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Assessing the Efficiency of National Innovation Systems in Selected African Countries

Rufus Kandie and Hellen Simiyu

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Assessing the Efficiency of National Innovation Systems in Selected African Countries

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Abstract

Innovation systems in African countries are largely characterized by low levels of science and technological activities, reliance on government or foreign donor funding, and weak industry linkages. Several efforts have been made by the African Union and national governments to support innovation in the region, yet the region still ranks low in terms of innovation performance. This study examines the efficiency of selected African National Innovation Systems and the drivers of efficiency, since innovation performance is affected not only by availability of resources, but also their efficient utilization. Secondary data retrieved from different sources, including UNESCO Institute of Statistics, Ibrahim Index of Governance, World Bank Development Indicators and African Economic Outlook was used in the study. Thirty (30) African countries were selected as the decision-making Units (DMUs). Bootstrap Data Envelopment Analysis was used to generate efficiency scores for each country, and Tobit regression to determine the drivers of efficiency. The results indicate that the selected countries are, on average, 54.2 per cent efficient, with Mauritius, Rwanda and Cote d' Ivoire being the best performers. Further, the selected countries were found to spend an average of 0.383 per cent of their GDP on Research and Development (R&D), which was way below the target of 1 per cent set by the African Union. It was observed that 4.4 per cent of the manufactured exports are high technology exports, which is quite low. On the drivers of efficiency, the Tobit results reveal that efficiency scores of the selected countries can be improved through three variables: Education, ICT infrastructure and increased labour force. The study concludes that the innovation outcomes realized do not match the investment made in all the selected African countries. Based on the results, there is need for higher investment in education through establishment of more learning and training institutions, and seeking experts to train and develop higher workforce capabilities. Given limited resources, the study recommends that governments invest in establishment of reliable ICT infrastructure through public private partnerships to attain higher interconnectivity and smooth flow of information and knowledge. Finally, the study recommends the establishment of more technical colleges to impart more skills, thus achieve higher productivity.

Abbreviations and Acronyms

ASTII	African Science Technology and Innovation Initiative
AU	African Union
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
GDP	Gross Domestic Product
GII	Global Innovation Index
GoK	Government of Kenya
ICT	Information Communication Technology
KENIA	Kenya National Innovation Agency
PPP	Public Private Partnerships
MRIC	Mauritius Research and Innovation Council
NACOSTI	National Commission for Science Technology and Innovation
NIS	National Innovation System
NRF	National Research Fund
R&D	Research and Development
STI	Science, Technology and Innovation
STISA	Science, Technology and Innovation Strategy for Africa
WIPO	World Intellectual Property Rights Organization

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1. Introduction

Innovation plays a crucial role in economic growth and development by enabling countries to improve productivity and competitiveness in production through creation, diffusion and utilization of knowledge (Nelson, 1987). It also provides answers to many societal, technological and business challenges by informing new ways of doing things (Szirmai, Naudé and Goedhuys, 2011). Firms obtain a competitive advantage through innovation activities and maintain it through continuous development, thus national competitiveness (Dogan, 2016). It is therefore important for a country to have an efficient and effective National Innovation System (NIS) to facilitate innovation and have an edge in achieving high and quality output (Koria et al., 2014).

National innovation system refers to the network of institutions in the private and public sector whose activities and interactions initiate, import, modify and diffuse modern technologies (Freeman, 1987). According to Afzal (2014), the system consists of economic regime, financial structure, physical infrastructure, education system, culture, among others (Lundvall et al., 2009). The NIS provides a framework for the flow of technology and information among people, enterprises and institutions, which are key to the innovation process (Bento and Fontes, 2015).

A strong and efficient NIS is characterized by the ability to develop and change its policies and objectives, high level of physical and technical infrastructure, adequate human capital and high level of institutional linkages. A weak and inefficient national innovation system is coupled with rigidity in change of policies, low level of human capital both in quality and quantity, low degree of institutional linkage, absence of physical and technical infrastructure, and devotion of little resources to innovation (Muchie and Baskaran, 2008).

Innovation systems in Africa are characterized by low levels of science and technology activities, reliance on government and foreign donor financing, weak industry linkages, low absorptive capacity of firms and limited use of intellectual property (WIPO, 2020). Notably, investment in R&D by all African countries still falls below 1 per cent of GDP, which is recommended by the African Union. The Africa Innovation Outlook 2019 indicates that Kenya is leading at 0.98 per cent, followed by South Africa at 0.82 per cent and Egypt at 0.8 per cent. Zimbabwe, Gambia, and Angola spend an average of 0.1 per cent of the GDP on R&D. Additionally, the growth in patent applications in the region does not tally with the growth in patents granted. Despite 26.77 per cent increase in patent applications between 2010 and 2019, patents granted increased by 3.125 per cent within the same period, signifying systemic weaknesses (WIPO, 2020).

This situation, coupled with gaps in the policies and legal frameworks required to encourage innovation within the region, have resulted to Sub-Saharan African countries lagging in terms of development and global competitiveness. In 2019, out of the 20 countries ranked lowest in the global competitive index report, 17 were Sub-Saharan Africa countries (World Economic Forum, 2019). More so, the region is ranked last in terms of innovation capacity, with a score of 29.4 per cent.

Despite the efforts by the African Union, regional bodies such as the East African Community and national governments to support innovation, innovation systems in Africa are still characterized by systemic weaknesses, particularly poor linkages between government institutions and industry (Hall, 2005; Watkins et al., 2015). The countries have failed to reap benefits and learn from efficient technologies. This is attributed to weak innovation systems, which are more prone to systemic failures and structural deficiencies (UNESCO, 2018).

According to Alnafrah (2021), innovation performance is affected not only by availability of resources, but also their efficient utilization. Innovation efficiency results in higher productivity in the sense that innovation inputs are effectively transformed into innovation outputs. This study explores the possibility of inefficiencies existing in selected African NISs, which could be contributing to the poor performance of the region. More so, it analyzes the potential drivers of efficiency of NISs in the region to provide recommendations on what African countries need to do to improve innovation performance.

The rest of the paper is organized as follows: Section 2 provides a discussion on innovation systems in Africa, Section 3 literature review, Section 4 findings and discussion, while the last section provides conclusions and policy recommendations.

2. Innovation in African

Most institutional structures that form part of the NISs, such as universities in Africa, were inherited from colonial rulers. Others that support innovation policy are relatively new, with majority having existed for less than a year. This has affected the construction of a contextualized system of structures that would be able to respond to local context issues and flow of resources among innovation actors (Havas, 2002; Etzwitz and Dsizah, 2008). The systems are generally young and the governments benchmark from best practice countries globally on how to best run the system to improve innovation.

The African Union has been on the forefront in promoting innovation in the region. Innovation is identified as a key driver for the envisaged socio-economic transformation for Africa as per the AU Agenda 2063. Promotion of higher education, building research capacity and investment in R&D, which are key inputs to the innovation process, are prioritized in the Science Technology and Innovation Strategy for Africa (STISA). To track innovation performance, the African Science, Technology and Innovation Indicators (ASTII) initiative was launched in 2005. Countries have been encouraged to incorporate innovation and STI in their national development agenda.

In recent years, most African countries have launched projects and policies to support innovation. For instance, Kenya developed the STI Act, 2013 with the intention to re-align STI programmes, strengthen the National Innovation Systems and streamline Kenya's innovation policy landscape (Government of Kenya, 2013a). Subsequently, three strategic organizations, namely Kenya National Innovation Agency (KENIA), National Commission for Science, Technology and Innovation (NACOSTI) and National Research Fund (NRF) were created to coordinate the process. NIS construction efforts in Rwanda have been directed towards increasing R&D investment, infrastructural development and STI capacity building (Yongabo and Goransson, 2020). Elsewhere, Nigeria has focused on creating strategic opportunities for researchers in R&D and new product development (Isola, Ogundari and Siyabola, 2010). Similarly, Mauritius has put concerted efforts towards the coordination of industry and academia to ensure that innovation becomes an organic part of the Mauritanian economy (MRIC, 2018).

The emerging African innovation systems are focused towards building internal capabilities to establish stable and performing innovation systems through investment in higher education system, technological development and investment in research and development (Scerri, 2016). According to the Global Innovation Report (2020), the best innovation performers with respect to various indicators are: Expenditure on R&D (South Africa, Kenya, Egypt); investment in education

(Botswana, Tunisia); stronger financial market (South Africa); openness to technology adoption and improving research base (Tunisia, Algeria, Morocco), active use of Information Communication and Technology (ICT) (Kenya) and Stronger Intellectual Property systems (Tunisia and Morocco).

Formal innovation performance in Africa is measured using the guidelines in the Oslo manual (Arunde et al., 2013). The manual provides a set of comparable innovation indicators among countries. This facilitates benchmarking and construction of coherent national innovation systems. In addition, the manual has been adopted by the African Science, Technology and Innovation Indicators (ASTII) initiative for the implementation of innovation surveys. Through the surveys, African countries gain the basis for review of existing policies and share their thinking on existing policy issues (Lizuka et al.,2015).

Looking at Africa innovation performance and comparing with other regions in the world, Africa still ranks lowest in terms of institutions, infrastructure and ICT adoption according to the Global Competitiveness report.

Table 1: Regional innovation ecosystem performance average score

Region	Institutions	Infrastructure	ICT Adoption	Innovation Capacity	Changes in Innovation Capacity (2018-2019)
East and Pacific	61.6	74.8	70.3	54	2
Eurasia	53.8	67.7	59.5	35.5	1.9
Europe and North America	64.7	79.7	70.4	58.1	0
Latin America and Caribbean	47.1	61.3	50.9	34.3	1.8
Middle East and North Africa	55.5	70.5	57.6	41.3	-4.3
South Asia	50.0	59.2	35.1	36.3	-0.1
Sub-Saharan Africa	46.9	45.0	34.3	29.4	3.6

Data Source: World Economic Forum (2020)

To catch up with the developed economies, Africa needs to build its resilience, which highly depends on the extent to which its countries and citizens harness innovation and create innovation development systems. Currently, Africa's potential for growth is not matched by investment in innovation (Naik, 2018). African nations need to enhance their capacity to import machines required to implement innovations, train or source sufficient workforce to implement the innovations, and develop adequate management capacities to oversee the innovations (World Bank, 2017).

3. Literature Review

3.1 Theoretical Literature

The study is supported by two theories, namely the New Growth Theory and the Production Theory. The theories highlight the role played by different innovation actors in facilitating the generation and transfer of knowledge in the economy.

3.1.1 New growth theory

Founded by Paul Romer, the New Growth Theory attempts to explain the process of long-run economic growth through endogenous forces such as human capital, knowledge spillover and information technology. The theory can be presented from two perspectives. The first approach assumes the endogenous broad capital models to demonstrate the externalities produced by investing in physical and human capital. These externalities link technological characteristics to knowledge spillovers and learning by doing. The second approach utilizes endogenous innovation growth models, which attribute technological progress to deliberate innovation (Crafts, 1996).

Since different countries have their own social, economic and political environments and different firms have their own capabilities to undertake R&D, innovation processes vary across countries. Therefore, countries experience varying growth rates. Allocating more resources to R&D increases the firm's incentive to innovate, leading to higher capacity by firms to develop new technological ideas, and translating to higher growth rate (Johnson, 2008).

Endogenous innovation growth considers the possibility for convergence. If a developed country innovates, the innovations are diffused and assimilated into production of developing countries at very low costs, then there can be a process of convergence between interdependent economies. As Romer (1993) emphasizes, rapid growth is a positive function of both access to new technological ideas, and the diffusion of these ideas through the production structure.

The new growth theory can be described as ingenious contribution to the NIS approach, because it builds a bridge between elements of economic growth theory and a modern, systemic approach to innovation, which is thus extended by a technique to carry out international comparisons in innovative strength.

3.1.2 Production theory

The production theory was founded by Cobb-Douglas (1928). The theory argues that the logarithms at a given level of output and input are linearly related. The theory purports that technological change affects the production function by either maintaining the expansion path fixed in the input space, or driving a neutral shift in the production possibility frontier.

Higher levels of innovation are associated with higher GDP per head. Therefore, due to technological gaps between countries, more technologically advanced economies are expected to produce higher GDP per capita. The real GDP is the best proxy to measure the productivity level of a country. To measure the level of technology at the national level, we use traditional variables of technological input (research expenditures) and technological output measures (patent activities). These indicators can be used to appropriate the total level of knowledge or productivity in a country (Fagerberg, 1994).

The theory states that a given quantity of output is produced using a given set of inputs in a country at a given period. In this case, technology is assumed to be different for each country. Therefore, the country's production function will shift as new and more efficient techniques are adopted over time. The production function is a useful tool for assessing the proportion of any increase in the level of output over time that can be attributed to the increase in factors of production, second to increasing returns to scale and third to technical progress (Mankiw, Romer and Weil, 1992).

3.2 Empirical Literature

The efficiency of national innovation systems has been examined by researchers across the world, with limited focus in developing countries. The innovation process is looked at differently by different researchers, with some splitting the process into two sub-processes: knowledge production and knowledge commercialization process (see for example Kaihua and Mingtingm, 2014; Guan and Chen, 2012 and Zhang, 2013). More so, the set of inputs and outputs used in estimating efficiency are different, with expenditure of R&D, researchers, publications and patents being the most common.

Zhang and Wang (2019), for instance, undertook a comparative study on National Innovation Efficiency between developed and emerging countries. The study looks at innovation activity in two stages: Research and Development (R&D) process, which transforms R&D inputs into knowledge and Business Process, which transforms R&D output into economic value. Gross expenditure on R&D, total researchers, patents, publications and high technology exports are considered in the DEA model. The findings of the study revealed that emerging countries are lagging behind in terms of R&D efficiency. None of the emerging countries in the sample attained 100% score. The average score for the emerging countries was 64.27%, with China leading with 90.11%. However, emerging countries are efficient in translating R&D output into economic value. Developed countries, on the other hand, are efficient in both stages of innovation process.

Using the Network Data Envelopment Analysis (DEA), Chen and Guan (2010) analyzed the efficiency of China's Regional Innovation System (RIS). The study decomposed the innovation process into two sub-processes: technological development and technological commercialization. The study revealed that one fifth of the RIS in China are efficient in the whole innovation process. The study also showed that there exists inconsistencies between technological development capacity and commercialization capacity in most RIS. The study concluded that commercialization capacity is more significant in influencing innovation performance.

With a focus on 23 European countries, Carayannis et al. (2016) took a multilevel and multistage approach by dividing the national innovation process into two sub-processes: Knowledge production and knowledge commercialization. Multi-objective DEA is used in the analysis by constructing separate frontiers for developing and developed economies in Europe. The study revealed that Germany and Switzerland have high overall efficiency, while Hungary and Denmark recorded low efficiency scores. Further, university patents, risk acceptance and networking are identified as important for innovation creation and commercialization.

Looking at innovation as a one stage process, Cai (2011) examined factors affecting efficiency of National Innovation Systems of BRICS countries. The study computed efficiency scores of each country and used Panel data and Principal Component Analysis (PCA) to investigate the factors affecting efficiency levels. Results revealed a big disparity in efficiency levels of NISs of BRICS. China, India and Russia recorded high scores, while efficiency scores for Brazil and South Africa were low. In terms of factors affecting efficiency, ICT infrastructure, R&D expenditure, trade openness, financial infrastructure and education system significantly affect efficiency of NISs.

Kontolaimou et al. (2016) used bootstrap DEA to analyze national efficiency in Europe. They compute technological differences between developed and developing countries. The findings indicate that developing countries in Europe exhibit a technological gap that is twice as big as the one characterizing developed countries. Like majority of the studies in Europe, Switzerland and Germany are among the most efficient countries as per the study. The study also shows that some developing countries appear to be very efficient with respect to the technology frontier they share, but seem relatively inefficient from the European metafrontier.

In an effort to establish the extent to which knowledge, institutions, governments and business establishments determine the effectiveness of NIS, Bartels et al. (2012) applied factor analysis and regression analysis in developing countries. The linkages between the 46 NISs of advanced economies were estimated at macro level using data from various international measures. The findings indicated that although structural dynamics of knowledge, management, governance and business relations, decision making and market are crucial in the performance of NIS, market forces in this context dictate the overall performance.

In Africa, Kona et al. (2014) examined the determinants of effectiveness and efficiency of the Ghana National System of Innovation and the Kenya National System of Innovation. They conducted a survey in the two countries and used regression analysis to analyze the data separately. The study concluded that to improve performance of the Kenya NIS, there is need to enhance linkages among innovation actors, build human resource capacity in STI, and enhance diffusion of ICT. Bamfo (2015) used pooled OLS and system GMM on panel data from selected African countries and established that institutional quality, human capital accumulation, R&D expenditure, competition and intensity of domestic trade have a positive and significant impact on innovation advancement in Sub-Saharan Africa.

Barasa et al. (2019) examined innovation inputs and efficiency of manufacturing firms in Sub-Saharan Africa at firm level. The study evaluated the impact of inputs such as internal R&D, human capital development and foreign technology adoption on technical efficiency of manufacturing firms in Africa. The study utilized cross-sectional firm-level data extracted from the 2013 World Bank Survey data. Technical efficiency was computed using the heteroscedastic half-normal stochastic frontier. The findings revealed that internal R&D and foreign technology have a negative effect on technical efficiency. However, the combination of internal R&D, foreign technology and foreign technology and human capital development produce effect on technical efficiency.

3.3 Overview of Literature

Much literature that has examined innovation efficiency at country level has been directed to advanced economies (Kontolaimu et al., 2016; Carayannis et al., 2016 and Cai, 2011). Examining innovation efficiency across countries is useful in establishing benchmarks and identifying areas of improvement (Guan and Chen, 2012). Majority of literature outline R&D expenditure and R&D personnel as the most commonly used inputs in the knowledge production process, and patents and scientific publications as the output.

The few studies on innovation efficiency that have targeted Africa have been done at firm level (Barasa et al., 2019 and Kona et al., 2014). It is noted that there are no common variables in these studies, and the choice is variables is mostly informed by the data source. The findings by Kona et al. (2014) emphasize on the need to strengthen linkages among innovation actors and between learning institutions and the production system.

4. Data and Methodology

4.1 Theoretical Framework

The underlying concept behind the technical efficiency theory is the production theory which dictates that the firm's output level is a function of the quantity of inputs used to yield a given level of output. The production function is presented in functional linear form as:

$$Q=f\,(X_1, X_2.............X_n) \qquad 4.1$$

Where Q is the level of output while X_1, X_2......X_n are inputs employed in the production process. According to Farell (1957), efficiency refers to the ability of the decision-making unit (DMU) to produce the highest level of output with a specific set of inputs. Koopmans (1951) argues that a producer is technically efficient if an increase in output requires an addition of at least one input or a reduction in at least one other output. Charnes and Cooper (1985) defines technical efficiency as the use of resources in the most technologically efficient manner to attain the highest possible output.

Efficiency could be input-oriented or output-oriented. Input oriented efficiency refers to the minimization of inputs to attain a given level of output (Farrell, 1985), whereas the output-oriented technical efficiency refers to optimization of output with a given set of inputs. The efficiency of a firm consists of two components: technical efficiency and allocative efficiency. Whereas technical efficiency is the firm's ability to produce maximum output from a given set of inputs, allocative efficiency is the firm's ability to use these inputs in optimal proportion, given their respective prices.

In the context of the national innovation system, technical efficiency refers to the manifestation of various dimensions that are part of production structures, human capital, technological capacity, financial and credit systems, technology sources and property rights and scientific research and their input-output relationships in the economy (Cassiolato and Lastres, 2011).

In this study, the understanding of NIS efficiency corresponds to the concept of technical efficiency introduced by Farell (1957). Innovations and research outputs are produced by national innovation networks that are located in different parts of the country. The study, therefore, assumes that each country is a Decision-Making Unit, which invests in innovation through investment inputs such as expenditure on R&D and personnel involved in research. The countries expect that this investment will result to a number of outputs, such as increased innovations and research outputs. The countries further interact with environmental factors that affect utilization of these resources.

4.2 Estimating Efficiency Scores

It is important to be able to measure efficiency of NISs to establish how resources are utilized in the innovation production process. However, measuring efficiency of institutions and systems is hard (Grup and Schubert, 2010). Frontier techniques are commonly used methods of estimating efficiency. Two approaches are considered: Data Envelopment Analysis (DEA) and the Stochastic Frontier Analysis (SFA).

DEA is a non-parametric approach where linear programming is applied to generate the efficiency frontier, then efficiency scores are computed relative to the frontier. It is more popular with studies on innovation efficiency (Guan and Chan, 2012; Pan, Hung and Lu, 2010; and Nasierouski and Arcelus, 2003). It is preferred because it does not need assumptions about the distribution of data, does not demand the specification of functional or distributional forms for errors, and can be applied for multi-input and multi-output variables.

The Stochastic Frontier Analysis is not commonly used because it uses econometrics to project production and costs, hence its flexibility is limited (Zhang and Wang, 2019). It is also criticized for predetermining the functional form in estimating efficiency of a Decision-Making Unit (DMU).

This study therefore adopts the DEA methodology in estimating efficiency scores of selected African countries.

4.2.1 Analytical Framework

Assuming that we have *N* DMUs, each with *K* inputs and *M* outputs. Let x_i represent a vector of inputs and Y_i represent a vector of outputs.

DEA constructs a non-parametric frontier that will show how far away each DMU is from the frontier. It is stated as a ratio:

$$U'Y_i/V'x_i \qquad 4.2$$

Where *U'* and *V'* are vectors of outputs and input weights, respectively.

To select optimal weights, the following mathematical problem is specified:

Max U,V $(U'Y_i/V'x_i)$, subject to:

$$U'Yi/V'x_i \leq 1 \text{ ; for } j=1,2................N \qquad 4.3$$

$$u, v \geq 0 \qquad 4.4$$

Solving this problem will help obtain values of *U* and *V*, such that the efficiency measure of each DMU is maximized subject to that all scores are less than or equal to one. However, we will obtain an infinite number of solutions.

The constraint: $V'x_i=1$, presented in equation 4.5 is included to avoid this situation. The problem is therefore restated as follows:

Max U,V (u'yi),Subject to

$$V^{\wedge'} x_i=1 \quad 4.5$$

$$U'Y_i - V'x_i \leq 0, i=1,2.........N \quad 4.6$$

$$u, v \geq 0 \quad 4.7$$

This problem is run *N* times to obtain the relative efficiency scores of all the DMUs.

4.2.2 Bootstrap DEA

According to Tziogkidis (2012), the presence of sampling bias and the fact that the scores of the DMUs in the sample depend on the DMUs that define the efficiency frontier would make efficiency scores generated from the original DEA model to be overestimated compared to the true frontier. Simar and Wilson (1998) introduced bootstrap DEA technique, which attempts to address shortcomings of the original DEA. The technique makes use of the sample dataset as a proxy population. It creates many artificial samples to draw bootstrap distribution of the statistic. Therefore, the possible effects of statistical noise and presence of outliers is minimized. This paper applies bootstrap DEA in an attempt to improve on accuracy of the scores.

4.2.3 Choice of DMUs and input/output indicators

According to Cai (2011), relative efficiency scores are highly affected by the input and output indictors and the number of DMUs considered in the model. A frontier constructed from a small number of DMUs may result to all countries recording scores of one. These results may be meaningless. To avoid such a situation, 30 countries are selected. They are: Angola, Botswana, Burkina Faso, Burundi, Congo Côte d'Ivoire, Eswatini, Ethiopia, Ghana, Kenya, Lesotho, Madagascar, Mali, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, South Africa, Togo, Uganda, Tanzania, Zambia, Algeria, Egypt, Mauritania, Morocco, Tunisia. The selection is also highly informed by availability of data.

Cai (2011) argues that the main inputs to the innovation production process are human and financial resources allocated to the innovation generating activities. Patents granted and scientific publications are commonly used outputs. More so, the African Science, Technology and Innovation Indicators (ASTII) initiative which adopted the Oslo manual sets out innovation and R&D indicators (R&D expenditure, researchers, R&D personnel, patents and publications). The choice of inputs and outputs is informed by this guide. High technology exports are also included as an output because empirical literature shows that it is a key output of the innovation production process. Foreign Direct investment (FDI) is also considered as an important input especially in generating high technology exports.

Table 2: Selected inputs and outputs

Variable	Measurement	Abbreviation	Data Source
Input Indicators			
Gross Expenditure on R&D	% of GDP	GERD	UNESCO Institute of Statistics, World Bank Development Indicators and Africa Economic Outlook 2019
No. of researchers	Full time equivalent (per 1 million inhabitants)	R_FTE	UNESCO Institute of Statistics
Foreign Direct Investments	Inflows per million dollar	FDI	World Development Indicators
Output Indicators			
Patents	Patent applications by residents	Patents	World Development Indicators
Scientific publications	No. of publications (per 1 million inhabitants	SCIPUB	UNESCO Institute of Statistics
High technology Eexports	Percentage of manufactured exports	HIGHTEC	World Development Indicators

Returns to scale selection: The Variable Returns to Scale (VRS) is recommended in cases where the NISs under study operate at different scales, have different institutional structures and operate under incomplete markets (Alnafrah, 2021). The Constant Returns to Scale assumes that all the NISs are operating optimally, and does not provide information on the returns' direction of the innovation process. This study adopts the VRS.

Orientation: The input orientation is adopted because the actors of the NISs are more able to control the inputs into the innovation production process. However, the output orientation would yield similar results because of the duality concept.

4.3 Estimating the Drivers of Efficiency

Empirical literature (Afzal, 2014; Cai, 2011 and Ayisi et al., 2019) shows that ICT infrastructure, labour force, education system, governance and financial structure are key determinants of performance of national innovation systems. However, these variables may not be equally important for the selected countries in this study. To obtain a better picture of the level of significance of these variables in African NISs, further analysis is necessary. This study applies Tobit regression model to establish the effect of these variables on DEA VRS technical efficiency results.

Table 3: Drivers of innovation efficiency

Variable	Measurement	Abbreviation	Data Source
Education system	Secondary school enrolment (% GDP)	Educ	World Development Indicators, 2018
ICT infrastructure	Mobile phone users (per 100 inhabitants)	Mphone	UNESCO Institute of Statistics
Regulatory Quality	Estimate index	RQ	World Development Indicators, 2018
Governance	Governance Index	Govn	Ibrahim Index of African Governance
Labour force	Population ages of 15 to 65 (% of total population)	POPN	World Development Indicators, 2018
Financial structure	Credit to private sector (% of GDP)	FS	World Development Indicators, 2018
	Broad money (% of GDP)	M2	World Development Indicators, 2018

Many empirical studies have adopted Tobit regression model in the second stage to analyze the effect of environmental factors on efficiency scores (Nasierowski and Arcelus, 2013; Guan and Chen, 2012; Chen, Hu and Yang, 2011 and Afzal, 2014). This is because the scores generated from DEA model range between 0 and 1 (Ji and Lee, 2010). OLS estimation may therefore yield inaccurate results.

The stochastic model underlying Tobit regression can be represented as:

$$Yt=\beta X_i+\mu_i \text{ if } \beta X_i+\mu_i>0 \qquad 4.8$$

$$=0 \qquad \text{if } \beta X_i+\mu_i\leq 0$$

$$i=1,2,3\ldots\ldots\ldots\ldots\ldots\ldots N$$

N is the number of observations, Y_i is the dependent variable, Xi is a vector of independent variables, μ_i is the independently distributed error term and β is a vector of coefficients.

The specific efficiency function for the National Innovation System of the selected countries can be written as:

$$E_i = \beta_1 EDUC + \beta_2 Mphone + \beta_3 POPN + \beta_4 RQ + \beta_5 FS + \beta_6 M2 + \beta_7 Govn + \mu_i \quad 4.9$$

4.4 Descriptive Statistics

The summary of the descriptive statistics for the input and output variables and the potential divers of efficiency are presented in Table 4.

Table 4: Summary descriptive statistics

Variable	N	Mean	Std Deviation	Min	Max
Number of researchers	30	250	397.488	11	1772
Gross expenditure on research and development	30	0.383	0.271	0.014	0.980
Patents	30	89	214.007	1	1027
Foreign direct investments	30	1887.867	4265.002	6	23337
Scientific publications	30	102.508	139.131	3.582	609.848
High technology exports	30	4.367	5.476	0.2	26
Education	30	56.6	24.06	20	101
Governance	30	53.397	10.184	36.100	77.2
Regulatory quality	30	-0.467	0.504	-1.474	1.019
Labour force	30	56.689	5.713	47	70.73
Mobile phone users	30	95.326	34.886	37.218	159.931
Financial system	30	33.520	29.523	10.900	129
Efficiency score	30	0.542	0.201	0.107	0.766

From Table 4, the selected African countries spend an average of 0.383 per cent of their GDP on research and development. This is way below the target of 1 per cent, set by the African Union. None of the countries has achieved this target since the maximum is 0.98 per cent, which is for Kenya. We can also observe that 4.4 per cent of the manufactured exports are high technology exports, which is quite low and pointing to the need for technology adoption in Africa. The study further establishes that, on average, there are 250 researchers per one million inhabitants in every country, which is relatively low given that innovation programmes are grown out of research. Patent applications in the region remain low as evidenced by average of 90 applications per country annually. This signifies low levels of innovation output.

5. Findings and Discussion

The efficiency scores of all the countries obtained from the bootstrap based VRS DEA process and the results of the Tobit regression model which shows the drivers of efficiency in Africa are outlined in the section. Further, a discussion of these findings is provided in the section.

5.1 Efficiency Scores from Bootstrap DEA

Table 5: DEA and bootstrap DEA results

Decision Making Unit	**DEA Results**		**Bootstrap DEA Results**	
	VRS	CRS	VRS	CRS
Angola	1	1	0.719	0.671
Botswana	1	0.997	0.723	0.829
Burkina Faso	1	1	0.715	0.718
Burundi	0.603	0.171	0.513	0.133
Congo	1	1	0.717	0.676
Côte d'Ivoire	1	1	0.766	0.753
Eswatini	0.573	0.572	0.468	0.476
Ethiopia	0.313	0.303	0.243	0.237
Ghana	0.541	0.472	0.437	0.372
Kenya	0.900	0.469	0.706	0.348
Lesotho	0.856	0.563	0.681	0.446
Madagascar	0.529	0.247	0.4153	0.193
Mali	0.426	0.213	0.364	0.177
Mauritius	1	1	0.739	0.755
Mozambique	0.363	0.362	0.284	0.284
Namibia	0.635	0.632	0.499	0.525
Niger	0.482	0.202	0.397	0.158
Nigeria	1	1	0.726	0.697
Rwanda	1	1	0.736	0.720
Senegal	0.132	0.107	0.106	0.083
South Africa	1	0.894	0.719	0.689
Togo	0.295	0.241	0.24	0.198
Uganda	0.647	0.599	0.527	0.466
Tanzania	0.401	0.399	0.312	0.306
Zambia	0.359	0.351	0.289	0.284
Algeria	1	1	0.718	0.676
Egypt	1	1	0.717	0.711

Mauritania	1	0.628	0.716	0.468
Morocco	0.422	0.404	0.336	0.317
Tunisia	1	0.876	0.715	0.670

Considering the bias corrected efficiency scores from Table 5, none of the sampled countries is fully efficient. Côte d'Ivoire, Mauritius and Rwanda record highest scores of 76, 74 and 73.6 per cent, respectively.

The selected countries are, on average, 54.2 per cent efficient in the innovation production process. This implies that if we hold all other factors constant, the countries have potential to improve outcomes (number of patents, high technology exports and scientific publications by 45.8% using the same set of inputs for them to operate on the efficient frontier).

Most of the highly ranked African countries under the Global Innovation Index ranking (South Africa, Mauritius, Kenya and Tunisia) record high scores of more than 70 per cent. However, this is not the case for Morocco, which is ranked top 100 in the world. Morocco is 33.5 per cent efficient according to our findings. This shows that the country has huge potential to improve efficiency in utilization of innovation resources and hence improve its innovation performance globally. It is also noted that there are countries which do not appear in the global innovation index ranking such as Cote d'vore but register better efficiency scores than best performers such as South Africa (0.72). In the East Africa region, Rwanda and Kenya record more than 70 per cent efficiency. Uganda and Burundi score 54 and 52 per cent, respectively, while Tanzania, which is ranked 4th in SSA is 31 per cent efficient.

Looking at some of the best practice countries as per this study, Mauritius for instance is ranked highest in SSA in the 2021 GII ranking, leading in infrastructure, institutions and creative outputs. The country has a National Innovation Framework, which addresses relating to funding for innovation, infrastructure, capacity building, creating a flexible regulatory framework and incentives to facilitate partnerships between private sector and government. This framework sets out what needs to be done, and there exists a clear monitoring framework that tracks progress in implementing the projects and programmes.

Rwanda leads among the low-income economies and is ranked position 102 globally. The country has emerged as one of the innovative African countries over the past decade. In its effort to support innovation, the government has set up knowledge producing institutions such as innovation hubs and universities, established a science granting council, which provides funds for industrial incubation centres, product labs and formal and informal sectors (Yongabo, 2020). The country has generally focused on promotion of high-tech sectors such as ICT and life sciences, and this has contributed to its good performance.

5.2 Analysis of the Drivers of Efficiency

To analyze the drivers of efficiency in Africa, we run a Tobit regression model with efficiency scores as the dependent variable, against potential factors that affect efficiency of the National Innovation System.

Table 6: Tobit regression results

Variable	Coefficient
Labour force	.010*** (0.003)
Education	.009** (0.001)
Governance	-.010** (0.002)
Mobile phone	.002*** (0.001)
Regulatory Quality	.024 (0.45)
Money supply	-.005** (0.001)
Constant	.221 (0.227)
Std errors in parenthesis *** p<.01, ** p<.05, * p<.1	

The Tobit regression results show that three variables, namely: labourforce, education and ICT infrastructure are statistically significant at 1 per cent. Regulatory quality is not statistically significant but presents an expected sign, meaning it positively affects technical efficiency of NISs in the selected countries. Governance and money supply are significant but with an unexpected sign. This could be attributed to problems with data.

An increase in secondary school enrolment by 1 per cent for instance has potential to move a country to the efficient frontier. This is because education inculcates knowledge, which is a powerful driver for capital development and productivity.

These findings are consistent with the findings by Kona et al. (2014), who concluded that building human resource capacity through education is important improving efficiency and effectiveness of national innovation systems in Kenya and Ghana. The results further agree with Lacopetta (2010) and Galor (2005), who attribute countries' transformation from imitation to innovation to investment in human capital through education.

An improvement in ICT infrastructure by increasing the number of mobile phone users per million inhabitants by 0.2 per cent would equally help a country attain efficiency. This is in line with Cai (2011), who identifies ICT infrastructure as a key factor towards enhancing the efficiency of the innovation system through its support for diffusion of knowledge and technology in the economy.

The study found a significant link between labour force and innovation efficiency. It was established that the selected labour force category, which constitute the youthful and working population is positively associated with the employees' ability to implement and capitalize innovations. This is in tandem with (Toner, 2011) who affirmed that youthful labour force produce economically novel achievements. The author argued that most inventions are produced by persons aged between 35-50 years. They also stated that more than 50 per cent of technological innovations are produced by persons younger than 40 years. These findings, however, contradict with Wydra (2009), who reported that ageing population have a higher innovation capacity and are the producers of most innovations due to experience and learning curve.

6. Conclusion and Recommendations

6.1 Conclusion

Africa's pursuit for economic development and sustainability is faced with challenges such as harmful effects of climate change and rapid population growth. The region's future resilience highly depends on the extent to which its countries and citizens harness innovation and create innovation development systems. To achieve this, it is important for policy makers to evaluate how their countries are utilizing their innovation resources to generate innovation outputs, in relation to other countries. This study attempts to do this by using the VRS Bootstrap DEA to identify the relatively efficient countries in Africa. Using the Tobit model, the study has also attempted to explain the drivers of efficiency of National Innovation Systems of the selected countries and therefore identified ways to improve efficiency of innovation systems in Africa.

The study concludes that the innovation outcomes realized do not match the investment made in all the selected African countries. This is because the efficiency scores fall below the efficiency frontier citing inefficiencies in the innovation systems of the selected countries. Although none of the selected countries has met the recommended investment threshold of one per cent of GDP in R&D, the existing capacity remains underutilized as the countries are still not fully efficient. Low levels of innovation output are demonstrated by low patent applications and low production of high technology exports across the region.

This study reveals that efficiency scores of the selected countries can be improved through three variables: Labor force, education and ICT infrastructure. Despite the potential of education to enhance efficiency of innovation systems school enrollment remains low in the region. It was established that only 56.6% of the population in the selected countries have attained secondary school education. It was also evident from the findings that majority of the population constitute the working population who are highly creative and have the potential to supply labour to be used for implementation of innovations. Further, the study concludes that ICT infrastructure is important for diffusion speed and scope of knowledge which in turn influences the efficiency of the National Innovation Systems.

6.2 Policy Recommendations

African countries need to relook into the utilization of the existing innovation infrastructure both human and capital to realize efficiency from the investments. This could be achieved through cross-examination of the system and strict monitoring and evaluation of innovation activities, to ensure proper utilization of available resources by institutions and firms. Similarly, the selected countries can benchmark with advanced economies to identify other potential areas of investment innovation to improve the performance of their national innovation systems.

There is need for more investment in education through establishment of more learning and training institutions and seeking experts to train and develop higher workforce capabilities. The African Innovation outlook (2019) shows that the best innovation performers invest more in education. Innovation focused curricula would also be crucial in building competence for innovation.

Governments may reinforce the investment and establishment of a reliable ICT infrastructure through public private partnerships to attain higher interconnectivity and smooth flow of information and knowledge. According to Bankole and Brown (2017), ICT infrastructure in especially the mobile market has experienced tremendous growth in Africa but at a sub-optimal extent except for countries such as Nigeria and Kenya thus the need to channel more investment towards this course to enhance efficiency through PPPs.

To ensure higher productivity of the labour force, a favorable environment for learning should be established through development of technical collages to train and impart skills on the youth and introduction of reward schemes to appreciate employees for noble innovations. This will encourage continuous creativity and innovation.

6.3 Study Limitations

The main limitation of this study is scarcity and accuracy of data. Most African countries do not carry out frequent surveys to determine how the identified innovation indicators are performing. According to the African Innovation Outlook (2019), only 10 countries submitted complete information on R & D expenditure. The UNESCO Institute of Statistics also has missing values for many African countries. This problem limited our sample size and affected the accuracy of our dataset. We therefore recommend that African economies invest more in data collection so that future research in the area can obtain more robust findings.

Secondly, a number of studies have looked at the Innovation production process as a two-stage process: Knowledge Production and Knowledge Commercialization process. This approach has been applauded for being a better representation of the NIS. Our study did not adopt this approach because of limited data. Future research in the area could consider taking this approach so that efficient countries in the respective stages can be identified.

References

Afzal, M.N.I. (2014), "An empirical investigation of the National Innovation System (NIS) using Data Envelopment Analysis (DEA) and the Tobit model". *International Review of Applied Economics*, 28(4): 507-523.

Alnafrah, I. (2021), "Efficiency evaluation of BRICS's national innovation systems based on bias-corrected network data envelopment analysis". *Journal of Innovation and Entrepreneurship*, 10(1): 1-28.

Ayisi, J., Ndakala, F., Nyanga, R., Daniels, C., Owuor, R., Ting, B. and Wanyaman, B. (2019), Assessing the potential for transformative innovation policy in Kenya.

Bamfo, A.A. (2015), Empirical analysis of the drivers of innovation in Sub-Saharan Africa. Doctoral dissertation, University of Ghana.

Bankole, F.O., Osei-Bryson, K. M. and Brown, I. (2011), ICT infrastructure utilization in Africa: Data envelopment analysis-based exploration. In Proceeding of special interest group on ICT and global development at Americas Conference on Information System (AMCIS) Workshop, Detroit, USA.

Barasa, L., Vermeulen, P., Knoben, J., Kinyanjui, B. and Kimuyu, P. (2019). "Innovation inputs and efficiency: Manufacturing firms in Sub-Saharan Africa". *European Journal of Innovation Management*.

Bartels, F.L., Voss, H., Lederer, S. and Bachtrog, C. (2012), "Determinants of National Innovation Systems: Policy implications for developing countries". Innovation, 14(1), 2-18.

Bento, N. and Fontes, M. (2015), "Spatial diffusion and the formation of a technological innovation system in the receiving country: The case of wind energy in Portugal". *Environmental Innovation and Societal Transitions*, 15: 158-179.

Blind, K. (2016), *The impact of regulation on innovation. In Handbook of innovation policy impact*. Edward Elgar Publishing.

Cai, Y. (2011), Factors affecting the efficiency of the BRICSs' national innovation systems: A comparative study based on DEA and Panel Data Analysis. Economics Discussion Paper, (2011-52).

Carayannis, E.G., Grigoroudis, E. and Goletsis, Y. (2016), "A multilevel and multistage efficiency evaluation of innovation systems: A multiobjective DEA approach". *Expert Systems with Applications*, 62, 63-80.

Chen, K. and Guan, J. (2012), Measuring the efficiency of China's regional innovation systems: Application of network data envelopment analysis (DEA)". *Regional Studies*, 46(3): 355-377.

Crafts, N. (1996), "Post-neoclassical endogenous growth theory: What are its policy implications?' *Oxford Review of Economic Policy*, 12: 30-47.

Doğan, E. (2016), "The effect of innovation on competitiveness". *Istanbul University Econometrics and Statistics e-Journal*, (24): 60-81.

Dutta, S., Lanvin, B. and Wunsch-Vincent, S. (eds.) (2018), *Global innovation index 2018: Energizing the world with innovation*.

Etzkowitz, Henry and James Dzisah (2008), "Rethinking development: Circulation in the triple helix". *Technology Analysis and Strategic Management,* 20 (6): 653–666.

Farrel, M.J. (1957), "The measurement of productive efficiency". *Journal of Royal Statistics Society*, 120(3): 253-290.

Freeman, C. (1987), *Technology and economic performance: Lessons from Japan*.London: Pinter.

Government of Kenya (2013), The Science, Technology and Innovation Act, 2013 No. 28 of 2013. Kenya Gazette Supplement No. 43.

Grupp, H. and Schubert, T. (2010), "Review and new evidence on composite innovation indicators for evaluating national performance". *Research Policy*, 39(1): 67-78.

Hall, A. (2005), "Capacity development for agricultural biotechnology in developing countries: An innovation systems view of what it is and how to develop it". Journal of International Development, 17 (5): 611–630.

Havas, Attila (2002), "Policy matter in a transition country ? The case of Hungary". *Journal of International Relations and Development*, 5(4): 380-402.

Isola, O. O., Ogundari, I.O. and Siyanbola, W.O. (2010), The Nigerian National Innovation System: A critical look at research and development (R&D) and innovation capabilities in selected universities. In PICMET, Technology Management For Global Economic Growth. IEEE.

Ji, Y.B. and Lee, C. (2010), "Data envelopment analysis". *The Stata Journal*, 10(2): 267-280.

Johnson, B. (2008), Cities, systems of innovation and economic development. Innovation, 10(2-3), 146-155.

Kontolaimou, A., Giotopoulos, I. and Tsakanikas, A. (2016), "A typology of European countries based on innovation efficiency and technology gaps: The role of early-stage entrepreneurship". *Economic Modelling*, 52: 477-484.

Koria, R., Bartels, F.L., Andriano, L. and Koeszegi, S. (2014), Effectiveness and efficiency of National Systems of Innovation: The importance of ICT, the Cases of Ghana and Kenya. In 2014 IST-Africa Conference Proceedings. IEEE.

Lammers, J.C. and Garcia, M.A. (2014), *Institutional theory*. In L. L. Putnam and D. K.

Lee, T. L. and Von Tunzelmann, N. (2005), "A dynamic analytic approach to national innovation systems: The IC industry in Taiwan". *Research Policy*, 34(4): 425-440.

Lemarchand, G . (2015), Latin America. In Schneegans, S. (ed.), UNESCO science report: Towards 2030. UNESCO Publishing.

Metcalfe S and Ramlogan, R (2008), "Innovation systems and the competitive process in developing economies". *Quarterly Review of Economics and Finance*, 48(2): 433-446.

Moraa H. and Gathenge, D. (2013), How ICT hubs models have impacted on technology entrepreneurship development. ICTD 13 Proceedings of the Sixth International Conference on Information and Communications Technologies and Development.

Muchie, M. and Baskaran, A. (2008), The impact of the national innovation systems on the flow and benefits of foreign direct investment to national economies.

Naik, P. (2018), "The relationship between stock market volatility and trading volume: Evidence from South Africa". *The Journal of Developing Areas*, 52(1): 99-114.

Nelson, R.R. (1987), "Innovation and economic development theoretical reprospect and prospect". In *Technology generation in Latin American manufacturing industries*. London: Palgrave Macmillan.

Romer, P. M. (1980), "Economic integration and endogenous growth". *The Quarterly Journal of Economics*, 106(2): 531-555.

Romer, P.M. (1993), "Idea gaps and object gaps in economic development". *Journal of Monetary Economics*, 32: 543-573.

Scerri, Mario (ed) (2016), The emergence of system of innovation on South (ern) Africa: Long histories and contemporary debates. Johannesburg: MISTRA/ Real African Publishers.

Schumpeter J.A. (1934), The theory of economic development. Cambridge: Harvard University Press.

Simar, L. and Wilson, P.W. (1998), "Sensitivity analysis of efficiency scores: How to bootstrap in non-parametric frontier models". *Management Science*, 44(1): 49-61.

Szirmai, A., Naudé, W. and Goedhuys, M. (eds) (2011), *Entrepreneurship, innovation, and economic development*. Oxford: Oxford University Press.

Tobin, J. (1958), "Estimation of relationships for limited dependent variables". *Econometrica: Journal of the Econometric Society*, 24-36.

Tsvetkova, A. (2015). "Innovation, entrepreneurship, and metropolitan economic performance: Empirical test of recent theoretical propositions". *Economic Development Quarterly*, Vol. 29, No. 4: 299-316.

Tziogkidis, P. (2012), Bootstrap DEA and hypothesis testing (No. E2012/18). Cardiff Economics Working Papers.

Watkins, A., Papaioannou, T., Mugwagwa, J. and Kale, D. (2015). "National innovation systems and the intermediary role of industry associations in building institutional capacities for innovation in developing countries: A critical review of the literature". *Research Policy*, 44(8): 1407-1418.

Yongabo, P. and Göransson, B. (2020), "Constructing the national innovation system in Rwanda: Efforts and challenges". *Innovation and Development*, 1-22.

Zhang, C. and Wang, X. (2019). "The influence of ICT-driven innovation: A comparative study on national innovation efficiency between developed and emerging countries". *Behaviour and Information Technology*, 38(9), 876-886.

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