and second PCs for both infrastructure stock and quality. A limitation of this approach is that the suggested PCs may still have small cumulative proportion of variance. In our case, the cumulative proportions of PC1 and PC2 are 0.67 and 0.70 for stock and quality variables, respectively. That leaves 33% and 30% of the data processes uncaptured. Unlike the first chapter, this essay prefers to improve the explanation of the infrastructure data (i.e. to raise the proportion of variance) and hence 4 PCs are retained in both cases. For analytical and interpretational convenience, we chose to have a single aggregate infrastructure stock (AIS) and aggregate infrastructure quality (AIQ). This is achieved by taking an average of the selected PCs, thus, having a single aggregate infrastructure index, which is believed to be better than PC1 and PC2 separately. This study does not discuss the eigenvectors of the principle components but are shown in the Appendix 1, Table A.1. Eigenvectors or loadings show the weights of individual infrastructures in each principal component.

5.4.2 Summary statistics

The descriptive statistics of the variables are presented in Table 5.2. The variables are the logarithms of GDP per capita (LGDP), domestic aggregate infrastructure stock (LDAIS), domestic aggregate infrastructure quality (LDAIQ), foreign aggregate infrastructure stock (LFAIS), foreign aggregate infrastructure quality (LFAIQ), effective aggregate infrastructure stock (LEAIS) and effective aggregate infrastructure quality (LEAIQ). Note that the effective infrastructure variables combine both domestic and foreign infrastructure features. LFAIS and LFAIQ are constructed using a distance-based weighting matrix as discussed in section 5.3.2.1. The table displays the summary statistics (Observations, Mean, Standard deviation, Minimum and Maximum) of the variables in logs.

Table 5. 2: Summary statistics

Variable	Obs	Mean	St.Dev	Min	Max
LGDP	585	6.753	1.134	4.691	9.628
LDAIS	585	0.000	0.546	-1.793	1.753
LDAIQ	585	0.000	0.544	-1.451	1.072
LFAIS	585	-0.413	2.656	-25.729	2.295
LFAIQ	585	-0.472	2.354	-21.044	0.872
LEAIS	585	0.020	0.730	-4.277	4.837
LEAIQ	585	0.345	3.050	-1.331	35.947

5.4.3 Panel unit root

The next step is to check the stationarity properties of the variables. The unit root approach by Im, Pesaran & Shin (IPS) is used to test for stationarity. Unlike the Levin, Lin & Chu (LLC) approach, one of the key advantages of the IPS is that it assumes individual unit root process. This study considers automatic lag selection based on the Akaike information criterion (AIC) with an intercept included. We reject the null hypothesis that all panels contain unit roots across all variables in level. Nevertheless, all the variables are stationary in their first differences.

Our panel VAR techniques that runs estimation in a GMM framework overcomes any potential threat that might be linked to stationarity properties of the data by employing differenced lag instruments. The estimations are validated by checking appropriateness of model specifications using Hansen’s J-statistic and further carry out model stability condition checks.

Table 5. 3: Stationarity test

	Level	First Difference
	W-t-bar	W-t-bar
LGDP	2.773	-11.843***
LDAIS	1.874	-12.982***
LDAIQ	0.610	-16.753***
LEAIS	1.796	-14.286***
LEAIQ	2.378	-12.541***
LFAIS	5.368	-13.132***
LFAIQ	0.808	-17.457***

Notes: IPS unit root tests. Eviews 9 estimates.

5.4.4 Panel VAR estimations

Our major purpose is to provide an insight on the economic growth effects of aggregate infrastructure spillovers across SSA states. We employ a Stata code for panel VAR by Abrigo and Love (2016) in order to achieve this purpose. The first thing is to determine the order of a panel VAR model, that is, selecting appropriate lags. Second, we estimate the preferred panel VAR model. After running the main model there are other post-estimation considerations. These include granger causality test, checking the stability condition and estimating the impulse-response functions.

5.4.4.1 Model fit

Table 5.4 displays the results used to identify appropriate panel VAR models. Model A is the estimated results of equation (5.2) for domestic and foreign aggregate infrastructure variables. Model B shows the results of equation (5.3) for the effective aggregate infrastructure that combines domestic and foreign infrastructure. Infrastructure may reasonably influence economic growth after some lags, thus, this essay runs model selection estimates for the first to fifth-order panel VAR. However, given our sample size and data features, Model A cannot run a fifth-order may be because of relatively more variables and hence a fourth-order panel VAR is applied (see panel I, Table 5.4). The lags of instruments for Model A and B are 5 and 7, respectively. The model selection measures by Andrew and Lu (2001) suggests that a first-order panel VAR is most appropriate across the two models, having the lowest MBIC, MAIC and MQIC. Moreover, the J-statistics of over-identifying restriction for the selected models are not significant and hence we cannot reject the null hypothesis of correct specification. The coefficient of determination (CD) depicts the proportion of variation explained by the panel VAR.

Table 5. 4: Model fit: Optimal lag-length selection

Panel I: Model A - Domestic & Foreign infrastructure variables						
Lag	CD	J-statistic	(P-value)	MBIC	MAIC	MQIC
1	0.999	112.236	(0.190)	-473.843	-87.764	-241.421
2	0.999	96.479	(0.048)	-343.080	-53.521	-168.763
3	0.999	71.326	(0.025)	-221.713	-28.674	-105.502
4	0.999	41.757	(0.019)	-104.763	-8.243	-46.657
Panel II: Model B - Effective infrastructure variables						
Lag	CD	J-statistic	(P-value)	MBIC	MAIC	MQIC
1	0.999	66.455	(0.119)	-236.456	-41.545	-119.786
2	0.999	81.152	(0.001)	-171.275	-8.848	-74.050
3	0.999	52.620	(0.036)	-149.321	-19.380	-71.541
4	0.999	38.689	(0.068)	-112.766	-15.311	-54.431
5	0.999	24.696	(0.134)	-76.275	-11.304	-37.384

Notes: Stata codes: Model A: pvarsoc lgdp ldais ldaiq lfais lfaiq, maxlag (4) pvaropts (instl(1/5)).
Model B: pvarsoc lgdp leais leaiq, maxlag (5) pvaropts (instl(1/7)).

5.4.4.2 Infrastructure spillover analysis

The first-order panel VAR of equations (5.2) and (5.3) are estimated in a GMM style using Stata. Table 5.5 presents the results of the growth elasticities for domestic and foreign aggregate infrastructure from the estimation of equation (5.2). The key results of interest are those displayed in panel I with log GDP per capita as the dependent variable.

In the Table, the coefficients of LFAIS and LFAIQ show evidence of spillover effects from foreign aggregate infrastructure stock and quality, respectively. The results suggest that a percentage increase in the foreign aggregate infrastructure stock will lead to an annual decrease in GDP per capita by roughly 0.04%. On average, increased infrastructure stocks in a SSA country tends to create negative spillovers on other countries, especially the nearest areas (having used distance weights). As previously discussed, negative spillovers are feasible (see for example, Yilmaz, Haynes, & Dinc, 2002 (telecommunication); Moreno & Lopez-Bazo, 2003 (transport); Baird, 2005 (transport)). As an explanation, Yilmaz et al. (2002) argue that communication technologies enhance locational freedom of firms and the firms could use this infrastructure as a competitive tool for pulling production factors. Similarly, we believe that certain SSA states (such as South Africa) with relatively well developed infrastructure stocks may attract more investment than the regional counterparts. Negative spillovers to the surrounding countries are implied when production factors (human and physical capital) are drawn to the economies with relatively high infrastructure stocks at the expense of those with less infrastructure.[47] Relocation of production factors, thus, cause

[47] The issue of brain-drain may also play an important role in this case.

the lagging areas to experience weak economic activity and ultimately poor economic growth.

Table 5. 5: Model A: Panel VAR results - gmmstyle based

DV	IV	Coefficient.	Std.Error	[Confidence Interval]	
LGDP					
Panel I	LGDP(-1)	0.819***	0.024	0.772	0.866
	LDAIS(-1)	-0.641***	0.018	-0.676	-0.605
	LDAIQ(-1)	0.719***	0.051	0.619	0.819
	LFAIS(-1)	-0.036***	0.001	-0.039	-0.034
	LFAIQ(-1)	0.092***	0.002	0.088	0.096
LDAIS					
Panel II	LGDP(-1)	-0.068***	0.020	-0.107	-0.029
	LDAIS(-1)	0.650***	0.016	0.618	0.682
	LDAIQ(-1)	0.465***	0.045	0.378	0.553
	LFAIS(-1)	-0.005***	0.001	-0.007	-0.002
	LFAIQ(-1)	0.028***	0.002	0.023	0.032
LDAIQ					
Panel III	LGDP(-1)	0,014	0,011	-0,007	0,035
	LDAIS(-1)	-0,061***	0,011	-0,082	-0,039
	LDAIQ(-1)	0,910***	0,032	0,848	0,972
	LFAIS(-1)	-0,001	0,001	-0,003	0,000
	LFAIQ(-1)	0,009***	0,001	0,006	0,011
LFAIS					
Panel IV	LGDP(-1)	2,230***	0,239	1,762	2,698
	LDAIS(-1)	0,782***	0,201	0,388	1,176
	LDAIQ(-1)	-8,073***	0,640	-9,327	-6,819
	LFAIS(-1)	0,926***	0,014	0,898	0,954
	LFAIQ(-1)	0,174***	0,034	0,108	0,241
LFAIQ					
Panel V	LGDP(-1)	1,082***	0,110	0,866	1,298
	LDAIS(-1)	0,820***	0,086	0,652	0,987
	LDAIQ(-1)	-4,059***	0,300	-4,646	-3,472
	LFAIS(-1)	0,117***	0,007	0,103	0,131
	LFAIQ(-1)	0,776***	0,011	0,755	0,797
No. of Panels = 39					
No. of Obs = 507					

Notes: DV stands for dependent variable. IV stands for independent variable.
Stata code: pvar lgdp ldais ldaiq lfais lfaiq, lags (1) instl (1/5) gmmstyle.

Remarkably, the coefficient for LFAIQ is positive (0.09) and significant, suggesting positive spillover effects from foreign aggregate infrastructure quality. Upgrading a country’s infrastructure quality is not only beneficial to the domestic economy but can also instigate economic growth in the surrounding countries. For instance, paved roads make it much easier for countries to transport cargo across borders. Improvement in the quality of electricity (by lowering transmission and distribution losses) increases the amount of electricity available to end users, including ability to export power for foreign consumption. Innovations in telecommunication sector consistently break the distance-related barriers. Consequently, the quality feature of aggregate infrastructure creates positive spillovers among SSA countries.

Contrary to other studies (for instance, Calderon & Serven, 2004; Calderon, 2009) that examined the infrastructure-growth nexus in Africa based on aggregate infrastructure, our results show evidence of negative growth impact from domestic aggregate infrastructure stock. In particular, a percentage increase in infrastructure stock reduces GDP per capita by 0.64%. Thus, in this particular case the panel VAR model suggest a negative growth effect from domestic infrastructure stock. It is possible for domestic infrastructure development to exert a negative pressure on growth. First, it could be due to diversion of resources from other competing investments, which may overwhelm the gains of having additional infrastructure (Canning & Pedroni, 2008; Chakamera & Alagidede, 2017). This might be relevant in the African context given the wider financing gaps, thus, increased infrastructure investment will be associated with huge opportunity cost in terms of alternatives forgone.

Second, economic growth may tend to fall when an increase in public infrastructure is funded by income tax (see Barro, 1990). A dilemma happens when the positive effect of a “supply side” measure (i.e. infrastructure development) implemented to stimulate economic growth via augmentation of production function is cancelled by negative effect from the “demand side” of the economy due to tax burden. Looking at the components of GDP {C + I + G +(X-M)}, we can also speak of a situation where tax revenue (used to fund public infrastructure) raises government spending (G) while possibly posing negative pressure on consumption (C) , investment (I) and net export (X-M) depending on how quick the effects of G translate into economic benefits, *ceteris paribus*. The negative effects could be more pronounced when a country imports resources to be used in the construction of infrastructure and the new infrastructure further takes several lags to be fully beneficial while demand will be sensitive to tax burden.

Third, we believe that the negative effects from aggregate infrastructure stock could be related to unproductive utilisation of infrastructure in most SSA states. Economic hardships associated with low economic activity and high levels of unemployment may lead to unproductive use of the infrastructure and fail to yield benefits over and above the construction costs of infrastructure. Unproductive use of infrastructure include the non-business related use of telecommunication devices (for example, mobile network on social media), which barely produce economic benefits. Again, non-economic use of roads while increasing pollution and congestion is problematic. Moreover, the negative effects on growth might be a result of certain types of infrastructure in the aggregate indices rather than all the individual infrastructures. The growth effects of the individual infrastructure sectors are demonstrated in essay two.

Unlike infrastructure stock, a 1% increase in domestic aggregate infrastructure quality raises GDP per capita by approximately 0.72%. Therefore, the quality of infrastructure is central to increased growth. This is in line with our theoretical expectation that better public infrastructure (paved roads, airports with paved runways, decrease in electricity transmission and distribution losses, enhanced telecommunication services, and improved drinking water) facilitate productivity. From a social perspective, improved water reduces the likelihood of getting infected with water-borne diseases and hence lessens health expenses. Also in panel I, the first lag of GDP shows a positive and significant effect on current GDP. Approximately 0.82% of GDP per capita in a current year will be as a result of a percentage rise in GDP per capita in the previous year. Consequently, high annual GDP can trigger economic activity in the following year and ultimately raising economic growth.

This study does not dwell much on other results where the infrastructure measures become dependent variables. We observe that the domestic infrastructure stock is positively influenced by its own lag, domestic infrastructure quality and foreign infrastructure quality. However, previous GDP levels and foreign infrastructure stocks do not necessarily translate into more infrastructure stock but rather tend to lower the current stock levels. It could be that investment in infrastructure stock in SSA is non-linear; often done based on political priorities. As expected, the results indicate that the previous levels of infrastructure quality (both domestic and foreign) can positively influence the current domestic infrastructure quality. Nevertheless, the infrastructure stocks (domestic and foreign) suggest a negative effect on current infrastructure quality. A possible explanation is that when the respective governments invest more in infrastructure quality enhancement they may cut the proportion towards additional stocks. Thus, the results of panels II and III imply that improvement in infrastructure quality is often associated with more infrastructure stocks in the following year but more stocks may lead to less quality improvement.

In panels IV and V, the foreign variables are positively affected by previous GDP levels and domestic infrastructure stocks. It shows improved consumption of foreign infrastructures based on preceding high income and infrastructure stock levels. This may probably confirm why foreign infrastructure stocks show evidence of negative spillovers. When considerable consumption of foreign infrastructure significantly promotes foreign markets, negative spillovers may occur in the domestic market. On the contrary, the results imply that when earlier domestic quality levels (LDAIQ) are high in the economy, the relevance of foreign infrastructure variables (LFAIS, LFAIQ) to the domestic production function tend to decline. Thus, as long as the domestic infrastructure quality is super, the consumption of foreign infrastructure shrinks.

Table 5.6 shows the growth contributions from effective infrastructure stock and quality. In panel I, the growth effects of both effective infrastructure stock and quality are positive and statistically significant. But the contribution of effective infrastructure quality is lower than the spillover effects from foreign infrastructure quality. Although the separate effects of domestic and foreign infrastructure stocks are negative (see Table 5.5), their combined effect is positive (0.018). The changes in growth coefficients should be interpreted with caution because this could be a statistical or econometric related issue. After the panel VAR estimations, the following sub-sections are part of post-estimation considerations.

Table 5. 6: Model B - Panel VAR results - gmmstyle based

DV	IV	Coefficient.	Std.Error	z	P>z	[Confidence Interval]	
LGDP							
Panel I	LGDP(-1)	0.919	0.009	97.520	0.000	0.900	0.937
	LEAIS(-1)	0.018	0.000	41.050	0.000	0.018	0.019
	LEAIQ(-1)	0.002	0.000	8.390	0.000	0.001	0.002
LEAIS							
Panel II	LGDP(-1)	-0.004	0.004	-1.160	0.248	-0.011	0.003
	LEAIS(-1)	0.915	0.004	245.260	0.000	0.908	0.923
	LEAIQ(-1)	0.065	0.002	34.660	0.000	0.061	0.069
LEAIQ							
Panel III	LGDP(-1)	0.003	0.011	0.250	0.804	-0.018	0.024
	LEAIS(-1)	-0.550	0.013	-43.050	0.000	-0.575	-0.525
	LEAIQ(-1)	0.731	0.003	249.670	0.000	0.725	0.737
No. of panels = 39							
No. of Observations = 507							

Notes: DV stands for dependent variable. IV stands for independent variable.
Stata code: pvar lgdp leais leaiq, lags (1) instl (1/7) gmmstyle.

5.4.4.3 Panel Granger causality test

This essay performs panel Granger causality to determine whether each explanatory variable in our regression models can really cause changes in the dependent variable. In the estimated models (equations 5.2 and 5.3), this approach checks the potential causality of any excluded (or restricted) variable. The null hypothesis is that the excluded variable does not Granger-cause equation variable against the alternative hypothesis that excluded variable Granger-causes equation variable. Table 5.7 presents the panel granger causality results for Model A.

Table 5. 7: Model A - Panel Granger causality Wald test

	Equation/Excluded	chi2	P>chi2
LGDP			
Panel I	LDAIS	1222.531	0.000
	LDAIQ	199.832	0.000
	LFAIS	709.215	0.000
	LFAIQ	2050.961	0.000
	ALL	2883.179	0.000
LDAIS			
Panel II	LGDP	11.969	0.001
	LDAIQ	109.311	0.000
	LFAIS	17.298	0.000
	LFAIQ	136.232	0.000
	ALL	301.984	0.000
LDAIQ			
Panel III	LGDP	1.799	0.180
	LDAIS	30.762	0.000
	LFAIS	2.187	0.139
	LFAIQ	54.133	0.000
	ALL	170.081	0.000
LFAIS			
Panel IV	LGDP	87.119	0.000
	LDAIS	15.125	0.000
	LDAIQ	159.153	0.000
	LFAIQ	26.706	0.000
	ALL	682.658	0.000
LFAIQ			
Panel V	LGDP	96.531	0.000
	LDAIS	91.846	0.000
	LDAIQ	183.607	0.000
	LFAIS	259.737	0.000
	ALL	403.300	0.000

Notes: Stata code: pvargranger.
H_0: Excluded variable does not Granger-cause Equation variable.
H_1: Excluded variable Granger-causes Equation variable.

We are mainly interested in the first panel of Table 5.7. The Chi-squared statistics for the aggregate infrastructure variables are highly significant, therefore, we reject the null hypothesis and concluded that both domestic and foreign aggregate infrastructure stock and quality Granger-cause GDP per capita. The joint causality of all the four infrastructure variables as shown by the Chi-squared statistic of "ALL" is also significant and hence all the infrastructures jointly Granger-cause economic growth. The causality outcomes buttress our initial findings of significant impacts of domestic and foreign infrastructure (stock and quality) on economic growth. Thus, the evidence of infrastructure- growth relationships as depicted in Table 5.5 are not coincidental but rather plausible and robust. Except for LDAIQ versus LGDP and LDAIQ versus LFAIQ under panel III, all other pairs of variables show bi-directional Granger causality evidence. Thus, only the following show unidirectional causality: $LDAIQ \rightarrow LGDP$ and $LDAIQ \rightarrow LFAIS$.

Table 5.8 shows Granger causality outcomes for Model B. Both effective infrastructure stock and quality Granger cause economic growth as indicated in panel I. One way Granger-causality is only implied from the effective infrastructure variables to LGDP ($LEAIS \rightarrow LGDP$, $LEAIQ \rightarrow LGDP$) as the Chi-squared statistics for LGDP are not statistically significant in panels II and III.

Table 5. 8: Model B - Panel Granger causality Wald test

	Equation/Excluded	chi2	P>chi2
LGDP			
Panel I	LEAIS	1684.736	0.000
	LEAIQ	70.450	0.000
	ALL	3041.882	0.000
LEAIS			
Panel II	LGDP	1.337	0.248
	LEAIQ	1201.173	0.000
	ALL	1301.801	0.000
LEAIQ			
Panel III	LGDP	0.061	0.804
	LEAIS	1853.561	0.000
	ALL	1876.334	0.000

Notes: See footnotes under Table 5.7.

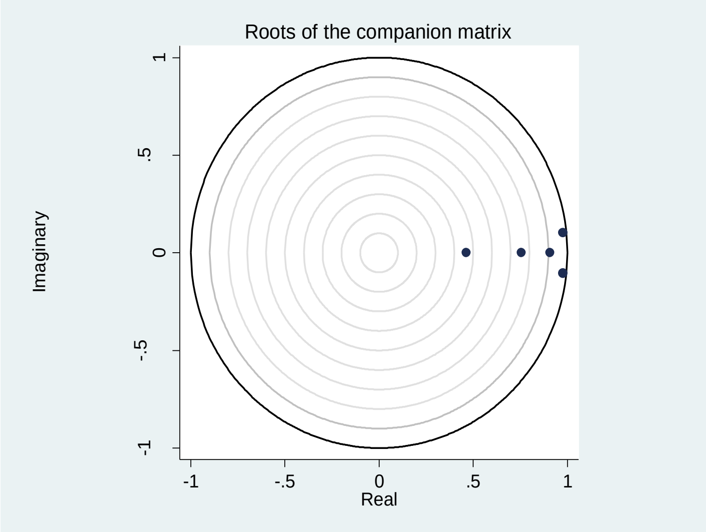
5.4.4.4 Stability condition checks

Prior to the estimation of impulse response functions, the estimated panel VAR models are checked for stability. Table 5.9 shows the results for both Model A and Model B. These results are accompanied by graphs (Figures 5.1 and 5.2).

Table 5. 9: Stability test

Model A			Model B		
Eigenvalues			Eigenvalues		
Real	Imaginary	Modulus	Real	Imaginary	Modulus
0.976	0.103	0.981	0.918	0.000	0.918
0.976	-0.103	0.981	0.823	0.165	0.840
0.908	0.000	0.908	0.823	-0.165	0.840
0.756	0.000	0.756	-----	-----	-----
0.464	0.000	0.464	-----	-----	-----

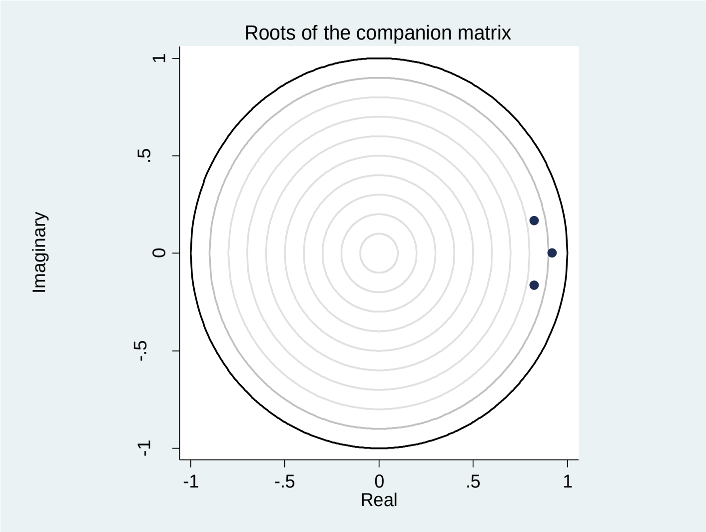
Notes: All eigenvalues lie inside the unit circle, thus, panel VAR satisfies stability condition.
Stata code: pvarstable.



Notes: The dots show the eigenvalues that lie inside the unit circle. Stata code: pvarstable, graph

Figure 5. 1: Model A - Stability condition

Source: Author's computations based graph.



Notes: See footnotes under Figure 5.1.

Figure 5. 2: Model B - Stability condition

Source: Author's computations based graph.

As confirmed by the values in the table and the dots on the figures, all the eigenvalues lie within the unit circle in each case. Consequently, our panel VAR models satisfy the stability condition and hence we proceed to run the impulse response tests.

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5.4.4.5 Impulse response

The impulse response results for Model A are displayed in Table 5.10. Panel I that shows the percentage of variation in GDP per capita explained by variations in the aggregate infrastructure variables is our main interest. It is revealed in panel I that economic growth is greatly explained by domestic aggregate infrastructure stock.

Table 5. 10: Forecast-error variance decomposition – Model A

	Response variable		Impulse variable				
			LGDP	LDAIS	LDAIQ	LFAIS	LFAIQ
Panel I	LGDP	lag					
		2	0.785	0.111	0.057	0.004	0.044
		4	0.488	0.309	0.092	0.009	0.102
		6	0.372	0.419	0.075	0.011	0.122
		8	0.316	0.483	0.058	0.014	0.128
		10	0.285	0.520	0.048	0.019	0.128
Panel II	LDAIS						
		2	0.036	0.920	0.037	0.000	0.006
		4	0.027	0.827	0.114	0.009	0.022
		6	0.025	0.764	0.138	0.034	0.039
		8	0.025	0.713	0.131	0.070	0.061
		10	0.026	0.657	0.130	0.102	0.085
Panel III	LDAIQ						
		2	0.045	0.011	0.942	0.000	0.002
		4	0.047	0.021	0.920	0.002	0.010
		6	0.055	0.058	0.860	0.005	0.022
		8	0.064	0.116	0.774	0.008	0.038
		10	0.071	0.184	0.681	0.010	0.054
Panel IV	LFAIS						
		2	0.053	0.208	0.082	0.656	0.002
		4	0.022	0.201	0.266	0.494	0.017
		6	0.015	0.214	0.379	0.353	0.039
		8	0.014	0.232	0.439	0.258	0.057
		10	0.015	0.249	0.472	0.195	0.069
Panel V	LFAIQ						
		2	0.078	0.076	0.093	0.318	0.434
		4	0.032	0.088	0.295	0.303	0.282
		6	0.019	0.125	0.403	0.244	0.210
		8	0.017	0.164	0.455	0.190	0.174
		10	0.017	0.197	0.482	0.148	0.155

Notes: Stata code: pvarfevd. FEVD standard errors and confidence intervals based on 200 Monte Carlo simulations.

The percentage of variation explained by LDAIS increases from 11% in lag 2 to 52% in lag 10. Moreover, the percentage of variation in growth explained by the foreign variables (LFAIS and LFAIQ) increases with the number of lags. Thus, the impact of the infrastructure variables on growth is more pronounced in the long-run. However, the response of GDP to domestic aggregate infrastructure quality (LDAIQ) tend to depict an inverted U-shaped relationship. The percentage of variation in GDP starts small (5%), rises to 9% in a space of 4 years and then declines as the number of years from initial quality enhancement increases.

Overall, the response of GDP to changes in domestic and foreign infrastructure stock persistently increases and tend to long-last. On the other hand, GDP's response to changes in domestic infrastructure quality may quickly diminishes, thus, short-lived. The responses of the infrastructure variables to each other and changes in the GDP level are demonstrated in the panels II, III, IV and V of Table 5.10. Most importantly are the responses of infrastructure development to changes GDP level, which are in the range 1% - 8% across the lags.

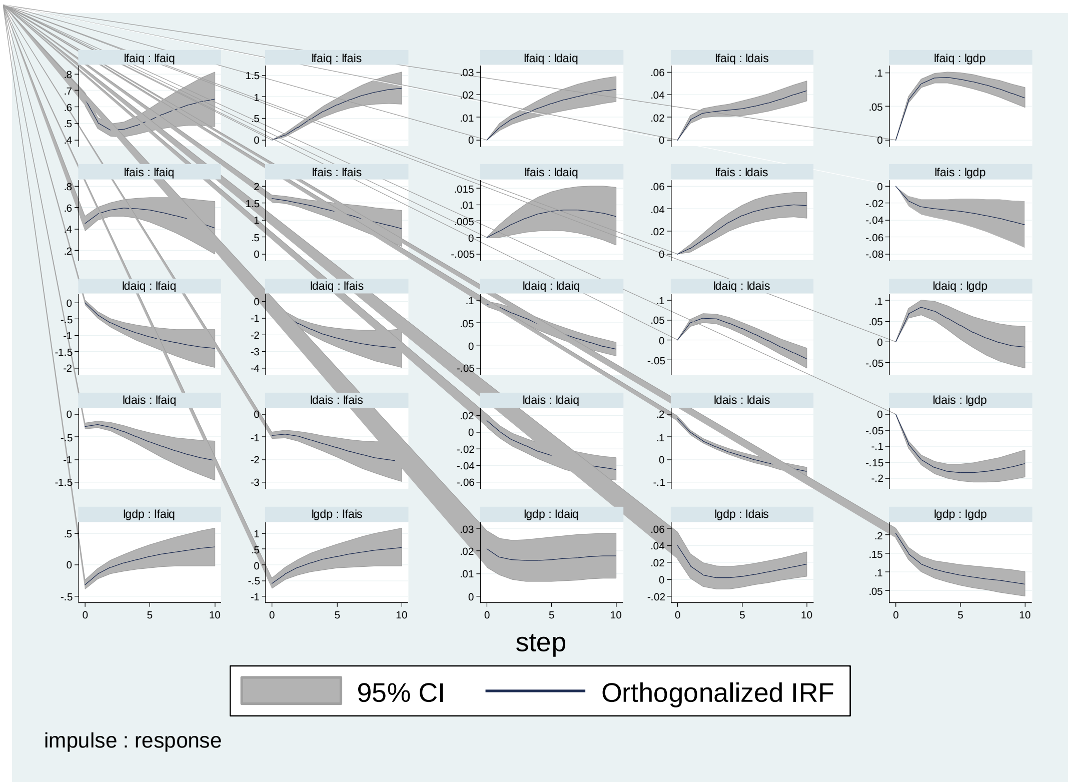
Table 5.11 shows the impulse response results for the effective infrastructure model. Under panel I of the table, it is clear that as much as 6% of variation in GDP per capita can be explained by effective stock of infrastructure while the effective infrastructure quality explains as much as 2% of variation. The percentage of variation increases with the number of lags. Consequently, the response of GDP to changes in the effective aggregate infrastructure level is relatively great in the long-term. However, the effective infrastructure stock and quality could not respond to changes in GDP (see panels II and III).

Table 5. 11: Forecast-error variance decomposition – Model B

	Response variable				Impulse variable
			LGDP	LEAIS	LEAIQ
Panel I	LGDP	lag			
		2	0.996	0.004	0.000
		4	0.979	0.020	0.001
		6	0.958	0.037	0.005
		8	0.940	0.050	0.010
		10	0.926	0.059	0.015
Panel II	LEAIS				
		2	0.000	0.991	0.009
		4	0.000	0.956	0.044
		6	0.000	0.917	0.083
		8	0.000	0.888	0.112
		10	0.000	0.873	0.127
Panel III	LEAIQ				
		2	0.000	0.277	0.723
		4	0.000	0.459	0.541
		6	0.000	0.564	0.436
		8	0.000	0.608	0.392
		10	0.000	0.619	0.381

Notes: see footnotes under Table 5.10.

In terms of the IRF graphs (Figure 5.3), we are interested on the last plots on the far right, which have LGDP as the response variable. As shown by the impulse response plots for LDAIQ:LGDP and LFAIQ:LGDP, positive shocks on domestic and foreign aggregate infrastructure quality can lead to increased GDP but the effects are short-lived. The impacts on GDP diminish in the long-term. Accordingly, the impulse response of GDP levels to changes in infrastructure quality levels follows an inverted U-shaped relation.



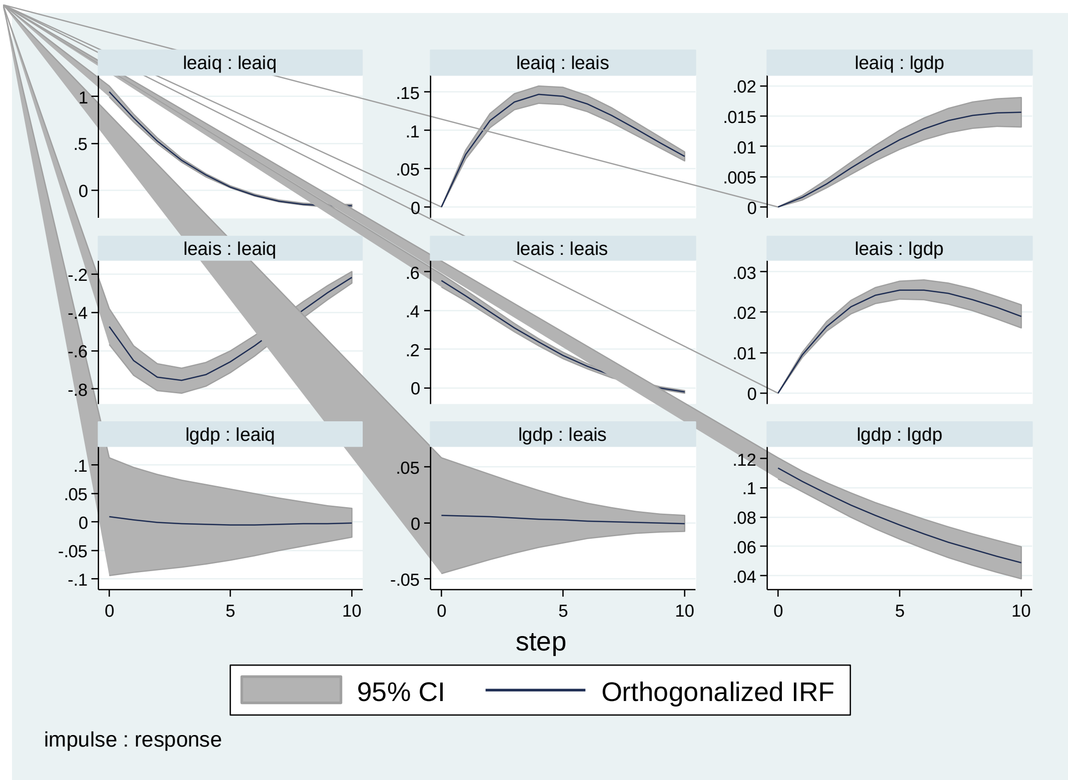
Stata code: pvarirf, mc(200) oirf byopt(yrescale).

Figure 5. 3: Model A - Impulse response plots

Source: Author's computations based graphs

The IRF plot for LDAIS:LGDP shows that positive shocks in domestic aggregate infrastructure stock exert a negative pressure on economic growth, however, the negative impacts become better in the long-run. It is probably that in the long-term the infrastructure stocks become more beneficial, recouping the cost of their construction and hence lessening the negative impacts. The LFAIS:LGDP plot depicts that a positive shock on foreign aggregate infrastructure stock can lead to continuous decrease in GDP and the impacts are long-lasting. This is linked to previous argument that foreign infrastructure development may act as a competitive weapon that improves a region with better infrastructure stock at the expense of the lagging surrounding areas. On average, those with poor infrastructure may persistently experience negative growth.

In terms of the effective infrastructure model, the IRF plot for LEAIQ:LGDP (Figure 5.4) suggests that a shock in the effective aggregate infrastructure quality can result in increased GDP. The positive impacts can exist for several years though at a diminishing rate. The plot for LEAIS:LGDP shows a positive impact on growth in the short to medium term yet in the long-term the impact becomes negative.



Notes: see footnote under Figure 5.3.

Figure 5. 4: Model B - Impulse response plots

Source: Author's computation based graphs.

In addition to the discussion above, we also believe that spatial density which deals with space may play a role in the provision and quality of infrastructure. While further research is required on the actual impact of spatial density on both infrastructure provision and quality, it influences the plans for the various infrastructure projects and the accompanying costs.

Furthermore, our analysis is somehow linked to "New economic geography" (NEG), however, we do not go deeper into the application of canonical new economic geography model that gives insight regarding the aspect of agglomeration forces. We therefore leave this issue as one of the areas for further study.

5.4.5 Implications of results

This essay has important policy implications. First, with increasing globalisation, raising infrastructure stocks may act as a competitive tool used to draw economic factors (human, financial and physical resources) from the surrounding countries with poor infrastructure stock. This implication is drawn from the negative spillover effects suggested by development in foreign aggregate infrastructure stock. Moreover, countries with better infrastructure may become lucrative destinations for foreign direct investment (FDI) and multinational companies. Under such circumstances, the areas with poor infrastructure stock may experience negative spillovers as they lose production factors to those with superior infrastructure.

Second, the occurrence of spillover effects through infrastructure stock and quality may differ. Our results demonstrated positive spillovers from foreign aggregate infrastructure quality but the spillovers from foreign aggregate infrastructure stock development are negative. Thus, the combined effect of paved roads, paved airport runways, reduced electricity transmission and distribution losses, enhanced IT infrastructure, and safe water will stimulate economic growth in the surrounding regions. For instance, paved roads enhances the use of road transport for long distances between two regions, and IT infrastructure improves communication and conduct of business deals between countries. Another important aspect of IT is its transferability across regional economies. Therefore, our results strongly suggest that it is not adequate to make policy based on spillovers of aggregate infrastructure stock alone as the quality features of infrastructure may produce vital spillovers, with a bearing on spillover-related policies. Some of spillover-related policy concerns are discussed below.

Third, the existence of spillovers brings out two major concerns for policy making: (i) whether there should be some form of cost-sharing arrangements between the regional economies that benefit from infrastructure spillovers, and (ii) the extent to which infrastructure investments are optimal in the presence of spillovers. A reasonable argument can be made for cost-sharing among beneficiaries in order to ease the investment burden of the economies that bear the costs of infrastructures responsible for major spillovers (or externalities). An example is when a coastal country's (e.g. South Africa) seaports or harbour generate enormous spillovers that benefit the surrounding landlocked countries (e.g. Zimbabwe). Zimbabwe cannot only benefit from South African harbour but also from SA's other transport infrastructures such as highways and railways from the seaports to the border. Despite the plausibility of sharing costs, it could be difficult to determine the cost-sharing structure that ensures a win-win situation.

On the issue of optimisation, some authors (for instance, Richaud et al., 1999) argue that infrastructure investment decisions at national level can be sub-optimal in the presence of spillovers and hence the decisions can best be made at a regional level. We concur with this argument and believe that investment decisions at a regional level would help lifting the SSA region as whole. This can be helpful when directing donor funds or other support from African Development Bank towards infrastructure development in SSA.

Fourth, the possible negative growth effects from domestic infrastructure stock development is a matter of concern. While policy makers might consider crowding out of private investment as a possible reason for negative impacts, we strongly argue that unproductive utilisation of the infrastructures could stand out. Public infrastructure might be under-utilised because of low economic activity, high unemployment, poor institutional qualities (e.g. violation of rule of law, political instability, poor democracy, high corruption levels) and limited investment funds in most SSA countries. Thus, in the absence of a favourable environment that fosters investment, public infrastructure may not yield returns above their construction costs.

Fifth, policy wise, thoughtful investment priorities are vital especially in SSA where financial gaps are wider as investment in infrastructure stocks may divert significant resources from other competing investments and possibly strain economic growth. Policy makers should therefore ensure balanced and optimal investments between public infrastructure and other investments, which requires a cost-benefit analysis. Additionally, funding public infrastructure from increased taxation demands careful attention since this may discourage consumption and drags per capita economic growth. To assist governments in the provision of infrastructure, policy makers need to consider private players. This will bring the necessary investment funds needed to increase the infrastructure stock levels.

Sixth, decision makers need to be aware of several lags involved before infrastructure's impact becomes substantial. The aggregate quality effects are more pronounced in the short to medium terms and eventually diminish in the long-term. We observed this from our impulse response results. This knowledge is vital when making infrastructure investment projections.

Lastly, positive infrastructure spillovers may facilitate regional take-off by creating important externalities, which enable the sound economic performance of some key economies to lift other regional states. Additionally, the positive effects of GDP lags on current GDP imply that it is possible for SSA countries to have a vicious cycle of economic growth, which is necessary for convergence and take-off. In the realm of the neoclassical convergence theory, higher impact from previous economic growth may suggest an expansionary gap (or catch-up gap) that still exist in SSA before reaching maturity stage. Such countries should experience higher growth rates and present great opportunities, which are imperative for investment decision.

SSA countries should ensure an appropriate budget towards quality enhancement, which stands to benefit not only the domestic economy but stimulate the surrounding areas through positive spillovers. Consequently, while SSA economies make efforts to address the infrastructure shortage problem, improving the quality of existing infrastructure is extremely necessary. This is also supported by our results in the previous essays.

5.5 Concluding remarks

Most previous studies have examined spillovers from single infrastructure stocks and what has been lacking is the knowledge from aggregated infrastructure perspective while accounting for quality features. The aggregate infrastructure measures provide an addition understanding regarding the spillovers from the general infrastructure system of an economy. Important spillovers may emanate from infrastructure quality features, and these may manifest in a different way from the stock spillovers. It is therefore encouraging to know the extent of spillover effects from both aggregate infrastructure stock and quality. This essay investigates spillover effects of aggregate infrastructure stock and quality in SSA. Each aggregate infrastructure index is a combination of electricity, roads, airports, telecommunication and water infrastructures. We create foreign aggregate infrastructure stock and quality indices using a distance-based weighting criterion. Panel VAR approach is used to do the estimations.

The results suggest positive spillover effects from aggregate infrastructure quality while the aggregate stock imply negative spillovers. Domestic aggregate infrastructure quality (stock) shows positive (negative) growth effects. These findings are bolstered by the panel Granger causality outcomes, summarised as follows:

$LDAIS \Leftrightarrow LGDP$; $LDAIQ \rightarrow LGDP$; $LFAIS \Leftrightarrow LGDP$; $LFAIQ \Leftrightarrow LGDP$;
$LEAIS \rightarrow LGDP$ and $LEAIQ \rightarrow LGDP$

where $\rightarrow$ denotes a unidirectional causality and $\Leftrightarrow$ denotes a bidirectional causality. In terms of impulse response, greater percentage of variation in GDP is explained by LDAIS, followed by LFAIQ. The IRF plots show that positive shocks on aggregate quality (domestic and foreign) lead to increased GDP in the short-term yet diminish in the long-term, creating an inverted U-shaped relation. Shocks in LDAIS lead to negative growth impacts, which become better in the long-term, creating a U-shaped connection.

The existence of spillovers may necessitate infrastructure investment decisions being made at the regional level than at country level. This allows the regional providers of infrastructure funds to look at SSA as whole; deciding the appropriate funds that each country should receive while accounting for spillovers in the projections. Furthermore, the formulation and implementation of cost sharing arrangements among beneficiaries could be necessary in the presence of substantial positive spillover effects. The results of this study are plausible and robust, however, future research should consider other weighting criteria such as neighbour-based weights and/or trade-based weights while still accounting for infrastructure stock and quality.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND POLICY RECOMMENDATIONS

6.1 Introduction

This chapter provides a summary and the conclusions drawn from each of the four essays of the thesis. The key policy recommendations of the study are given as well. Lastly, this chapter shows some areas that require further research.

6.2 Summary and conclusions

This study investigated the relationship between infrastructure and economic growth in SSA based on certain important themes within which there have been some empirical research gaps. Our analysis considered the nexus between aggregate infrastructure (both stock and quality) and economic growth. The aggregate infrastructure indices were developed based on the PCA technique, which was used to cluster electricity, telecommunication, roads, airports, water and sanitation infrastructure. Additionally, this study addressed the infrastructure-growth causation question using a new approach that involved the application of a hybrid index that captures both the quantitative and qualitative effects of aggregate infrastructure. While it is important to have knowledge of the impact of aggregate infrastructure on growth, this studies took a further step to reveal the short and long-run growth contributions from the stock and quality variables of each infrastructure sector. Among the infrastructure sectors, we further examined the electricity sector in SSA using a different proxy for electricity stock and with electricity-related CO2 emissions introduced into the analysis. Beyond the outlined areas, this study investigated the spatial spillover effects from aggregate infrastructure. Specifically, *infrastructure-growth nexus*; *direction of infrastructure-growth causality*; *electricity consumption, CO2 emissions and growth*; *spatial spillovers of infrastructure* were the key themes of focus in this research. Based on these themes, this study addressed the following research questions:

1. Do aggregate infrastructure stock and quality stimulate economic growth?

2. What is the direction of causality between infrastructure and economic growth?

3. How do different infrastructure sectors impact economic growth in both short and long-run?

4. To what extent are electricity-related CO2 emissions alter the nature and magnitudes of electricity (stock and quality) growth contributions?

5. Do foreign aggregate infrastructure stock and quality developments produce vital spatial spillovers that impact economic growth in a country?

The first and second research questions were answered in chapter one while the rest of the research questions were answered each in a separate chapter. This study has already discussed the existing research gaps and our contributions to each of the themes. It is therefore imperative to summarise the key findings of the study.

6.2.1 The nexus between aggregate infrastructure and Economic Growth

This study investigated the economic growth effects of aggregate infrastructure stock and quality in a GMM framework. In addition, we examined the direction of causality between infrastructure and economic growth. The overall results suggested positive and robust growth effects from both infrastructure stock and quality, with relatively more contribution emerging from quality. However, we cannot conclude that the relative great impact of infrastructure quality means quality is more superior but this might be as a result of the sanitation effect being absence on the aggregate stock indices while it is captured by the aggregate quality indices. Another striking result of the essay is the evidence of a unidirectional causality from infrastructure to growth, which was only revealed via the application of a hybrid index while the separate infrastructure stock and quality variables do not show any causality evidence. Also particularly in this essay, the hybrid effects are relatively high than the stock effects, suggesting some extra effects from quality features.

6.2.2 Long and short-run growth effects of each infrastructure sector

By employing a five-step panel approach, this study examined the growth effects of each infrastructure stock and quality measure. The findings revealed positive long-run economic growth effects from electricity stock, telecommunication stock and the qualities of transportation, sanitation and telecommunication. Also in the long-run, our results indicated that water stock has no significant impact while transportation stock can exert a negative pressure on growth. For the short-term effects, we found positive short-term growth effects from telecommunication stock and electricity stock, telecommunication quality and sanitation quality, while electricity quality showed negative growth effects. Moreover, the short-run coefficients for transport and water quality variables were not statistically significant. In this essay the hybrid effects are generally smaller than the stock effects. Unlike the essay above, it is important to know that this essay applied a product aggregator in the construction of hybrid indices.

6.2.3 Electricity crisis and the effect of CO2 emissions on infrastructure-growth

We investigated the impact of electricity-related CO_2 emissions on the growth contributions of both electricity stock and quality. The results indicated that electricity-related CO_2 emissions can undermine the positive effect of electricity stock on growth and intensifies the negative growth impact of electricity quality. Thus, both high levels of electricity transmission and distribution losses, and electricity-related CO_2 emissions are counterproductive. This essay also assesses the degree of electricity shortage. It was revealed that only 35% of SSA's total population had access to electricity by 2012 yet South Asia and MENA (which has Northern African countries) had approximately 78% and 96% in the same year, respectively. In terms of electricity power transmission and distribution losses, SSA is relatively better than MENA and South Asia, however, the losses are still considered high. SSA showed the highest CO_2 emissions from electricity heat and production (mainly from solid fuel sources).

6.2.4 Spatial Spillover Effects of Aggregate Infrastructure Stock and Quality

This study took an extra step in the analysis of infrastructure spillovers by investigating the evidence for spatial spillover effects from the perspective of aggregate measures of infrastructure while accounting for quality features of infrastructure, something that was missing extant literature. A distance weighting-based criterion was used to construct the foreign infrastructure variables and the Panel VAR approach was employed in the estimation of spatial spillovers. We found strong and positive spatial spillovers from foreign aggregate infrastructure quality but the use of foreign aggregate infrastructure stock suggested negative spillovers. Domestic aggregate infrastructure quality (stock) showed positive (negative) growth effects. To bolster our results, panel Granger causality tests indicated evidence of causality between the aggregate infrastructure (domestic and foreign) variables and economic growth, mostly running in both directions and hence supporting a feedback hypothesis. Furthermore, the impulse response plots indicated that positive shocks on aggregate quality (domestic and foreign) lead to increased GDP in the short-term yet diminish in the long-term, creating an inverted U-shaped connection. A shock in domestic infrastructure stock leads to negative growth impacts, which become better in the long-term.

6.3 Policy implications and recommendations

The Africa Infrastructure Country Diagnostic (AICD) was initiated in line with severe infrastructure gaps in SSA, thus, the AICD project would assist in monitoring donor funds. In an effort to establish the economic growth of infrastructure from an empirical perspective this study is among the few studies that has provided both the expected contributions of infrastructure stock and quality to growth per capita in SSA. Restated in this section are the key policy implications and recommendations that are not only relevant to the respective governments but also crucial to projects such as the AICD and other developing countries.

A number of interesting policy implications are drawn from our findings. The application of different aggregators when developing hybrid indices that simultaneous capture both infrastructure stock and quality has produced slightly two different outcomes but suggesting the importance of infrastructure quality development in SSA. The hybrid indices in chapter two are based on linear aggregator and the hybrid effects are higher than the stock effects. It implies that adding the quality effects of infrastructure to the stock effects will produce a higher combined impact on GDP. This shows an extra effect emerging from infrastructure quality features. On the other hand, the hybrid indices in chapter three are based on product aggregator and in this case the hybrid effects are generally smaller than the stock effects. The importance of this second aggregator is that one may infer possibility of moderation by treating the quality features as potential moderator of the relationship between infrastructure stock and economic growth. Thus, in our case, the quality attributes of infrastructure in SSA tend to reduce the growth contributions from the existing infrastructures. In other words, the poor levels of infrastructure quality in SSA tend to moderate the effective impact of infrastructure stock on economic growth.

On the issue of causality, our results imply that the sole application of infrastructure quantity measures (as commonly in the earlier literature) may fail to detect causality between infrastructure and economic growth. In this study, the application of stock and quality effects separately showed no causality while the hybrid indices that combines the two effects detected causality. It may suggest that the stock or quality measures alone could not have enough power to reveal the infrastructure-growth causality. The hybrid indices are vital in this case as we are able to apply a single index with both stock and quality attributes to address the direction of causality issue. More so, they show how an entire infrastructure and its efficiency is related to GDP. Our evidence of unidirectional causality from hybrid infrastructure to GDP per capita implies that policies that are meant to minimize expenditure on additional, maintenance and upgrading of infrastructure will hinder economic growth. However, an increase or decrease in GDP levels in SSA seems to have no effect on infrastructure.

More so, another important aspect is the poor economic growth impact of agricultural water for the rural population. Form a policy perceptive, the provision of water in rural areas is not sufficient to guarantee significant economic returns. Other agricultural inputs (such as skills, seeds, fertilizers and chemical) are required for the farmers to have a better harvest. Apart from that, when it comes to comes to the infrastructures available to the rural population, policy makers should also bear in mind of the measurement-related problems. In this case, infrastructure such as water for irrigation and road networks in rural communities play a fundamental role in rural areas. However, the importance and contribution of rural economy may not be fully represented in the GDP measure. We acknowledge that these measurement problems may exist beyond the rural setting but it is our belief that the rural economy could be the biggest casualty given the challenges of obtaining information from such backward areas.

Another important result in this study is the existence of spatial spillover effects from both infrastructure stock and quality. In our analysis the use of foreign aggregate infrastructure stocks tend to have a negative impact on domestic economic growth, thus, implying negative spillovers. This is based on aggregate measures of infrastructure but does not imply that all individual infrastructure sectors may generate negative spillovers. We believe higher levels of infrastructure stocks may provide a competitive advantage to an economy by attracting vital economic factors and firms away from the regions with poor infrastructure. Under such circumstances, policy makers should expect negative spillover effects in the lagged neighbouring regions.

On the other hand, aggregate infrastructure quality enhancement can produce crucial spillovers that stimulate economic development in the surrounding countries. From a policy position, this is vital for the up-lifting of SSA as whole since strong infrastructure quality in certain key countries can lift the surrounding regions. This is also necessary in the process of SSA catching up with other leading regions. While infrastructure is basically beneficial to every economy, policy makers must have a good understanding of the time lags that may pass before infrastructure becomes more beneficial.

Most importantly, evidence of spillovers effects raises two policy concerns. First, infrastructure investments at country level could be sub-optimal in the presence of spillovers. Thus, investments done at a regional level is likely optimal by ensuring proper accountability of spillover effects among SSA countries. Decision makers at the regional level (including AfDB and AICD) may consider possible spillovers when allocating and directing external or donor funds towards infrastructure development among SSA economies. Second, spillover effects necessitate the formulation of cost-sharing arrangements among beneficiaries. This can reduce the cost burden incurred by a country originators of vital spillovers. Though the design of an appropriate cost-sharing structure might be difficult, we recommend the existence of such arrangements to ensure a most win-win situation.

Other key policy concerns are related to the severe shortages of infrastructure in SSA. The levels of infrastructure stock in SSA countries have a bearing on their respective economic activities. While this study has confirmed the positive contribution of infrastructure stock to economic growth, we have reasons to believe that the region has not reached the potential growth benefits of infrastructure investments due to the shortage of infrastructure. Therefore, the role of public infrastructure as an additional factor of production or complementary factor to private inputs of production is weakened. Despite complementing private inputs, different public infrastructure types may complement each other. It is therefore imperative for policy makers to consider also the aggregate growth impact of the entire infrastructure system. In order to address the shortage of infrastructure, substantial investments in infrastructure development are needed. Most importantly, infrastructure investments must consistently be made on annual basis rather than pushing for more infrastructure during election phases. Investments that are motivated by the need to hold a political office are not sustainable. Most of such infrastructure projects tend to halt once an election period has passed. In this case, it is vital to set priorities straight by ensuring sustainable infrastructure investments and hence looking beyond one’s political career.

Also on the issue of addressing infrastructure shortages, we acknowledge the wider financing gaps in SSA, thus, the sources of infrastructure funding matter. Governments are often best placed to provide public infrastructure mainly because of the charactering of public goods that include non-excludability and non-rivalry. Public infrastructure is vital to every economic citizen and it is primarily the duty of every government to provide public infrastructure. However, infrastructure funding from tax revenue may produce some problems. This may put a negative pressure on the ultimate GDP per capita when crowding out of private investment happens. High tax burdens may also discourage private consumption and aggregate demand, which may lead to a decline in GDP. Furthermore government funding of infrastructure may lead to an enormous shift of the limited resources from other vital investments. The construction costs of certain infrastructures such as roads could be high and these infrastructures may imply negative growth effects when they fail to generate economic benefits beyond their construction costs.

In addition, infrastructure funding from tax revenue is hampered by the huge size of informal sector in most SSA countries. Some of these informal business undertakings are motivated by the high levels of unemployment. One of the problems of informal sector is that business activities are not recorded for tax payment. Dealing with tax evasion is also a challenge. Consequently, the governments in SSA do not fully receive tax revenue while even those who evade the payment of taxes they want to use the various pubic infrastructures. Regardless of the importance of public sector in the provision of infrastructure, private participation is needed in the supply of certain public infrastructure. This becomes another source of infrastructure finance. We have already seen the involvement of private participation in the provision of telecommunication services. Though private participation might be difficult in other sectors such as roads and railways, it is possible to raise private sector involvement in the electricity sector which seems to be the most struggling sector (associated with load shedding) in SSA. Private power producers are vital in the region; they may undertake solar energy projects and other energy projects including off-grid small power plants.

Apart from solving the shortage of infrastructure, the findings of this study strongly confirm the benefits obtainable from improving the quality infrastructure. However, electricity quality implies negative growth effects in SSA. This is not a surprise given deterioration in the quality electricity sector in the region as represented by a rise in the ratio of electricity transmission and distribution losses (RETDL). Though we cannot say the distribution losses translate into power outages, the kWh that are lost as transmission and distribution losses can lower the quantity of electricity that reaches the end users. Moreover, poor quality of the telecommunication sector as represented by the lower levels of information technology (IT) infrastructure is another notable concern in SSA. We believe it is among the reasons for weaker growth effects of the telecom sector. Overall, the main implication drawn from our analysis of both the aggregate infrastructure and individual infrastructure sectors is that, it is not only about the quantity (or stock) of infrastructure a country has but also and most importantly the qualities of such infrastructure. When the existing infrastructure stocks are in poor state then they will not effectively generate economic benefits. Policy makers should always ensure a separate annual budget directed towards maintenance and upgrading of infrastructure. The World Bank's estimated US$37 billion of annual investments for infrastructure maintenance and operations in Africa is warranted.

Educating the ordinary people in SSA about the effective use of public infrastructure in order to prolong their duration is also essential. It is because malicious damage of public infrastructure (such as electricity and telecommunication cables, public tapes and public terminals) is still common in most African countries. Besides the issue of quality, it is our belief that the growth contributions of other infrastructure such as telecommunication and even negative impacts from transportation stock (combination of roads and airports) may reflect underutilisation utilisation of the infrastructures given low economic activity in most SSA countries. Other SSA countries have a large number of second hand and inefficient cars that may contribute more to pollution. Most of these cars are not used for business purposes and do not economically contribute anything. It seems also that the penetration of mobile service with its internet or data services has not been fully a taken advantage of. Though these technologies are key in various commercial fields including education and marketing, other social media purposes (Instagram, Whatsapp, Facebook, Twitter, and YouTube) barely yield economic benefits. What is required in SSA are conducive environments (that ensures for instance, more economic activity, lower unemployment rates, improved education) that foster the productive utilisation of infrastructure. A favourable environment encompasses the one with less corruption levels which cause misuse of public funds and scare away potential investors.

Also in the area of SSA's power sector, our closer analysis has indicated that the proportion of electricity generation from renewable sources (excluding hydro) is very low. On the other hand, the region has most of its electricity power from coal sources. For sustainable growth, it is important for policy makers to put more effort on elevating the amount of energy from renewable sources. Africa should grab the advantage of the long hours of sunshine to harness more energy from solar sources. Due to the greater proportion of SSA's population without electricity especially in rural areas, small hydro power plants together with solar systems that operate as off-grid in decentralised manner might be used to supply power to many people. The majority of population without electricity shows an opportunity when those people become future consumers of electricity especially in productive undertakings such as irrigation in rural communities. Policy makers however should bear in mind that these small-scale power systems lack vital economies of scale to minimise generation costs. Electricity pilferage (non-technical loss) which is common in most SSA countries calls for appropriate measures from the respective governments in order to reduce the transmission and distribution losses of power.

Due to large coal reserves in SSA, countries can continue generating power from this source while making effort to diversify their electricity sources. Hydro, solar and wind energy sources are most vulnerable to weather related risks and hence in this case coal may still light the nations. However, coal has been the major emitter of electricity-related $CO2$ emissions in the region. Our findings indicated that these emissions can reduce the growth contributions of the electricity sector in SSA. Consequently, policy makers should put in place appropriate measures to reduce the effects of these pollutants. Such measures include the implementation of carbon taxes and the use of carbon capture and storage technologies. We argues that where carbon taxes are applicable their design should consider the extent to which such emissions may alter the growth effects of electricity supply. This is necessary to ensure a carbon tax that minimises the $CO2$ emissions without discouraging the electricity output. Given the extent of electricity shortages in SSA, we rather recommend investing in carbon capture technologies. Most importantly, several SSA countries need to improve the efficiency of aged and inefficient coal plants.

While most researches tend to focus on the core infrastructures (telecommunication, electricity and transportation), it is important for policy makers to increase the percentage population with access to safe water and sanitation. Benefits are obtainable from improving health and reducing the burden of healthcare expenditures. The availability of these infrastructures enhance labour productivity and minimise the number of lost working hours due to sickness.

As far as investment in most infrastructure is concerned, policy makers need to be aware of possible time lags before the infrastructure become more beneficial. For instance, transportation infrastructure may take several years to appropriately benefit an entire agglomerated region through network dynamic externalities. A practical challenge for policy making is the estimation of these externalities to fully understand the overall benefits from transportation network.

6.4 Areas of further study

Despite some impressive findings, the carrying out of this study encountered certain challenges. We could not find the actual quality scores for telephone and mobile services, thus, the quality scores of information technology (IT) infrastructure was used as a proxy given the importance of this variable in the telecommunication sector. Again, finding a variable that represent the stock of water in an entire nation was another challenge and hence we employed access to water for agriculture for the rural population as a proxy for the stock of water. Most observations for railway data was missing and thus it is omitted from the analysis. Moreover, failure to find a better proxy for sanitation stock is another obstacle. Some weaknesses might be found in the quality measures (as also specified by Calderon and Serven, 2004), which has been a challenge in the literature.

Given our analysis and the implications of the results, there are prospects for future research in the infrastructure-growth analysis literature. First, it would be remarkable for future researchers to constantly attempting to find improved measures of infrastructure variables. Most importantly, due to difficulties in terms of quantifying the quality attributes of most infrastructure sectors, it is an area that should receive more attention.

Second, it is important for future studies to investigate the moderation effect of the infrastructure quality from a moderation analysis framework. In practice, it seems often tempting to make projections based on the available infrastructure stocks without a proper analysis of how the quality (or state) of such infrastructure may disrupt the projected outcomes. When a measure of infrastructure quality is available, moderation analysis allows policy makers and researchers to treat quality as a potential moderator of the expected growth effects of the existing infrastructure stock. One is able to obtain the size of the moderation effect as quality controls the performance of the infrastructure.

Third, further studies may investigate the influence of CO2 emissions on electricity stock and quality from a time series perspective for the effects of these emissions may differ across individual countries. Non-dependency in terms of electricity efficiency indicators (LRETDL, LMRETDL and LCO2EM) may imply heterogeneity across individual SSA countries in terms of efficiency. Consequently, in the presence of heterogeneity, the countries may need slightly different policy guidelines when addressing electricity efficiency.

Fourth, though our results for infrastructure spillovers are plausible and robust, future research should consider other weighting criteria such as neighbour-based weights and/or trade-based weights while still accounting for both infrastructure stock and quality. This study have not considered these other weighting criteria for the reasons discussed in chapter five.

Fifth, it will be interesting to estimate the spillovers from aggregate infrastructure stock and quality using other techniques such as the global VAR technique. It will be important to see if the evidence for positive (negative) spillover effects from foreign infrastructure quality (foreign infrastructure stock) can be established using other methodological approaches. Again in the analysis of spillovers, further studies may also employ canonical new economic geography model that gives insight regarding the aspect of agglomeration.

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Appendices

Appendix 1: Data information and Eigenvectors for chapter five

Table A. 1: Eigenvectors or Loadings

	Components				
Variable	PC 1	PC 2	PC 3	PC 4	PC 5
Eigenvectors for infrastructure stock					
LELES	0,505	0,122	-0,507	0,541	0,425
LAIRS	0,548	-0,348	0,178	0,274	-0,687
LTELS	0,428	0,453	-0,360	-0,651	-0,241
LWATS	0,125	0,746	0,591	0,280	-0,013
LROADS	0,496	-0,319	0,482	-0,362	0,538
Eigenvectors for infrastructure quality					
LELEQ	-0,015	0,838	0,530	0,054	0,114
LAIRQ	0,378	0,461	-0,685	0,300	-0,293
LTELQ	0,525	-0,205	0,475	0,083	-0,671
LWATQ	0,552	-0,186	0,123	0,490	0,636
LROADQ	0,525	0,093	-0,096	-0,812	0,215

Notes: Eviews 9 estimates. Eigenvectors shows the weight carried by each variable in the principal components.

Table A. 2: Electricity Stock and Quality - GMM Approach

	Stock			Quality	
Variables	*Model 1*	*Model 2*	*Variables*	*Model 3*	*Model 4*
LNELEST	0,789***		LRETDL	-0,606***	
LMELEC		0,723***	LMRETDL		-0,651***
LNTRAD	0,082	0,115		0,418***	0,413***
LNFDEP	-0,128***	-0,165***		-0,062	-0,024
LNINFLAT	-0,275***	-0,288***		-0,360***	-0,354***
LLOCDUM	0,730***	0,659***		0,850***	0,924***
_CONS	2,649***	2,925***		3,867***	3,711***
Obs	385	385		385	385
R-squared	0,653	0,677		0,462	0,404
Root MSE	[0,654]	[0,630]		[0,814]	[0,857]
1st Stage regression summary stats					
Adjusted R-squared	0,712	0,749		0,526	0,475
Partial R-squared	0,501	0,539		0,372	0,337
Test of endogeneity (orthogonality conditions)					
GMM Chi2	27,924	21,854		54,988	57,908
	(0,000)	(0,000)		(0,000)	(0,000)

Note: GMM estimates based on Stata 13. These GMM results are compared to the 2SLS results in Tables 4.5 and 4.6, case I. In this case of just-identified, there is no difference between the 2SLS and GMM estimates as indicted also by Wooldridge (2001). Electricity stock measures are endogenous variables (i.e. LELEC and LMELEC). Endogeneity tests have the null hypothesis that the variables are exogenous. [ ] and ( ) represent standard errors and p-values, respectively.
*** denotes significant at 1% level

Table A. 3: Data information and list of countries

Variable	Period	Source
Infrastructure stocks based on:		
Net electricity generation capacity (Blns kWh)	2000-2012	Analyse Africa - Primary source: US Energy Information: International Energy Statistics
Telephones (subscriptions per 100 persons)	2000-2014	Analyse Africa; World Bank Group: WDI
Mobile (subscription per 100 persons)	2000-2014	Analyse Africa; World Bank Group: WDI
Roadways (km)	2000-2014	CIA Factbooks; Photius Coutsoukis
Airports (total number)	2000-2014	CIA Factbooks; Photius Coutsoukis
Agricultural Water (% of rural population with access)	2000-2014	Mo Ibrahim Foundation: Ibrahim Index of African Governance
Infrastructure quality based on:		
Electricity distribution losses (Blns kWh)	2000-2012	Analyse Africa - Primary source: US Energy Information: International Energy Statistics
IT infrastructure scores (proxy for telecommunication)	2000-2014	Mo Ibrahim Foundation: Ibrahim Index of African Governance
Paved roads (km)	2000-2013	CIA Factbooks; Photius Coutsoukis
Airports with paved runways (proxy for airport quality)	2000-2013	CIA Factbooks; Photius Coutsoukis
% of population with access to drinking water	2000-2014	WHO/UNICEF: Joint Monitoring Programme
% of population with access to sanitation	2000-2014	WHO/UNICEF: Joint Monitoring Programme
Other variables:		
GDP per capita ($US) - (dependent variable)	2000-2014	Africa Analysis - *primary source:* IMF
Inflation (Consumer prices: Annual Percentage)	2000-2014	World Bank Group: World Development Indicators
Terms of Trade	2000-2013	World Bank Group: World Development Indicators
Human Development	2000-2014	Mo Ibrahim Foundation: Ibrahim Index of African Governance
Trade (% of GDP): (proxy for trade openness)	2000-2014	Analyse Africa- *primary source:* World Bank Group: WDI
Domestic Credit to Private sector (% of GDP) [Financial Depth]	2000-2014	World Bank Group: World Development Indicators
Land Area (Square km)	2000-2014	Photius Coutsoukis
Population (millions of persons)	2000-2014	Africa Analysis - *primary source:* World Bank Group: WDI
Political stability & absence of violence/terrorism (-2.5 - 2.5)	2000-2014	Analyse Africa - *primary source*: Mo Ibrahim Foundation
Governance (scale: 0-100)	2000-2014	Analyse Africa - *primary source*: Mo Ibrahim Foundation
Personal Safety (0-100)	2000-2014	Analyse Africa - *primary source*: Mo Ibrahim Foundation
Freedom (rating: 1-7) (1-2.5 free, 3-5 partly free, 5.5-7 free)	2000-2014	Analyse Africa - below is the primary source: Freedom House: Freedom in the World

Sub-regional categories:	*List of countries*
South Africa	Angola, Botswana, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Zambia, Zimbabwe
West Africa	Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo
Central Africa	Cameron, Cape Verde, Chad, Congo Republic, Democratic Republic of Congo, Equatorial Guinea, Ethiopia, Gabon
East Africa	Burundi, Comoros, Eritrea, Kenya, Rwanda, Sao Tome Principe, Tanzania, Uganda

Appendix 2: Regional infrastructure levels

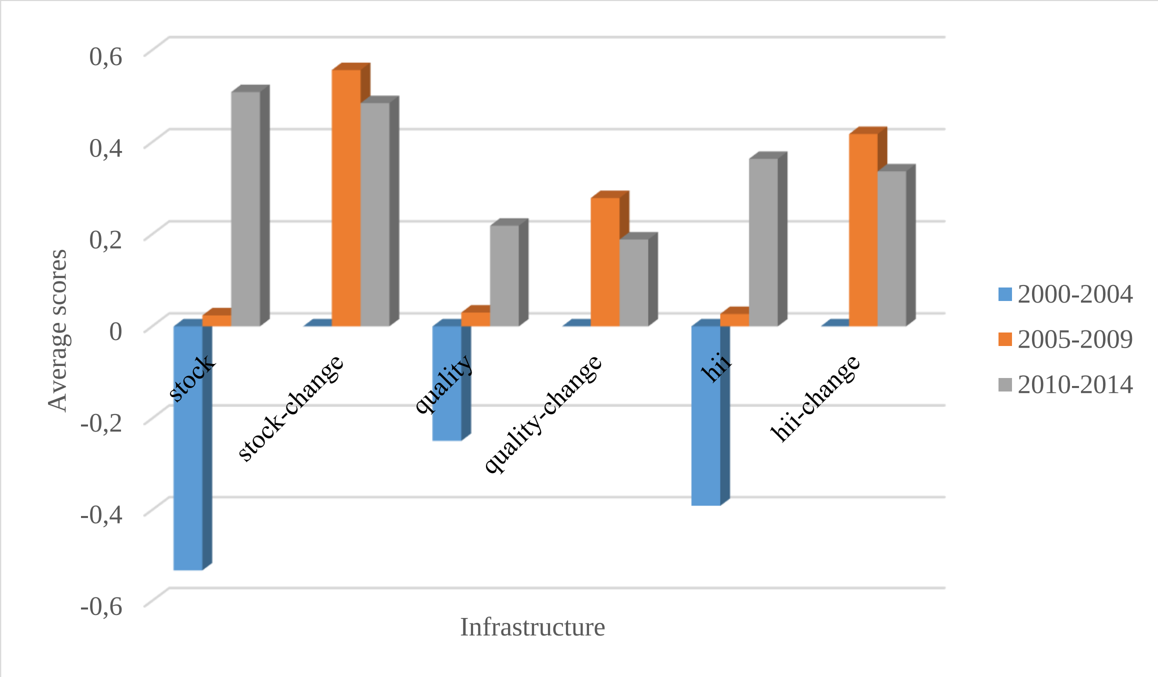


Figure 2. 5: SSA changes in infrastructure levels

Source: Author's constructs based on selected principal components

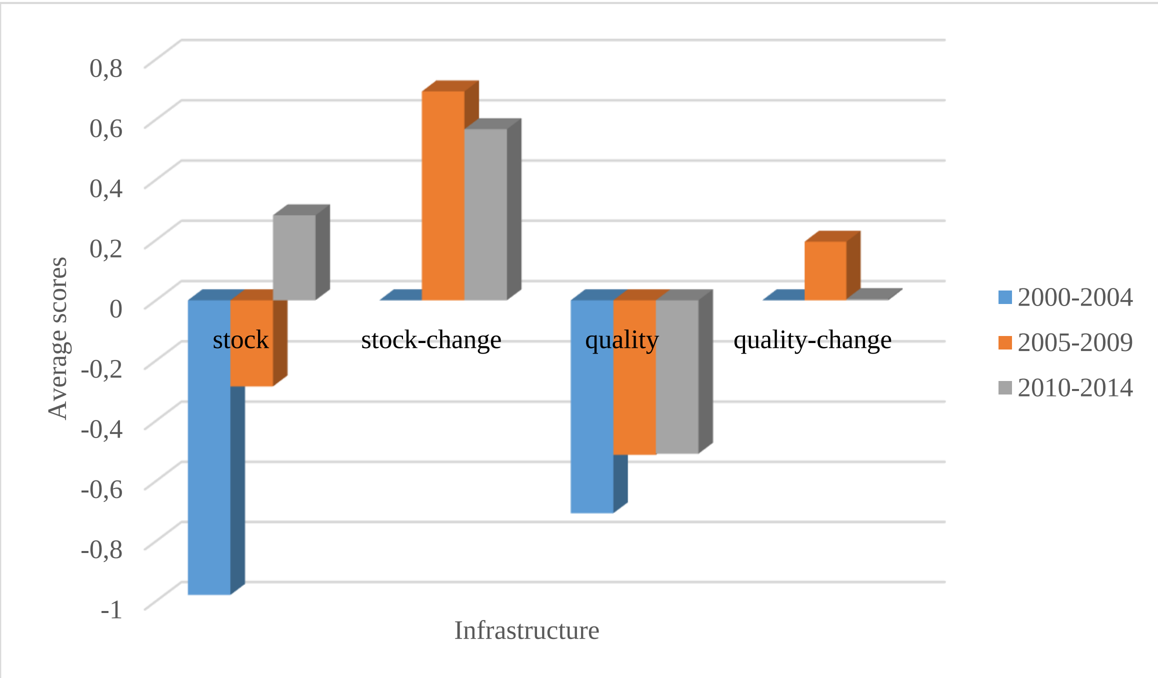


Figure 2. 6: CA infrastructure stock and quality developments

Source: Author's constructs based on selected principal components

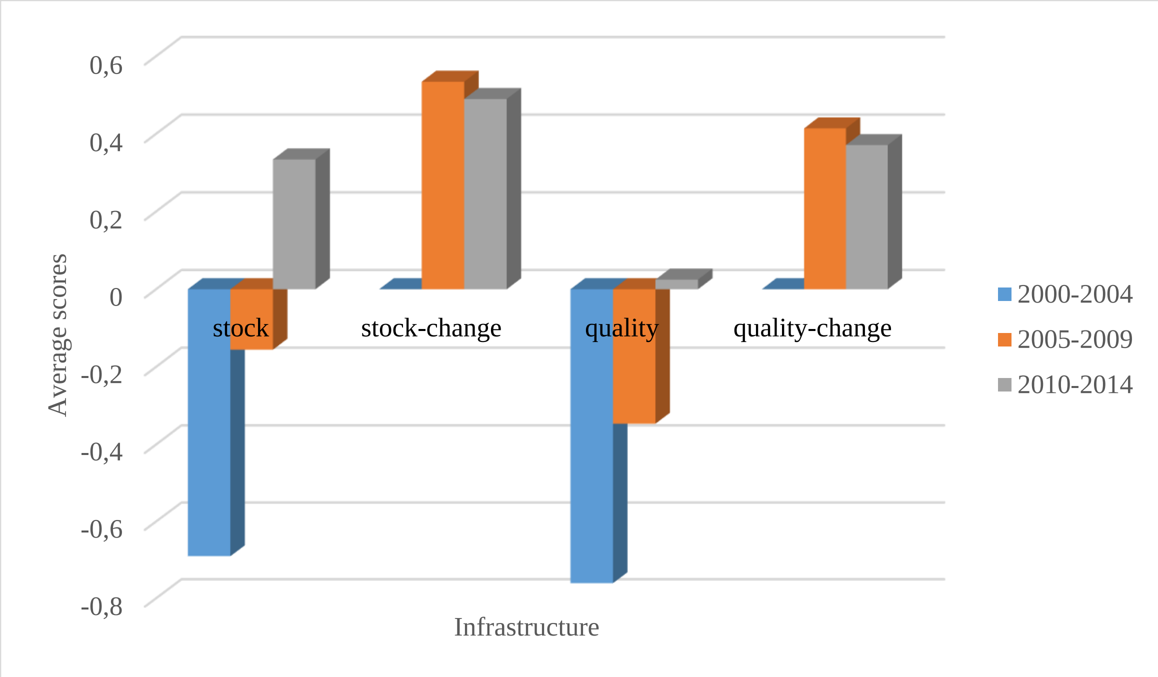


Figure 2. 7: EA infrastructure stock and quality developments

Source: Author's constructs based on selected principal components

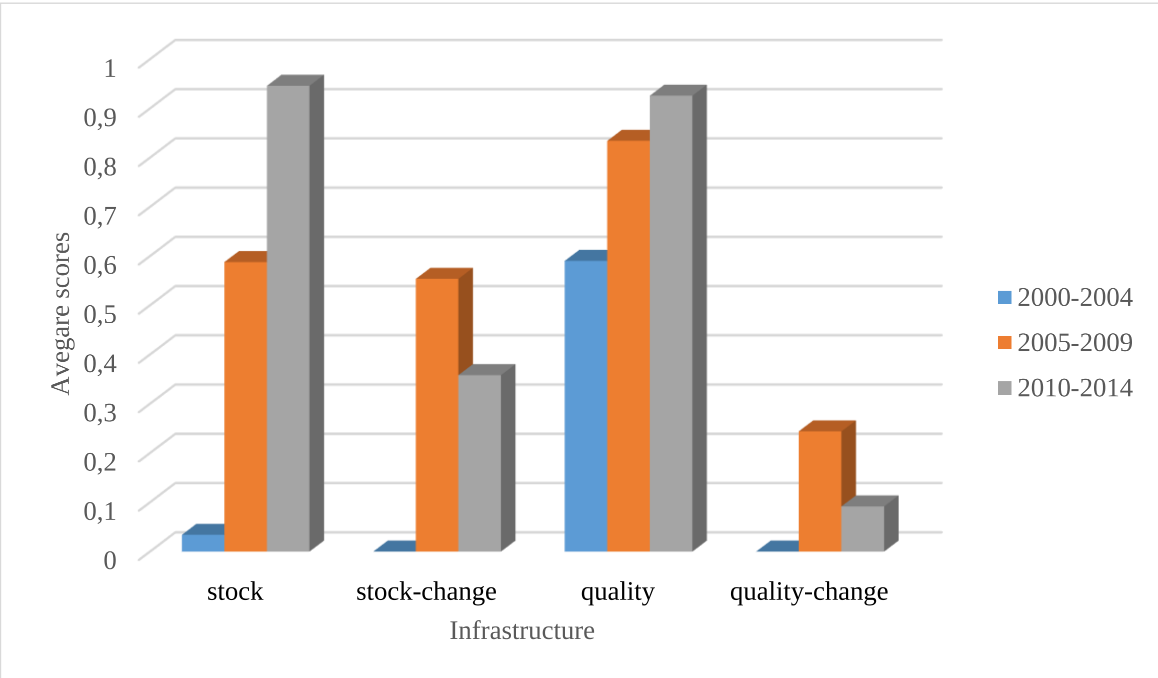


Figure 2. 8: SNA infrastructure stock and quality developments

Source: Author's constructs based on selected principal components

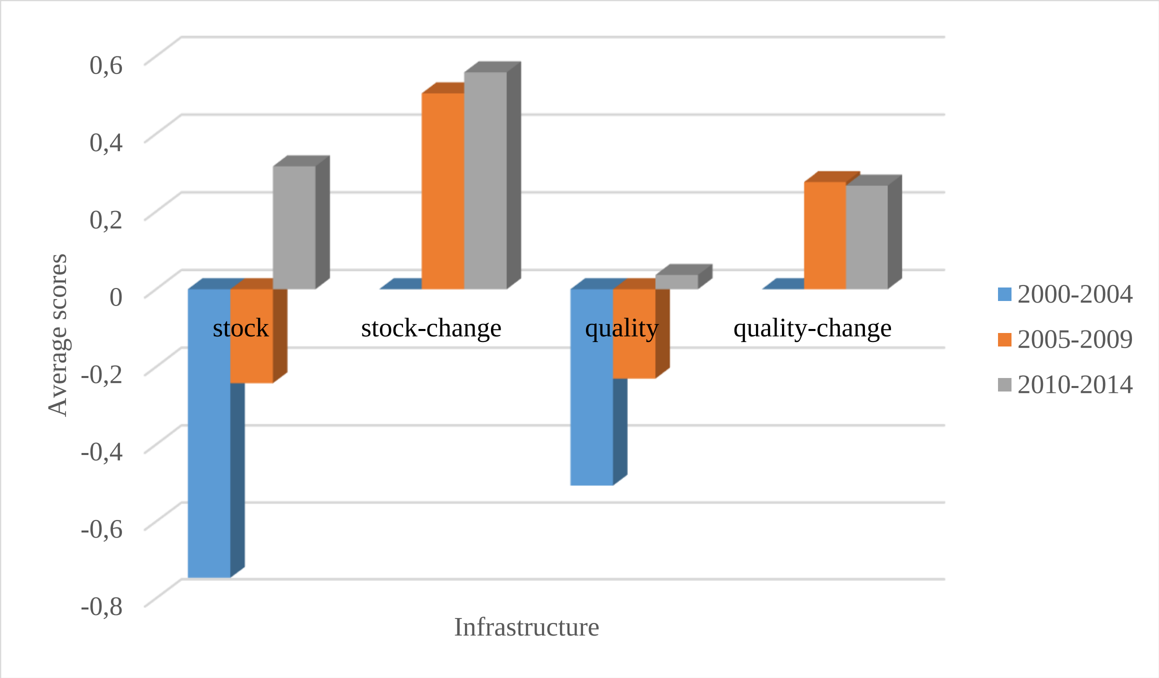


Figure 2. 9: WA infrastructure stock and quality developments

Source: Author's constructs based on selected principal components

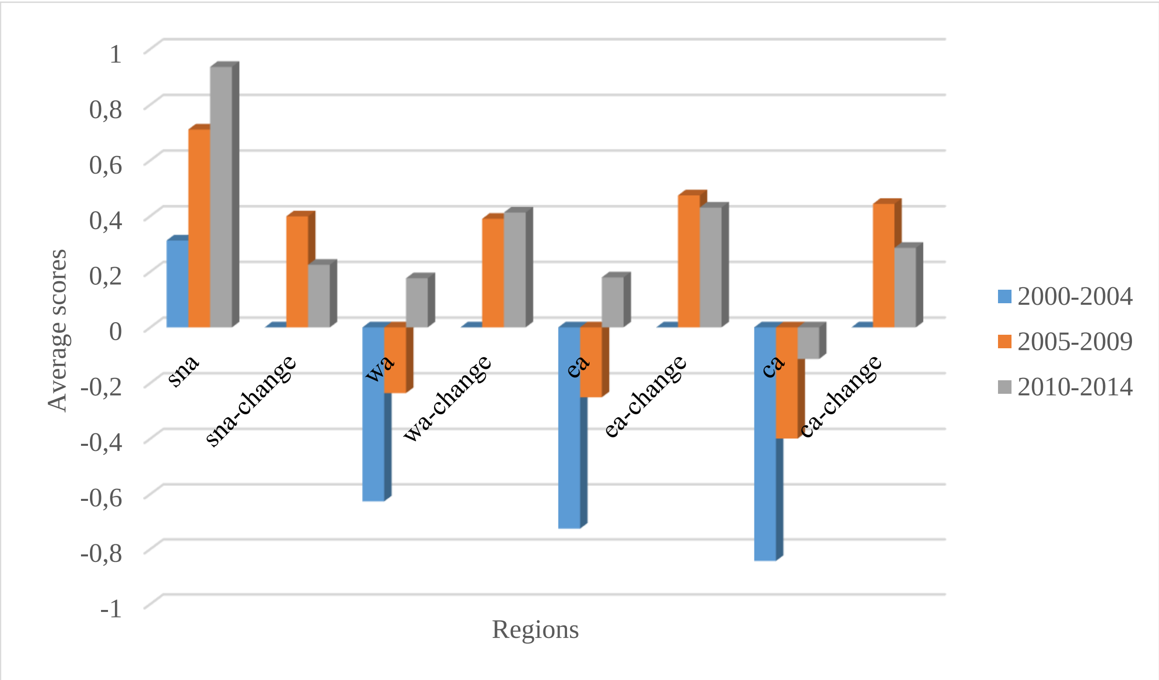
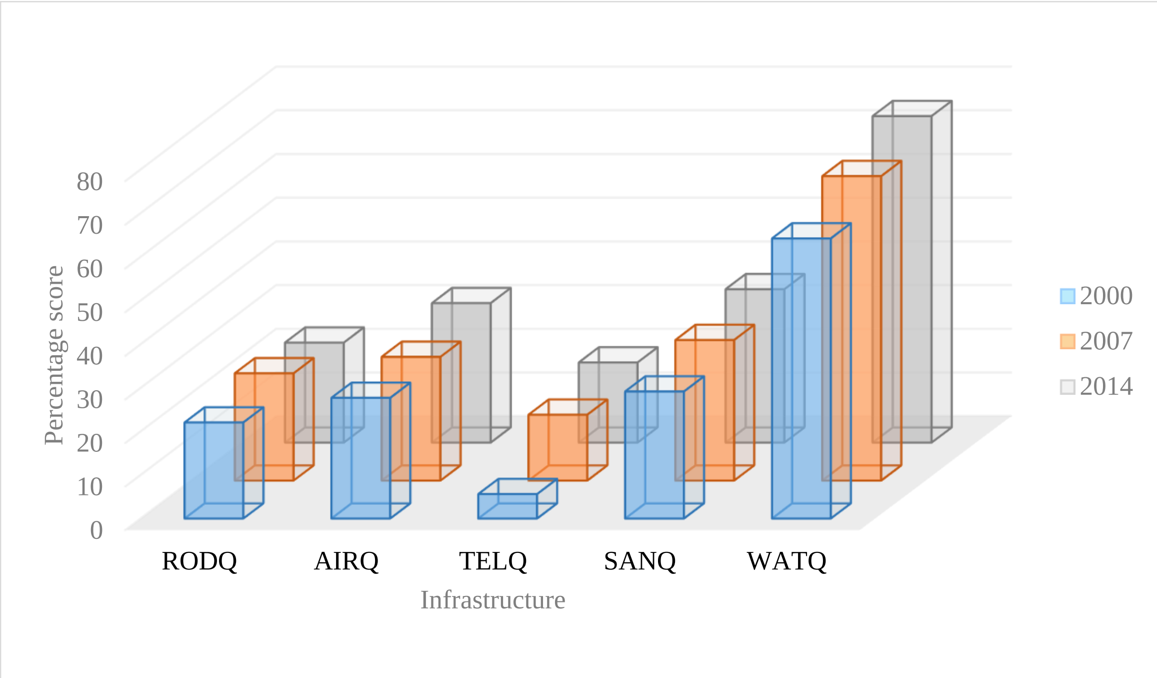


Figure 2. 10: Changes in hybrid infrastructure – Sub regions

Source: Author's constructs based on selected principal components

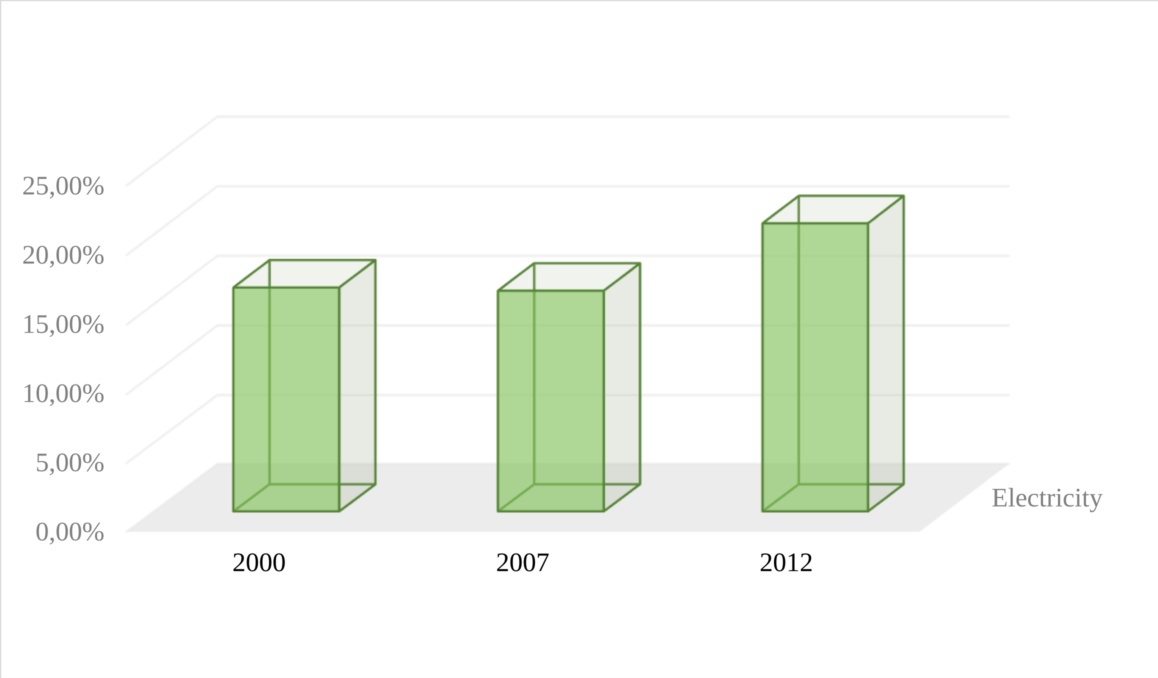
Appendix 3: Stock and Quality levels for various infrastructure sectors



Note: Despite substantial increase in telecommunication subscriptions, the quality as represented by growth in IT infrastructure has been at lower levels in most SSA states. Thus, the risk at which the information technology infrastructure will prove inadequate to business needs is still high. RODQ, AIRQ, TELQ, SANQ and WATQ stands for the quality measures of roads, airports, telecommunication, sanitation and water, respectively.

Figure 3. 1: Qualities of single infrastructures

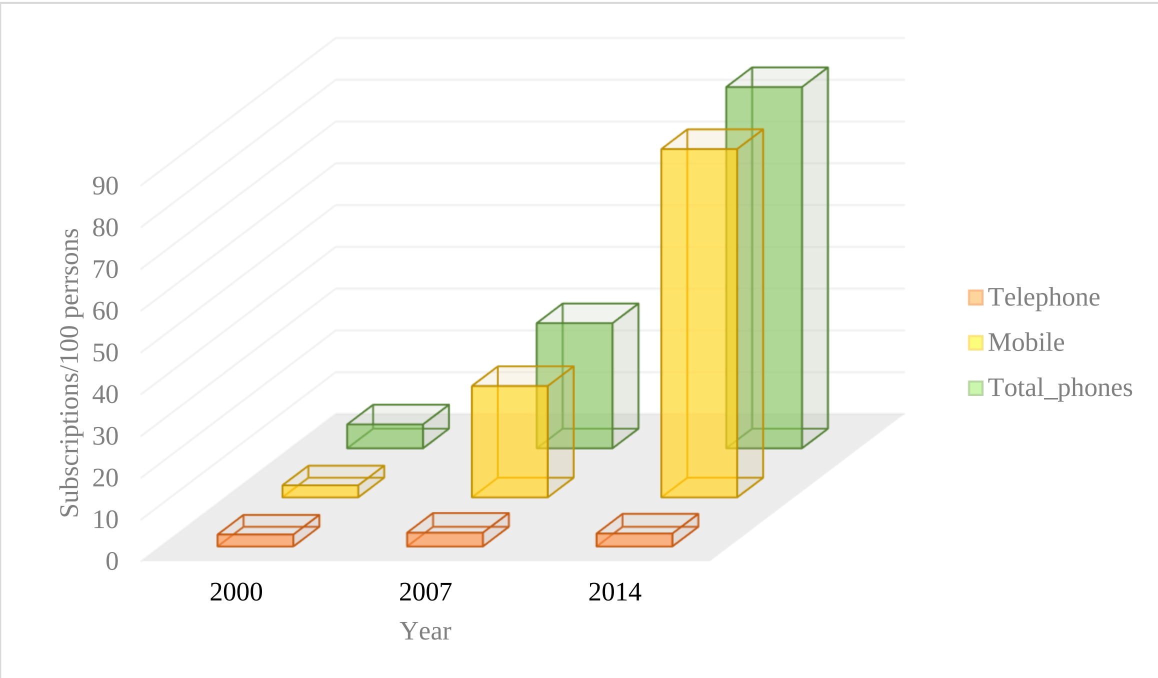
Source: Author's constructs based on data from the respective sources shown in Table A.1



Note: Electricity quality is represented by the ratio of electricity transmission & distribution losses to the total electricity generation capacity.

Figure 3. 2: Quality of electricity

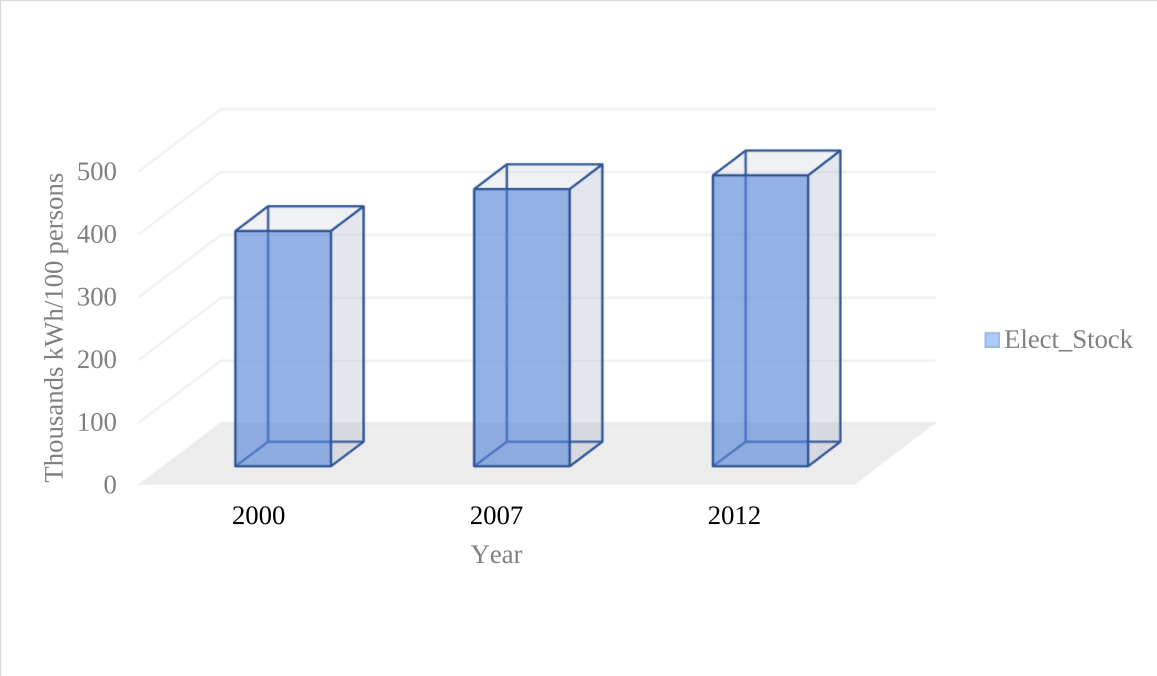
Source: Author's constructs based on data from Analyse Africa



Note: Total phones is the combination of telephone and mobile subscriptions. No much improvement in terms of fixed telephone subscriptions while there has been a substantial rise in mobile subscriptions.

Figure 3. 3: Stock of telecommunication

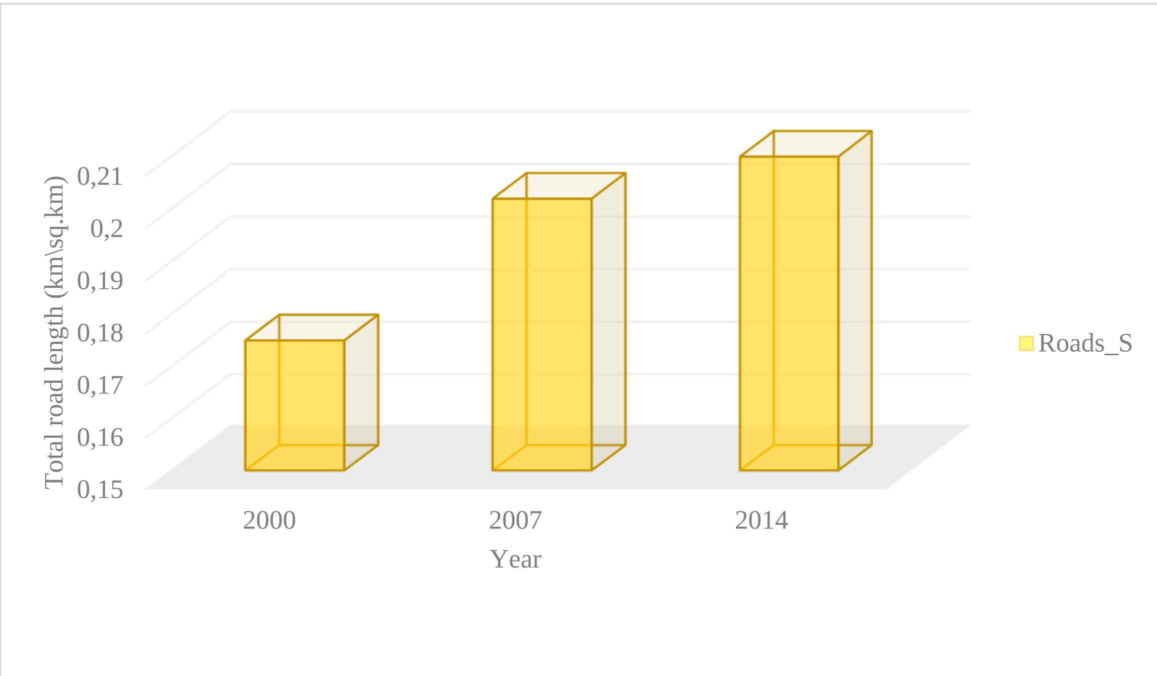
Source: Author's constructs based on data from Analyse Africa



Note: The original data from Analyse Africa was in billion kWh of generation capacity. We converted the data to thousands kWh. The estimates are averages of kWh per 1000 persons in SSA.

Figure 3. 4: Stock of electricity

Source: Author's constructs based on data from Analyse Africa



Note: Average length of total roads (i.e. paved plus unpaved roads).

Figure 3. 5: Stock of roads

Source: Author's constructs based on data from the CIA Factbooks

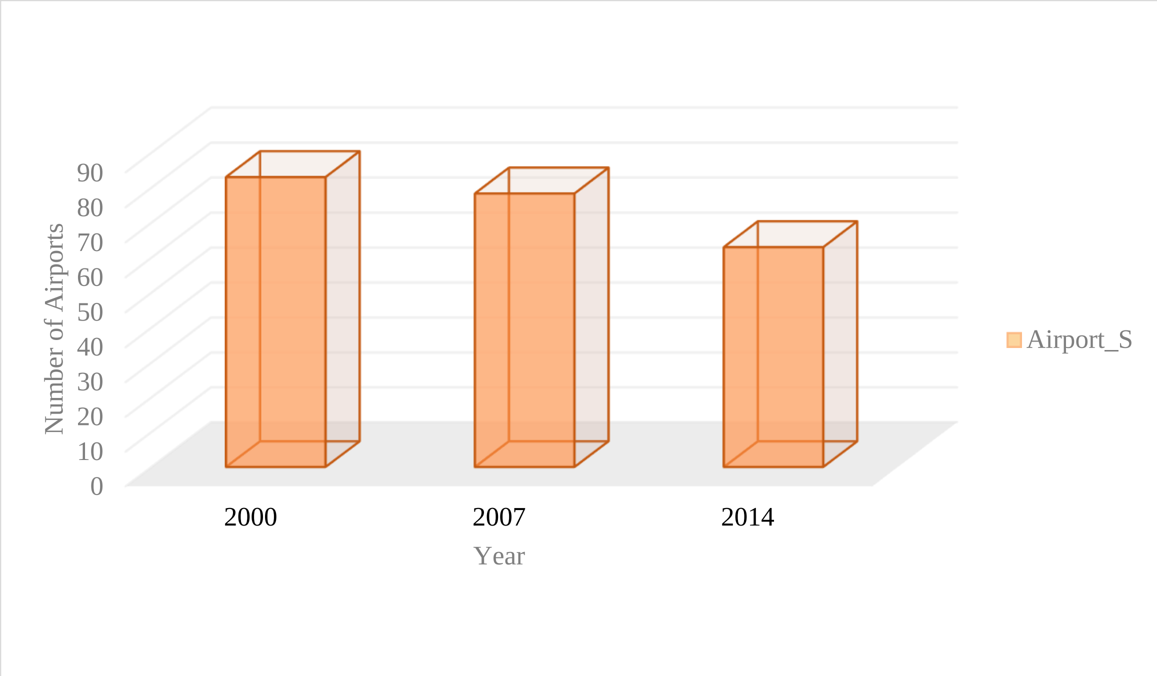
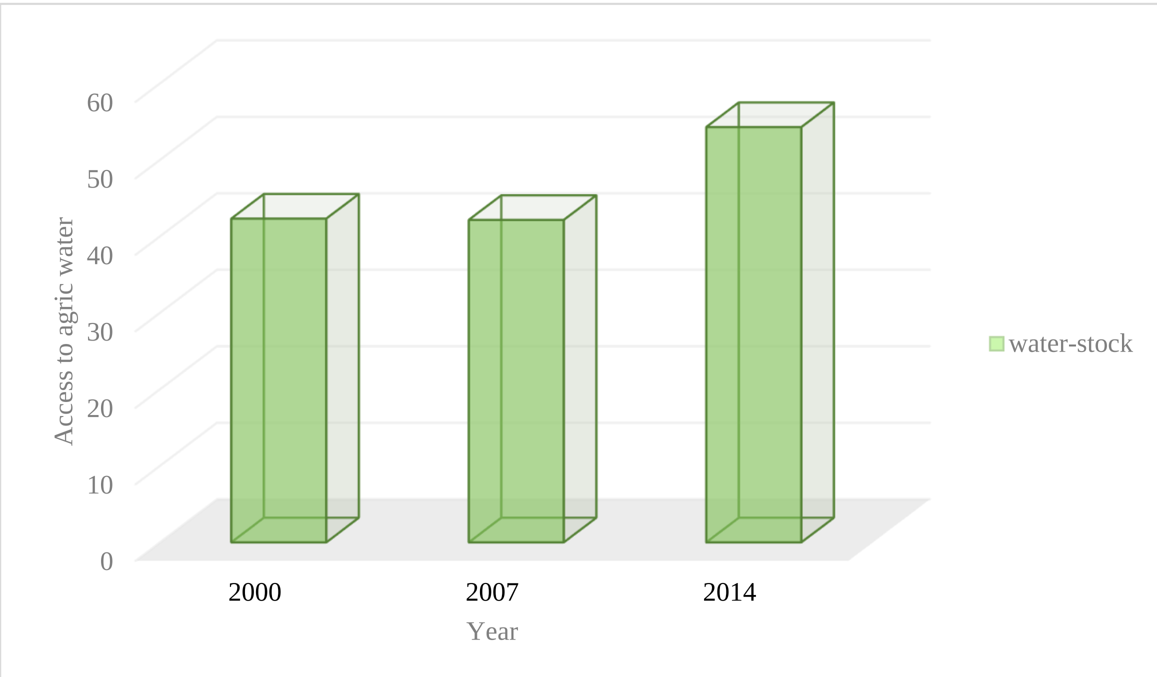


Figure 3. 6: Stock of airports

Source: Author's constructs based on data from the CIA Factbooks



Note: This shows access to agricultural water resources for the rural population. Agriculture has been an important sector in most African countries especially in rural areas.

Figure 3. 7: Water stock

Source: Author's constructs based on data from Mo Ibrahim

Appendix 4: Electricity Supply and Efficiency - SSA economies compared

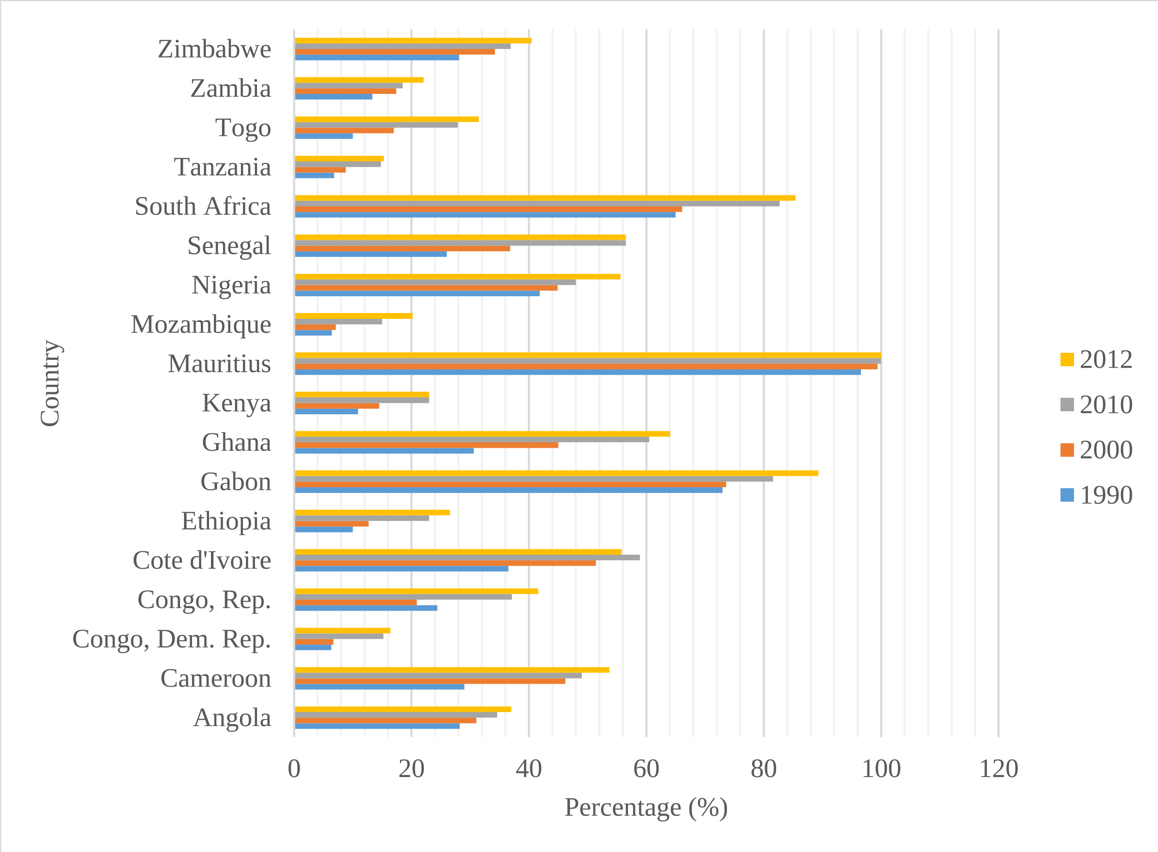


Figure 3. 8: Access to electricity (% of population)

Data source: Author's construct based on World Development Indicators

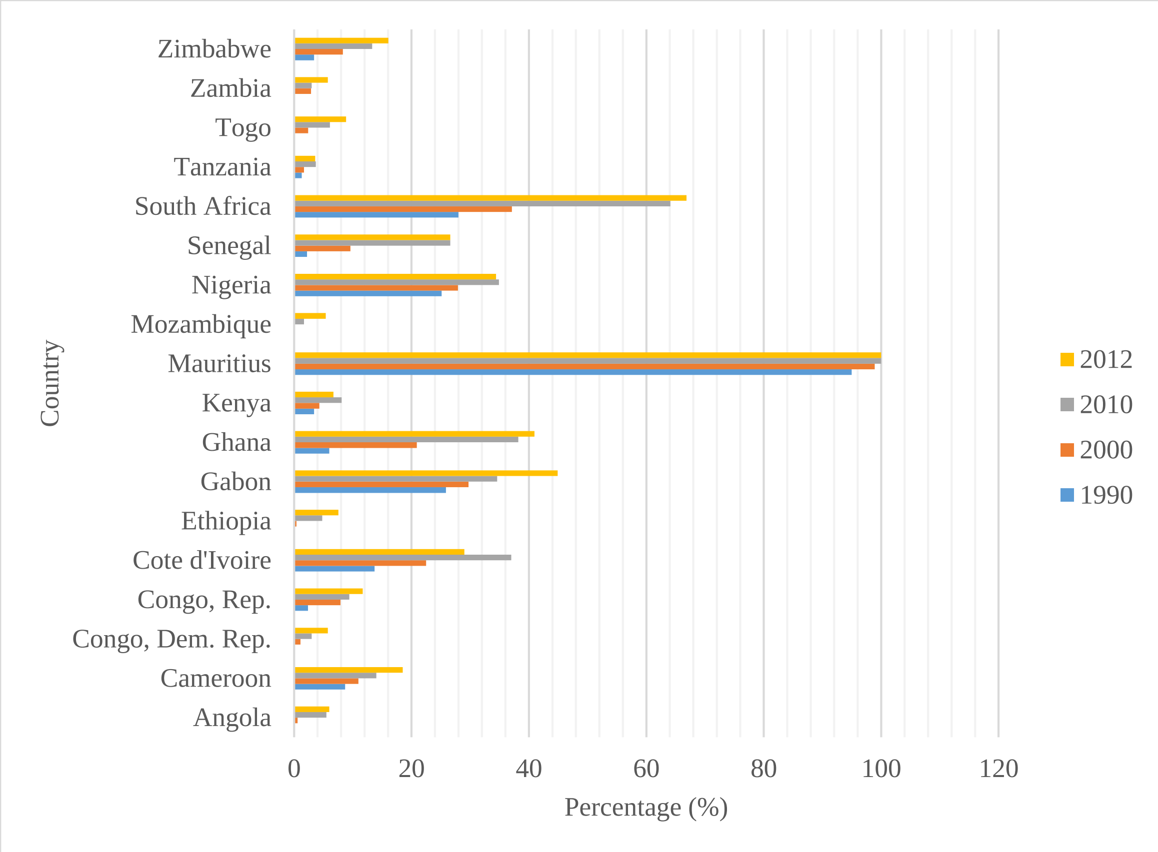


Figure 3. 9: Access to electricity, rural (% of rural population)

Data source: Author's construct based on World Development Indicators

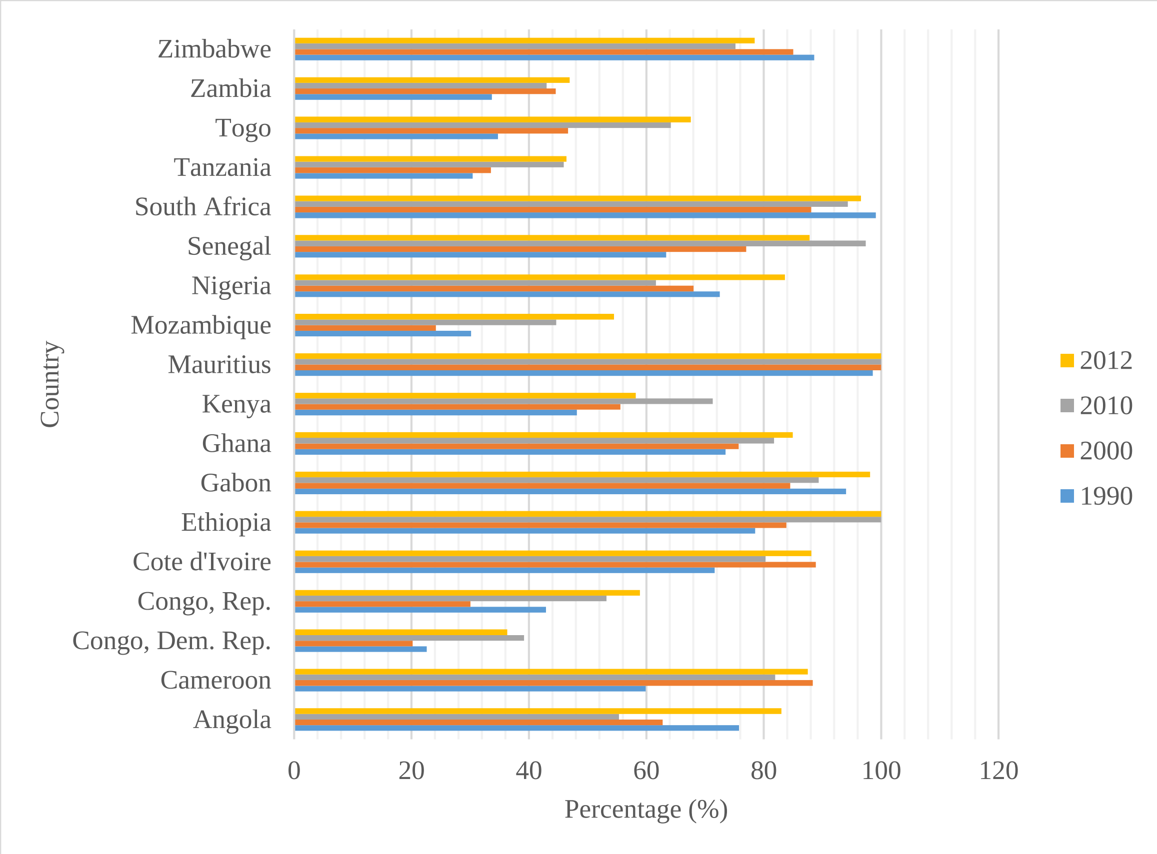


Figure 3. 10: Access to electricity, urban (% of urban population)

Data source: Author's construct based on World Development Indicators

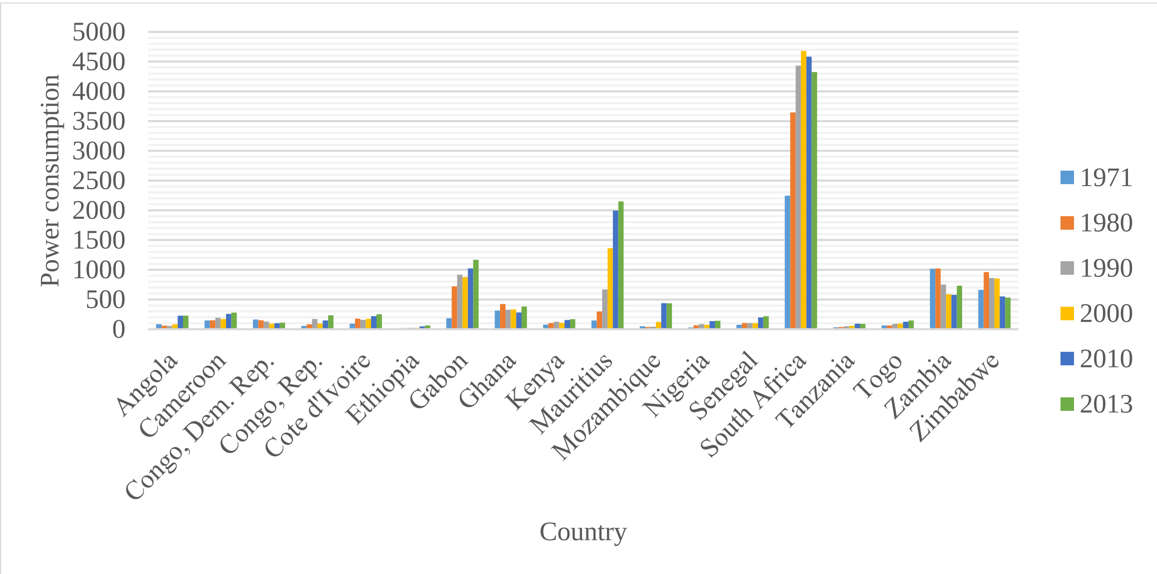


Figure 3. 11: Electric power consumption (kWh per capita)

Data source: Author's construct based on World Development Indicators

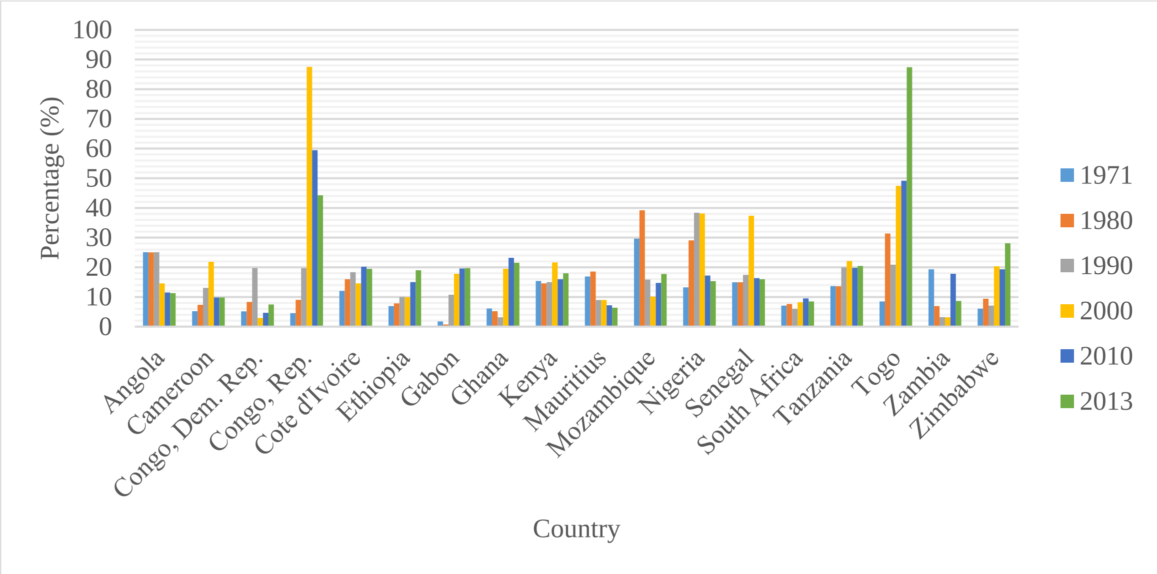


Figure 3. 12: Electric power transmission and distribution losses (% of output)

Data source: Author's construct based on World Development Indicators

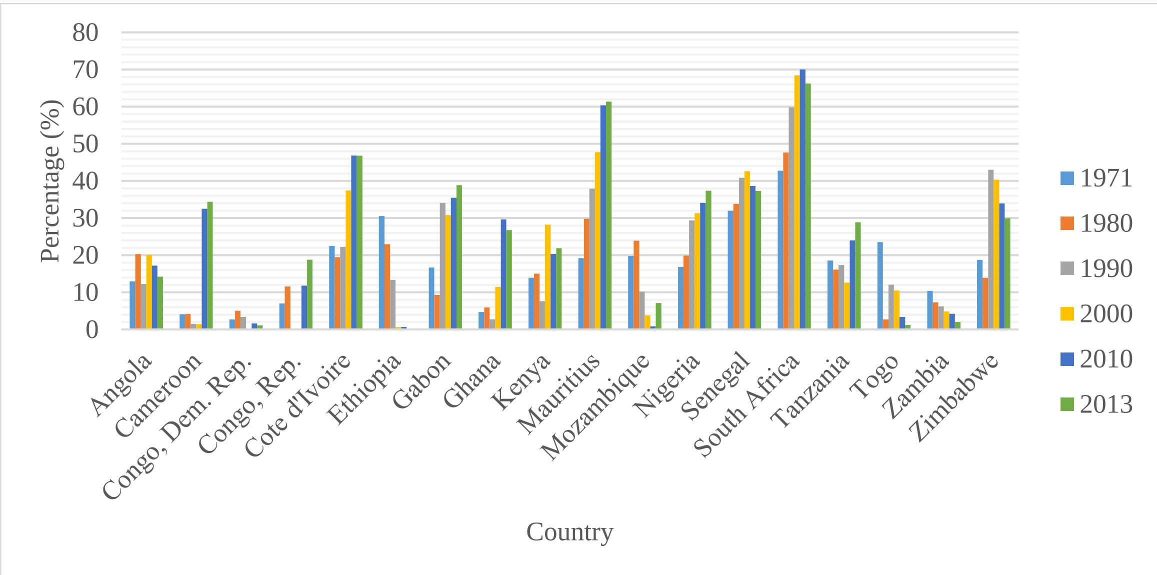


Figure 3. 13: CO2 emissions from electricity and heat production, total (% of total fuel combustion)

Data source: Author's construct based on World Development Indicators