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EFFICIENCY OF TELECOMMUNICATION INDUSTRY IN NINE WEST AFRICAN COUNTRIES FROM 1994 TO 2013

BY

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DECLARATION

I, PATRICK ASIEDU do hereby certify that this thesis is a result of research I have personally undertaken under the guidance of my supervisors toward the attainment of the Master of Philosophy (MPhil) degree in Economics at the Department of Economics, University of Ghana.

I accept the responsibility for any errors and omissions that may be identified in this work.

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ABSTRACT

Over the last two decades, the telecommunication industry in most economies has been growing rapidly. The fast-paced growth of telecommunication utilities can be attributed to a number of factors such as advancement in technology, research and development in Information Communication and Technology and regulatory reforms such as market liberalization, privatization and incentive regulations.

The main objective of the study is to empirically investigate efficiency and productivity of operators in the telecommunication sector in West African Region for the period 1994-2013 using stochastic frontier analysis. Specifically, the study sought to estimate the level of efficiency, evolution of technical efficiency and factors that influence technical efficiency among countries in West African telecommunication sector.

At the 5% level of significance, the number of telecommunication subscriptions, telecommunication employees and annual investment had positive coefficient which means, these variables have significant effects on revenue and technical efficiency of the telecommunication companies across the nine countries. Annual investment has positive impact on technical efficiency with regressor coefficient value of 0.056 which is significant at the 5% level.

It is recommended to the management of Telecommunication companies across the nine countries to invest more in their capital stocks by replacing relatively old equipment with new ones. This will have the tendency to increase contributions of their capital to output as well as make it possible for them to operate closer to their frontiers. It is also recommended to stakeholders in the industry to take regular maintenance of machinery seriously especially with relatively old ones.

DEDICATION

This thesis is dedicated to God Almighty, the Father of our glorious Jesus Christ, my Parents, Samantha, Elsie, Joan, Phanuel and Perez, Uncle Francis, Auntie Janet, Bishop Nobleson, Rev Foster Mensah and friends who have one way or the other contributed towards my academic pursuits.

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ABBREVIATION

ACE	Africa Coast to Europe
CEAO	Communaute des Etats de l'Afrique de l'Ouest
CEMAC	Central African Economic and Monetary Community
EAC	East African Community
ECOWAS	Economic Community of West African States
DMU	Decision Making Unit
FTE	Full-Time Equivalent
GDP	Gross Domestic Product
GRA	Ghana Revenue Authority
GSM	Global System for Mobile Communications
ISDN	Integrated Services Digital Networks
ITU	International Telecommunication Union
ICT	Information Communication Technology
MRU	Mano River Union
NRAs	National Regulatory Authorities
R&D	Research and Development
SADC	Southern African Development Community
SFA	Stochastic Frontier Analysis
TA	Technical Assistance
UEMOA	West African Economic and Monetary Union
WWW	World Wide Web
WARCIP	West Africa Regional Communications Infrastructure Program
WATRA	West African Telecommunications Regulatory Assembly
WACS	West African Cable Systems

CHAPTER ONE

INTRODUCTION

1.0 Background

The term telecommunication was first used for wired telephony. Today, telecommunication is one of the most crucial contemporary Information and Communication Technology (ICT). They include wireless and wired telephony; different mobile services, such as cellular telephones and paging; voice and data transmission; and Integrated Services Digital Networks (ISDN), which supply high quality of voice and high data communication rates (International Telecommunication Union (ITU, 2010).

The telecommunication industry in most economies has been overgrowing. The fast-paced expansion of telecommunication utilities could be attributed to various factors, including advancement technology, Research and Information, and Communication Technology (ICT) Development, and regulatory reforms such as market liberalization, privatization, and incentive regulations. Outputs of the world economy have been overgrowing in recent years because the telecom sector serves as an enabler for another sector.

The telecommunication policy (liberalizations, privatization, incentive regulations, and others) reforms in Africa occurred when wireless mobile technology was developed. Most Sub-Saharan African countries began to adopt telecom reforms between the 1990s and 2000s. Almost all African countries have established an independent telecommunication regulator to ensure the equal level field for all the market operators to protect consumers' welfare and promote the telecommunication sector development by the year 2010 (Moshi et al., 2013).

The global telecoms sector is a unique and vibrant industry that is constantly evolving due to the new technology and infrastructure which continue to filter into the sector. According to BuddeComm, in 2020, there were around 7.7 billion active mobile broadband subscriptions worldwide and over 1.1 billion fixed broadband subscribers globally. These could be primarily due to the deployment of 4G and 5G long-term evolution (LTE).

Global System for Mobile Communication Association (GSMA) figures indicate the following: Between 2008 and 2019, mobile users grew more than 477 million, increasing mobile penetration rate from less than 33% to almost 45%. For the Economic Community of West African States (ECOWAS), subscriptions grew from 36 million to 185 million during the same period. Mobile internet users grew by 100 million with 26% penetration (GSMA,2019).

Mobile money in Western African is a crucial driver of financial inclusion. Around 59% of the combined adult population of Ghana, Benin, Senegal, and Cote D'Ivoire use mobile money services on an active basis. According to Global Systems for Mobile Communication Association (GSMA) figures, in 2019, there were 133.6 million registered mobile money accounts. The distribution of registered mobile money accounts in Sub-Saharan Africa shows the following: Eastern Africa (53%), Western Africa (35%), Central Africa (10%), and Southern Africa (2%).

All West African countries have introduced new laws and regulations covering telecommunications, with the majority establishing National Regulatory Authorities (NRAs) to implement rules governing the sector and protect consumer’s interests.

While liberalization has spurred the telecommunication revolution in Sub-Saharan Africa, the state of liberalization is incomplete. The process of liberalizing fixed-line markets has not progressed much. Licensing regimes across the region are gradually evolving from technology-specific licenses to service-specific licenses. (Williams et al., 2011)

1.1 Problem Statement

It has been noted that development in telecommunication technology is one of the driving forces of globalization and the increasing growth of the world economy (Lam et al., 2010). Development in satellites, optical fiber, mobile telephony, the internet, and World Wide Web (WWW) has dramatically improved the world's communications and improves the exchange of information between different people worldwide.

Privatization and the liberalization of the telecom sector in most countries have resulted in to increase in productivity, and tariff has declined dramatically, leading to a rise in consumers' welfare (Lam et al., 2008).

A well-developed mobile communication sector that operates efficiently can be significant in economic growth and development. The mobile communication industry contributed US$ 155 billion to the economy of Sub-Saharan Africa, with an increase of 57% since 2008. The telecom industry’s contribution to GDP for ECOWAS was US$ 52 billion in 2018 (GSMA Wireless Intelligence, 2019).

Mobile communication contributes to public funding in taxes, fees, and operational charges. Over the years, taxations revenue from mobile operators has increased significantly in Sub-Saharan Africa; US$ 17 billion was paid to the Government in taxes and fees in 2019. The mobile ecosystem in ECOWAS's contribution to public funding in 2019 was US$ 4.4 billion (GSMA, 2020). Furthermore, the mobile telecom sector in ECOWAS supported 1.6 million directly and indirectly jobs. The sector made a substantial contribution to public sector funding, with over US$ 4 billion raised through consumer and operation taxations in 2018.

Mobile telecom operators' revenue has also been increasing over time. The increase in revenue has implications for operators' network investment expansion, increased dividends, increased wages and salaries, increased taxes and levies payment, and increased social investment contributions. Mobile revenue in Sub-Saharan Africa amounted to over US$ 44.3 billion, representing an 8% contribution to Sub-Saharan Africa GDP (GSMA, 2020). Mobile operator's revenue in West African telecom sector was US$ 17 billion and operator Capex of US$ 8.5 billion for the period 2019 -2020.

Furthermore, the social investment contributions of the mobile communication sector are enormous. Through its social investment, the telecom sector initiatives have had a positive impact on the achievement of Millennium Development Goals such as poverty and hunger, universal education, gender equality, child health, maternal health, HIV/AIDS, environment, and partnership.

The telecommunication sector is an enabler for other sectors of the economy to ensure efficiency and competitiveness in trade, education, agriculture, health, financial service, and aviation. Therefore, the inefficient functioning of the telecommunication sector would have multiplicative effects on other sectors by posing a barrier to development. The contributions of the telecommunication sector enumerated above indicate that as the operators become efficient, their contributions would also increase, leading to increased consumers' welfare, economic growth, and development.

Liberalization and reforms of the telecommunication sector in West Africa have led to fierce competition among the operators in the sector. The competition has called for telecommunication operators to improve their operating efficiency regarding the inputs (resources) usage and their corporate performance in terms of teledensity and improve quality of service delivery to maintain their profits.

Despite the significant expansion and growth of the telecommunication industry in West Africa, a lack of quantitative study on efficiency and productivity traced such expansion in the industry to efficiency. The countries in the study are nine, and the period spans 20 years.

Finally, the degree to how the technical efficiency levels have changed by implementing the telecommunication sector reform initiatives is yet to be examined. This study is required to conduct an empirical study and contribute to the literature by estimating the level and analyzing the evolution of efficiency and productivity over 20 years period 1994-2013 by using Stochastic Frontier Analysis (SFA).

1.2 Objectives of the Study

The main objective of the study is to empirically investigate the efficiency and productivity of operators in the telecommunication industry in nine West African countries, namely; Benin, Burkina Faso, Cape Verde, Cote D'Ivoire, Ghana, Mali, Nigeria, Senegal, and Togo, for the period 1994-2013 using stochastic frontier analysis. Specifically, the study seeks to;

a. Determine the level of technical efficiency in the telecommunication sector during 1994 - 2013.
b. Determine the evolution of technical efficiency of each country over the period 1994-2013 for each country.
c. Assess the factors that determine the technical efficiency of the telecommunication sector.

The study would seek answers to the following questions:

a. What are the technical efficiency levels in the telecommunication sector in nine West Africa for 1994-2013?
b. Have the technical efficiency levels changed over 1994-2013 for each country?
c. What factors influence technical efficiency in the telecom sector?

1.3 Justification of the Study

In the recent period, recognizing the contributions of the telecom sector to economic growth and development, there is the need to investigate the technical efficiency of telecommunication operators as a means to compare their performance and explore strategies that would help these operators and policymakers in promoting and improving the telecommunication utilities (Sadjadi et al., 2010).

Telecommunication services expansion is usually associated with increasing returns to scale due to the rapid rate of technological innovation in the sector. From a regulatory and policy perspective, it is essential to provide insight into how efficiently the significant operators in West African country's telecommunication industry have used the various inputs during the expansion process as well as the drivers of productivity pattern (Eria et al., 201l).

The study results would have significant contributions in the following areas: It would provide evidence for policymakers in resource allocation decisions. This information would assist telecom managers in resource allocation decisions at the micro-level issues such as input mix, the scale of operation, and rational use of the available resources. The research would contribute to the literature in technical efficiency study in the telecommunication industry.

1.4 Research Methodology

Technical efficiency is shown by the movement of the decision-making unit closer or further from the present or past frontier. (Eria et al. 2011).

The empirical analysis would be conceptualized in the sector of the telecommunication sector. The traditional assumption that economic units (telecommunication) operate at the production possibility frontier suggests output set is the maximum attainable output and that they are all equally productive for a certain level of inputs (Symeou. 2011). However, in reality, economic units may use the best practice technology with various degrees of efficiency.

Due to the main limitation of Data Envelopment Analysis (DEA produces results that are very sensitive to measurement of error), Stochastic Frontier Analysis would be employed to estimate the technical efficiency of the telecommunications sector. The parameters would be evaluated with maximum likelihood estimation.

1.5 Organization of the study

This study is organized into six main chapters; the first chapter gives a background to the study in which the problem statement and the research questions, objectives of the study, and significance of the study are outlined. Chapter two reviews the literature on the measurement of telecommunication efficiency using stochastic frontier analysis. Chapter Three provides an overview of the telecommunications sector reform in West Africa. Chapter four details the conceptual framework and methodology used in this study. Chapter five presents an analysis and discussion of findings from the research. Chapter six is dedicated to the summary, policy recommendations based on the study's findings, and limitations of the study. Attention is also given to recommendations for future research in the last chapter.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter provides a review of the literature on technical efficiency. The review begins with the theoretical literature, followed by a review of empirical literature specific to the measurement of efficiency level using Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (DEA) in the telecommunication sector.

2.1 Theoretical and Conceptual Framework

2.1.1 Introduction

This section reviews some theories employed in efficiency measurement estimations. Firstly, it reviews the theory of production, the theory of distance function, and efficiency measures. Secondly, efficiency measurement approaches**.**

2.1.2 Theory of Production

The microeconomic theory of production provides the framework for the evaluation efficiency of the telecommunication sector. The theory of production considers a firm as a production system where inputs defined as the resources utilized in the production process are transformed or converted into desirable outputs. In broad economics and operations management sense, the production process may take various forms: manufacturing, services, transportation, and supply (Dwivedi, 1980; Ray, 1999).

Production theory deals with the input-output relationship, expressed in money or physical quantity terms. The technical and technological relations between inputs and between output and inputs, for example, capital-labor ratios, capital-output ratios, and labor-output ratios, are of interest in production theory.

Furthermore, a production function may take the form of a schedule of a table, graphed line or curve, an algebraic equation, or a variety of mathematical modeling. In algebraic or mathematical format, for example, the relationship between capital input (K) combined with labor input(L) to produce output Q can be expressed as $Q= f (K, L)$. This mathematical format describes the technological possibilities of the firm in reference.

2.2 Efficiency Measurement Approaches

Efficiency measurement empirically begins with Farrel (1957), who drew inspirations upon the work of Debreu (1951) and Koopmans (1951) to define a simple measure of firm efficiency that could account for multiple inputs. Farrel (1957) proposed that the efficiency of a firm consist of two components; allocative efficiency, showing the ability of a firm to employ the inputs in optimal proportions, given their respective prices and the production technology and technical efficiency, showing the ability of a firm to obtain maximal output from a given set of inputs. These two measures are then combined to measure total economic efficiency (Coelli et al., 2005).

The determination of the output-and input-orientated efficiency measures require the production function to be known. It is, however, complicated to know precisely the underlying function. This problem led to the efficient isoquant estimated from the observed data. Farrell (1957) suggested using either of the following two approaches to estimate and use a non-parametric and using parametric function, such as the Cobb-Douglas form (Coelli et al., 1998). The first approach led to the development of data envelopment analysis (DEA), and the second one led to the use of parametric techniques such as deterministic and probabilistic frontier models. The two approaches are briefly reviewed below, starting with Stochastic Frontier and then Data Envelopment Analysis.

2.2.1 Stochastic Frontier Analysis

The problem of computing rather than estimating the parameters in both the deterministic and probabilistic approaches led to the specification of stochastic production function by Aigner, Lovell, and Schmidt (1977) and Meeusen and van de Broeck (1977). The stochastic production frontier specifies each firm's output as bounded above by a stochastic frontier because its placement is allowed to vary randomly across the firms. In this approach, the firms are made to be technically inefficient relative to the frontier. The error term in the model is made up of two components. One component shows the randomness outside the firm's control, and the other component shows (inefficiency) randomness under the firm's control. The specification of frontiers as stochastic makes it possible to conduct statistical estimation and inference.

Several different functional forms are used in the literature to model production functions:

Cobb-Douglas (linear logs of outputs and inputs), Quadratic (inputs), Normalized quadratic, and Translog function. Translog function is commonly employed in the literature. It is a generalization of the Cobb-Douglass function. It is a flexible, functional form providing a second-order approximation, and it is also possible to impose restrictions on the parameters (homogeneity condition) (Greene, 2003).

2.2.2 Data Envelopment Analysis

Data Envelopment Analysis is a non-parametric mathematical programming technique that measures the relative efficiency of inputs and outputs across peer decision-making units (DMU) in some production or service process (Charnes, Cooper, and Rhodes, 1978). The basic idea is that DEA extended the traditional concept of productivity or efficiency analysis (input to output ratio) and made it suitable for performance evaluation and benchmarking within the context of multiple performance measurements (Zhu,2003). DEA techniques have been widely applied in measuring efficiency in telecommunications because it calculates the most efficient telecom companies or the best-practice frontier in a given set of firms.

DEA was developed by Charnes, Cooper, and Rhodes (1978). The two types of envelopment surfaces in DEA are constant returns to scale (CRS) and variable returns to scale (VRS). Two models underpin DEA; these are Charnes, Cooper, and Rhodes (1978) DEA model (CCR Model) and Banker, Charnes and Cooper Model (1984).

However, Data Envelopment Analysis has the following main limitation: It produces sensitive results to measurement error.

2.3 Empirical Literature

Many empirical studies have been carried out in productivity and technical efficiency measurement in many developed and developing countries. Most of these studies, such as Puiu

(2013), Yan (2009), Moshi et al. (2013), have primarily used the DEA approach, while only a few of them have used the SFA approach. In this subsection, empirical works that employed Data Envelopment Analysis (DEA) in the telecommunication sector are reviewed in 2.3.1, followed by works that employed Stochastic Frontier Analysis (SFA) in the telecommunication sector 2.3.2. The reviews are arranged from empirical studies in developed countries, such as the USA, Europe, the OECD, China, India, and African and ECOWAS countries. The literature review section is meant to provide information on the method that has been applied in the estimation efficiency levels in the literature. The review also captured the efficiency levels and inputs and outputs variables used in the various studies. This is important because it will inform the choice of inputs and outputs variables for this study.

2.3.1 Application of Data Envelopment Analysis in the Telecommunication Sector

In a study of Taiwan's integrated telecommunication firms, Yang et al. (2009) employed DEA window analysis under constant return and variable return-to-scale to measure telecom operators' efficiencies over 2001-2005. Output variables include operating revenue, mobile phone subscribers, and mobile phone calls. The input variables used in this study include assets, operating costs, and operating expenses. This study indicates that acquisitions impact scale efficiency, and privatization and market liberalization strengthen Taiwan's telecom sector Competitions.

A study by Sexana (2012) employed DEA (CCR and BCC) sensitivity analysis to measure comparative efficiencies of mobile telecom operators in India. The input variables employed by the Author were expenditure, call success rate, call drop rate, and voice quality. The output variables include; complaints per 1,000 bills, number of subscribers, and gross revenue. The finding shows an 86.36% total average efficiency for the 126 utilities. Under the BCC model, there was a 98.86% average technical efficiency.

Lam et al. (2008) applied Data Envelopment Analysis (DEA) approach to measure the productivity of China's telecoms sector at the provincial level. The study employed business revenues and the total number of subscribers as output variables for the two models. The study also used two input variables: capital (capacity of long-distance telephone exchange, the capacity of local telephone exchange, the capacity of mobile telephone exchange, and the length of long-distance optical cable lines). The labor variable includes the number of staff. Using total revenue as output, the results for the overall average efficiency score were 0.806 in 2003, 0.83 in 2004, and 0.86 in 2005. Using the total number of subscribers as output average efficiency score was 0.957 in 2003, 0.964 in 2004 and 2005.

Hisali et al. (2011) employed a non-parametric approach – Data Envelopment Analysis to estimate total factor productivity growth in Uganda's telecommunications industry. A panel data set of six years period (2001-2006) was used. Four inputs and five outputs variables were measured. The inputs variables include; cost of investment, non-wages operational cost, number of employees, and staff cost (salaries and wages). The outputs measures focus on provider outputs, namely, telephone calls to other networks, international in-bound calls, and international outbound calls and total revenue. The study's analysis revealed a mean value of 1.000, 0.954, and 0. 954 for technical efficiency change, technological progress, and TFP change, respectively. There were 4.6% productivity gains accounted for more by technical or technological progress than technical efficiency.

A study by Huang et al. (2009) applied the DEA method to study the operational efficiency of 15 telecom companies. Panel data from 2004-2007 were selected from the annual report of each operator and CNN fortune 500 databases. The input variable is a total asset, and the output was operational revenue. The results indicate that the efficiency of selected telecom operators in Europe (0.976) and Asia (0.975) was higher than that in American (0.822).

Furkan et al. (2011) employed DEA to measure efficiency and the Malmquist index to estimate TFP of G8 countries and Turkey for the period 2007 to 2010. Input variables are capital expenditure, debt, total access lines, and employees. The output variables include; revenue, net income, and mobile subscribers. Over the period under study (2007-2010), technical efficiency change was 1.027, and TFP change was 1.048.

In a study of the efficiency of marketing expenses, Papadimitriou and Prachalias (2009) investigate the capability of global telecom companies on how to maximize the efficiency of the productive factors. The study employed DEA to measure the relative efficiency of each operator for four distinct periods (1998, 2001, 2004, and 2006). The input variables for the study were the number of staff, investment, market expenses, traffic of fixed telephony, and traffic of mobile telephony. Whiles the output variables used are total revenue for each operator. The finding shows an 80.36% for 1998, 83.41% for 2001, 87.88% for 2004, and 90.48% for 2006 are the final productive efficiency rates of the telecom operators.

Lam et al. (2010) assessed the impact of mobile telecommunication on economic growth and telecommunications productivity. The study covered 112 countries for the period 1995-2004. Total telecommunication services revenue was used as the input variable. The number of main telephone lines, annual investment (capital expenditure), and the total number of full-line employees were the input variables. The study employed the DEA-based Malmquist index to measure the TFP of the telecommunication sector. With Second-Stage regression analysis, mobile penetration, per-capita GDP, and regional dummy were identified as factors affecting TFP. The study also finds that average TFP growth was 6.7% per annum for 1995-2004 and technological change was the primary source of TFP growth. Finally, the study reveals that countries with competition and privatization in telecom have achieved a higher TFP growth than those without competition and privatization.

Jin-Li et al. (2008) study the impacts of industrial policy on the efficiency and productivity of Asia-Pacific telecom firms under circumstances of competition and productivity. The Authors employed a two-stage method to examine the efficiency score of twenty-four telecom firms during the period 1999-2004. DEA (Malmquist TFP) was used to estimate the technical efficiency score of the firms, and the Second Stage Tobit regression was used to estimate the determinate of inefficiency among the forms. The input variables employed by the study were the revenue of fixed-line services and non-fixed-line services. The input variables were the number of employees and the number of fixed assets. The finding of the study shows 0.551 overall technical efficiencies. Also, there was 0.2% average annual factor productivity growth over 1999-2004. The studies indicate that TFP growth of the telecom forms is mainly due to technical innovation more than technical efficiency change.

A recent study by Suleiman, Hemed, and Wei (2017) explored the efficiency of telecommunications companies in Tanzania. Data Envelopment Analysis (DEA) and Slack Based on Measure (SMB) were employed. This study used company report data from 2010 to 2016 for 27 reports. The study results showed three operators categorized as efficient, Vodacom in the first rank and Airtel and Tigo. However, the other four operators were less efficient.

Moshi et al. (2013) analyzed production efficiency changes in the Africa telecom industry from 2000 to 2009. The study employed DEA based Malmquist index to estimate efficiency changes and technological change scores. The study employed full-time telecom staff and telecom investment stock as an input variable. The output variables are the number of subscriptions, numbers of internet uses, and total revenue. The study also estimated the determinant of productivity growth by employing revenue, mobile subscriptions, internet users, international network operators, regulation presence and experience wealth (GDP per capita), and population as the primary determinant variables of productivity in the African telecom sector. The study shows technological change affects productivity growth more than technical efficiency—moreover, market competition and the number of subscriptions positively impact Africa's telecom sector productivity.

Madden et al. (1999) and Lam et al. (2010) had included African countries in their analysis globally. However, their results on productivity growth of African countries showed opposite developments. The former showed that productivity in African's telecommunications industry declined by 3.7% per annum from 1990 to 1995; the latter found that productivity had grown at an annual rate of 6.8% from 1980 and 2006.

Bollou et al. (2008) investigated the productivity changes of six West African countries between 1995 and 2002 using the DEA approach. The results showed that productivity in the telecommunications sector of the West African countries grew at 2.5%; however, the growth rate was declining quickly.

2.3.2 Application of Stochastic Frontier Analysis in the Telecommunications Sector

Uri (2003) adopted the translog distance function to explore the impact of regulation on technical efficiency. The study examined 19 local exchange carriers for the 1988-1999 period in the US telecom sector. Output variables are the number of local dial equipment minutes, the number of intra-LATA billed access minutes for intrastate calls, and the number of inter-LATA billed access minutes for interstate calls. The input data includes the number of employees, central office switching equipment, central office transmission equipment cable, wire facilities, and total operating expense. No identifiable change in technical efficiency for the period 1988-1998. Total factor productivity growth over the period was mainly due to innovation rather than technical efficiency.

Daigyo et al. (2011) employed a Stochastic Frontier Analysis (SFA) to investigate the impact of incentive regulation in the US telecommunication industry. The output measures used in the study were local calls, intra-lata tolls call, and inter-lata tolls calls. The input variables are the number of total switches, the number of access lines, and the number of employees.

Hendrawan et al. (2019) analyzed the efficiency of Southeast Asia telecommunication operators using Stochastic Frontier Analysis. The studies used 14 telecommunication operators from five Southeast Asia countries for the period 2008 to 2017 using secondary data from the financial statement of the operators. Capital expenditure, operating expenditure, personnel expenses, and total assets were the input variables. Revenue, number of subscribers, and Average Revenue Per User were the output variables. Inflation was an environmental variable. The finding showed that except for the environmental variable, all the output and input variables positively affect efficiency. The research concluded from 2008 to 2017, Telkom was the operator with the highest efficiency value of 0.862 above the average efficiency of 0.689.

Jha and Majumdar (1999) used panel data and the stochastic production frontier estimation approach to measuring the productivity of the telecommunications sector for 23 OECD countries for the period 1980–1995. They found that mobile technology diffusion had a positive and significant impact on the productivity of the telecommunications sector.

Li and Lyons (2012) used panel data for 29 OECD counties and China from 1991-2006 and found that the presence of an independent industry regulator affected mobile network penetration and expansion positively.

Battistoni et al. (2006) estimated the Stochastic Frontier translog production function for EU countries, using a panel data set covering the 1995–2002 period. Their results show that the average TE values among the new EU members in the 1990s were somewhat higher than those of the old members but are slightly lower than the latter after 2000. Furthermore, a convergence of TE values among EU countries.

Moriwaki et al. (2010) employed stochastic frontier analysis and estimated Cobb-Douglas and translog production using panel data sets. The study covered the period of 1983-2007 to investigate the productivity and efficiency of Asia-Pacific countries' telecommunication industries. The output variable used was telecom revenue; the input variables were capital stock, the total number of telephone employees, and the total number of fixed and mobile cellular phone subscribers. The study's findings suggest a positive and standard technological change all over the region. The USA was the technological frontrunner. Population per capita GDP and fixed phone penetration rates are the critical determinants of technical efficiency.

Yang and Chang (2007) used panel data and the stochastic frontier analysis model to analyze and compare the telecom industry in 28 Asian countries from 1994-2003. The only output variable was total revenue, while the input variable includes; the number of employees and average annual investment. The study results reveal that Japan has the highest technical efficiency of 0.78 on average, and Tajikistan has the lowest value, only 0.01 on average.

Wallsten (2001) used a panel database of 30 countries in Africa and Latin America from 1984-1997 to investigate telecom reforms on telecom performance. The Author considered privatization, competition, and regulating variables as critical determinants of telecom performance. The finding reveals that with fixed-effect regression, competition (measured by mobile operators are not owned by the incumbent) positively affects telecom performance. Privatization combined with an independent regulator positively correlates with telecom performance measures, but privatization alone does not impact telecom performance.

In conclusion, although Stochastic Frontier Analysis has extensively been examined in efficiency estimation in other sectors such the Banking, Insurance, Agriculture, Manufacturing, Education, Health, among others (Ogundari et al. (2010); Kumbhakar & Lovell (2000), Kumbhakar et al. (2014), Baduneneko & Kumbhakar (2017), Lai & Kumbhakar (2018), Owusu-Ansah, et al. (2010). Few empirical studies could be found on the application of Stochastic Frontier Analysis in the telecommunication sector for ECOWAS countries in the literature. Data Envelopment Analysis in efficiency estimations (DEA produces susceptible results for measuring errors). There is the need to employ Stochastic Frontier Analysis (SFA) to estimate the efficiency of the telecommunication sector to ascertain the level of efficiency to aid operators and policy makers' decision in ECOWAS.

CHAPTER THREE

TELECOMMUNICATION SECTOR IN WEST AFRICA

3.0 Introduction

This chapter consists of two subsections. The first subsection highlights a brief background on the West African Telecommunication Regulators Association (WATRA). It elaborates on telecommunication sector interventions and supports from the World Bank and the International Telecommunication Union (ITU). The second subsection provides a brief background of the nine ECOWAS countries selected for this study (Benin, Burkina Faso, Côte D'Ivoire, Cape Verde, Ghana, Mali, Nigeria, Senegal, and Togo) in respect to the countries demographic-economic indicators, telecommunication sector history, and telecommunication sector statistics.

3.1 The West African Telecommunications Regulators Association

West African Telecommunication Regulators Association (WATRA) was established in November 2004 by the ECOWAS Member States and Mauritania. Its membership includes 15 independent NRAs and departments to regulate telecommunications services. WATRA's formation was to address sub-regional telecommunications industry challenges, develop a harmonized regulatory identity to increase investors' confidence and sector investments, and contribute to industry human resource and capacity building efforts (ITU, 2010)

WATRA aims to coordinate dialogue on telecommunications policy and regulations in the region. The objectives of WATRA include the following: promote the establishment and operation of efficiency, encourages the establishment of modern legal and regulatory structures for telecommunications service delivery in all States in the sub-region, adequate and cost-effective telecommunications networks and services in the West African sub-region, collaborate and co-operate with the International Telecommunications Union (ITU) towards the attainment of its agenda for global telecommunications development, among others (Kessides et al. 2007).

3.2 World Bank Support

In the 1990s, the Bank shifted its ICT strategy from support to large infrastructure projects to smaller technical assistance (TA) lending interventions. The technical assistance focused on building enabling sector environments to mobilize private investments, using competition as the primary policy tool to improve efficiency and innovation while facilitating regulatory capacity development (Kessides et al. 2009).

Furthermore, the World Bank developed a $300 million West Africa Regional Communications Infrastructure Program (WARCIP) to expand the geographical reach of broadband networks and reduce communications costs within the region (World Bank 2010). The WARCIP funding support has three components: 1. Supporting connectivity: a. International connectivity - facilitating membership to the Africa Coast-to- Europe Cable Consortium; b. Regional/national connectivity leveraging alternative infrastructure; 2. Creating an enabling environment for connectivity; and, 3. Project implementation support (Project Information Document (PID) Concept Stage 2011).

3.3 International Telecommunication Union Support

By 2003 regulatory reforms within ECOWAS contributed to accelerated sector progress and penetration rates for mobile communications. The International Telecommunication Union (ITU) directly assisted governments, conducted studies, provided training tools, organized workshops, and forums, and sponsored regional and sub-regional organizations. Interventions were based on implementing the ITU's Telecommunications Development Bureau operational plan and focused on accelerating the creation of an environment to facilitate the rapid extension of access to Information Communication Technology. The ITU contributed to improvements in frequency and numbering management and interconnection, which was a source of conflict amongst operators (ITU, 2003).

Between 2004 and 2007, the ITU collaborating with the EU, implemented the West African Common Market Project to harmonize policies governing ICT markets within ECOWAS. In 2009 WATRA identified access to submarine cables as a pressing priority of its members and requested the assistance of the ITU in developing guidelines and regulations for access to submarine cables (International Telecommunication Union (ITU, 2012)

3.4 ECOWAS COUNTRIES PROFILE

3.4.1 BENIN

The economy of Benin remains underdeveloped depends on subsistence agriculture, cotton production, and regional trade. Benin has GNI (PPP) per capita income of US$ 1,726, life expectancy at birth of 59.3, Human Development Index (HDI) of 0.476, and 5.3 Foreign Direct Investment in 2005-2012 as a percent of GDP (UNDP, 2013).

In 2000, the mobile sector liberalized, and currently, there are five mobile operators, namely, MTN. MOOV, Bell Benin Communications, Libercom, and Glo Mobile.

Benin has mobile cellular telephone subscriptions of 9.63 million (ITU, 2013), 83.7 mobile cellulars per 100 inhabitants, 99 percent of Benin's population covered by mobile service. Even though there is a law on the liberalization of the telecom sector, the fixed telephony market segment remains a public monopoly, with Benin Telecom SA being the only service provider. In terms of fixed-line teledensity, 1.6 percent (The World Bank. 2014).

There are eight internet access providers in the Internet market segment to respond to the market demand; Benin Telecom SA, Isocel Telecom, Connectoe Benin Pharaon Service Plus, Communitec, OTI, Firstnet, and Campus Numberique Francophone (Chabossou, 2010). Internet users as a percent of the population are 3.8, and fixed-line broadband per 100 inhabitants of 0.1 (UNDP, 2013)

Table 1: Demographic Data for nine ECOWAS Countries

Country	*Population (million)*	*Life Expectancy At Birth 2013*	*GNI/Capita PPP 2011 (USD)*	*HDI (2013)*	*FDI (% GDP 2012)*
Benin	9.0	59.3	1,726	0.476	1.6
Burkina Faso	17.0	56.3	1,602	0.388	0.1
Cote D'Ivoire	20.0	50.7	2,772	0.452	1.4
Cape Verde	0.51	75.1	6,365	0.636	2.8
Ghana	25.0	61.1	3,532	0.573	8.1
Mali	16.0	57.2	2,523	0.462	1.7
Nigeria	162.0	52.5	5,353	0.504	3.6
Senegal	13.0	63.5	2,169	0.485	2.0
Togo	6.0	56.6	1,129	0.473	1.5

Source: UNDP Human Development Index 2013 Database.

3.4.2 BURKINA FASO

Burkina Faso is a landlocked country and located in the middle of West Africa. It has 274,200 square kilometers with a population of 18.3 million people. According to UNDP HDI 2013 Database, Burkina Faso has a life expectancy at birth of 56.3, GNI (PPP) per capita of US$ 1,602, Human Development Index (HDI) of 0.388, FDI net inflow of 0.1 percent of GDP, and expenditure on education in 2005-2012 was 3.4 as a percent of GDP.

In the telecommunication sector, Burkina Faso has a fixed-line and mobile penetration of 0.9 percent and 60.6 percent, respectively. Internet users and fixed broadband penetration of 3.7 percent and 0.1 percent, respectively (The World Bank, 2014).

The telecoms sector of Burkina Faso has an independent regulatory Authority of Electronic Communication and Ports and ICT agency that supervised the ICT project of the Government. Over the past two decades, the sector reforms have improved and have created a relatively competitive environment for telecommunication services. The mobile sector liberalized in 2000, and the incumbent operator Onatel privatized in 2006, and a majority stake of 51 percent offset to Marco Telecom of Marocco (Kesses et al. 2007).

Currently, there are three mobile telecom operators; Airtel Burkina, Onatel (Telmob), and Moov. Mobile access is relatively high, with 86% of households owning a portable telephone, mobile cellular subscribers per 100 inhabitants 0f 93.5, active mobile broadband per 100 inhabitants of 28.8, and 3G coverage of 32.0%. Burkina Faso has a mobile subscription of 11.2 million (ITU, 2017).

Table 2: Telecom Performance Indicators for ECOWAS

Country	*Fixed Line (per 100 people)*	*Mobile Users (% 100 pop.)*	*Internet Users (% 0f Pop.)*	*Fixed-Broad Band (per100 people)*	*Telecom Revenue (% of GDP)*	*Population Covered by mobile*
Benin	1.6	83.7	3.8	0.1	6.3	99
Burkina Faso	0.9	60.6	3.7	0.1	N/A	N/A
Cape Verde	14.2	86.0	34.7		7.9	96
Cote d'Ivoire	1.4	91.2	2.4	0.1	7.0	95
Ghana	1.1	101.0	17.1	0.1	2.4	87
Mali	0.8	98.4	2.2	0.0	6.3	N/A
Nigeria	0.2	66.8	32.9	0.0	2.6	96
Senegal	2.5	83.6	19.2	0.7	9.8	91
Togo	0.9	49.9	4.0	0.1	9.2	91

Source: The Little Databook on ICT, The World Bank, 2014

3.4.3 CAPE VERDE

Cape Verde is Small Island Developing State located off the West African Coast in the Central Atlantic Ocean. The economy of Cape Verde is service-oriented, with transport, commerce, tourism, and public service representing the majority share of the country's GDP.

From table 1, Cape Verde's life expectancy at birth (2013) is 75.1, GNI per Capita of 6.363 US$, HDI figure of 0.636, and 5.6 % of GDP expenditure on education.

Cape Verde's telecommunication sector policy and regulation formally started after independence in 1975. From table 2, Cape Verde's fixed-line (per 100 people) is 14.2, mobile users (percent of 100 people) of 86.0%.

3.4.4 COTE D'IVOIRE

Cote d'Ivoire depend on agriculture and related activities, which engage roughly two-thirds of the population. Cote d'Ivoire is the world's largest producer and exporter of cocoa beans and a significant producer and exporter of coffee and palm oil. The country also produces oil (Index Mundi, 2014). The country's GNI (PPP) per capita income of US$ 2,774 and 0.452 Human Development Index (HDI). Cote D'Ivoire's expenditure on education as a percentage of GDP for 2005-2012 was 4.6 and foreign direct investment net inflow 1.4 percent of GDP. The country's GDP (PPP) as established in 2013 was US$ 43.67 billion (UNDP HDI 2013 Database)

The telecommunication sector in Cote D'Ivoire has undergone restructuring and liberalization that began in 1991. The sector has experienced rapid growth since granting the first Global System for Mobile Communication (GSM) license. The telecom sector has recently introduced new regulations, injection of new investments, and market maturation that has paced way to strengthen the sector for growth.

According to data from the Group of ICT Sector Operators, the telecom sector in Cote D'Ivoire accounted for the majority share of the 8% GDP contribution from the ICT sector. Although the telecom sector consisted of six operators in 2016, three operators dominate the market, namely, France-based Orange, South African Firm MTN, and MOOV. These operators combined accounted for 95.8% mobile subscribers and 96.7% of mobile telecom revenue in 2015 (ARTCI, 2018).

According to figures from the telecommunication/ICT Regulation Authority of Cote D'Ivoire (ARTCI), the total revenue of the mobile segment was CFA 872 billion, and the total investment was CFA 251.4 billion in 2016. Mobile subscriptions grew from 4 million subscriptions in 2006 to over 32.2 million in 2017, while mobile internet subscriptions reached a total of 16.9 million in

2017, representing 14% penetration. Furthermore, by 2014, mobile money registered accounts grew by 33% from 2 million and raised to 8 million in 2017.

The telecommunication Decree underpins the telecommunication sector legal framework number 14 of 1997, which was enacted to provide for the formation of an independent regulator. Decree No. 98-86 passed in February 1998, defining the functions of the independent regulator. The laws established the Agence des Telecommunications de Cote d’Ivoire (ATCT) as the independent regulator and the Conseil de Telecommunication de Cote d’Ivoire (CTCI) as the highest telecommunication authority responsible for arbitration (Kessides et al 2007).

3.4.5 GHANA

Ghana's telecommunication sector was driven by two policies: The National Telecom Policy (NTP) and the ICT for Accelerated Development (ICT4AD). In terms of the institutional framework, the Ministry of Communication and the National Communication Authority are the two institutions responsible for the telecom policy formulation and regulations (Ministry of communication, 2003).

The market structure of Ghana’s telecommunication sector is based on the open market and competition principles. The presence of competition in the market has resulted in rapid growth in the country's subscriber base, reduced tariffs, comprehensive network coverage, and high quality of services, along with the creation of employment opportunities.

The mobile telephone operators are MTN Ghana, Vodafone Ghana, AirtelTigo, and Glo mobile. The fixed network operators are Vodafone Ghana and Airtel, and MTN. The fixed-line telephone segment is almost a monopolistic market since Vodafone controls 97% percent of the market share, AirtelTigo market share of 2.08%, and MTN with the most negligible market share 0.48% (NCA, 2020).

National Communication Authority data, Ghana has a mobile voice subscription of 40.4 million (130.85% penetration rate), a total fixed telephony subscription of 307, 668 and a total data subscription of 26.5 million (85.99% penetration rate) in 2020. MTN Ghana has consistently been the market leader for both data voice subscriptions. The voice and data market share of MTN is 57.20% and 72.33%, respectively. Vodafone 20.7% voice market share and 11.54% data market share. AirtelTigo has 20.11% for voice and 14.83 data market share, and Glo Mobile has the least 1.93% and 1.29% voice and data market share, respectively, according to NCA 2020 figures.

According to the Bank of Ghana's statistics, Ghana's mobile interoperability recorded a total volume of over 1.12 million transactions representing the value of GHS 95.88 million in 2019. Three out of the four mobile operators currently offer mobile money services (MTN, Vodafone, and AirtelTigo). Cumulatively, Ghana registered mobile money accounts was 29.5 million in the first quarter of 2019. During the same period, the total volume of mobile money transactions was 436,723,487, with a total value of transactions of GHS 66.4 million (BoG, 2020).

3.4.6 MALI

Mali is a landlocked country and located southwest of Algeria, occupying about 1.2 million square kilometers in West Africa. Mali is a low-income economy with a fledging market-based economy dominated by subsistence farming and herding (Kessides et al., 2007).

The Ministry of telecommunication is the government body responsible for the telecoms sector. The Telecommunication Regulatory Committee was established in 1999 as the autonomous regulatory body. The International Monetary Fund (IMF) has helped make the telecoms sector liberalized and open up competition (Kessides et al., 2007).

ITU's statistics show that Mali's mobile-cellular telephone subscription was 19.7 million and mobile-cellular per 100 inhabitants of 129.07 (ITU, 2013). Internet user penetration rate is 2.2 and fixed-line per 100 inhabitants of 0.8 percent (The World Bank, 2014). Currently, there are two mobile and fixed-line service operators; the national telco Sotema and its mobile subsidiary Malitel privatized in 2009, and Orange (France Telecoms the second mobile and fixed-line operators in 2003)

3.4.7 NIGERIA

Nigeria is a Western African country bordering the Gulf of Guinea and between Benin and Cameroon. Nigeria occupies a total land space of 923,768 square kilometers. Following the 2014 statistical rebasing exercise, Nigeria has emerged as Africa's largest economy with a 2014 GDP estimated to US$ 479 billion. Oil has been the Government's dominant source of revenue since the 1970s. The real GDP growth rate in 2014 was 7 percent. GDP per capita (PPP) in 2014 was US$ 6,100. The Agriculture, industry, and services sectors contributed 20.6%, 25.6%, and 53.8% respectively in 2014 (The World Factbook, 2015)

Nigeria's telecommunication industry restructured in 1992 with a communication Decree promulgation, which led to establishing the Nigeria Communication Commission (NCC) as the sector regulator (Kessides et al., 2007). The commission aims to promote healthy competition among the telecom service operators and ensure efficient and quality telecom services in Nigeria.

The NCC regulatory checks and balances, deployment of massive network infrastructure, and affordability of GSM lines have led to the growth in the number of active lines from 400,000 in 2001 to 184.4 million in 2019 (AFRINVEST, 2020).

Nigeria's telecommunications sector has been recognized as the fasters growing telecommunication sector in Africa after South Africa. The industry is mainly an oligopolistic market dominated by active players, namely; MTNN, Globacom, Airtel, and 9Mobile. MTNN is the market leader, ranking highest with a share of 37.2% and 42.9% of total voice and data subscribers, followed by Globacom, with 28.0% and 22.9% of total voice and data subscribers, respectively. Airtel Africa accounts for 27.2% and 27.4% of total voice and data subscribers. 9Mobile has the least 7.4% and 6.4% total voice and data subscribers. (NCC, 2020).

The Nigeria Communication Commission estimated that total investment in the telecom industry had reached US$ 70 billion in 2019. National Bureau of Statistics data on GDP showed the telecom sector contributed about 7.4 trillion Naira in 2019, representing an 11.4% year-on-year growth.

3.4.8 SENEGAL

Senegal is primarily a rural country with limited natural resources located on the westernmost point of Western Africa's Sahel region. Its key export industries are commercial, fishing, phosphate, mining, and fertilizer production (Raul et al., 2012). The total land space is 196,722 square km, and the country has 14 regions, 370 rural communities, and 14,400 villages. According to World Bank data in 2015, Senegal has a population estimated at over 16 million.

The telecommunication sector has proliferated during the last decades in Senegal, primarily owing to the adoption of mobile telephony, a drastic increase in wireless subscribership, and an increase in fixed lines since 2008. Senegal has the highest levels of mobile access in Sub-Saharan Africa.

About 93% of households had a portable telephone in 2015. According to International Telecommunication Union figures in 2017, Senegal's mobile cellular subscription per 100 inhabitants was 99.4, individuals with the internet as 29.6%, and fixed telephone subscription per 100 inhabitants of 1.8 in 2017 (ITU,2017).

There are three mobile network operators in Senegal, namely the incumbent SONATEL offering service under the Orange brand, TIGO, a subsidiary of Millicom, which has been in the country since 1999, and EXPRESSO, a subsidiary of SUDATEL, which launched an operation in 2009 (ITU, 2017). The three mobile operators in the country covered 86% of the Senegal population. Orange Sonatel tops the telecom market share with 56.5%, TIGO market share as 22.8%, and 20.6% market share for EXPRESSO (GSMA, 2014).

The Ministry of Post and Telecommunication is in charge of ICT policy and strategy in Senegal. The Telecommunication and Post Regulatory Authority was created in 2001 as the telecom sector regulator.

3.4.9 TOGO

Until 1986, telecommunication activities in Togo were the responsibility of a directorate of the Ministry in charge of posts and telecommunications. From 1986 to 1990, those activities entrusted to the Office des Postes et Télécommunications du Togo (OPTT), which in 1991 transformed into a State-owned company governed by the rules of management applicable to private companies. In 1996, the Government adopted a sectoral policy statement that opened the way for reforming the sector—resulted in the splitting of OPTT into two State-owned companies, one responsible for posts (the Société des Postes du Togo (SPT)) and the other for telecommunications (the Société des Télécommunications du Togo (Togo Telecom)). Within the framework of this reform, Togolese Act No. 98-005 of 11 February 1998 on Telecommunications enacted, liberalizing the sector. The Act defines the responsibilities of the Minister responsible for telecommunications as well as those of the Regulatory Authority for the Postal and Telecommunication Sectors (Autorité de réglementation des secteurs de postes et de télécommunications) (ARP&T) established. At the same time, it introduced a licensing regime setting out requirements for telecommunication services and established arrangements in respect of interconnection.

Two decrees immediately followed the 1998 Act: Decree No. 98-034 of February 1998 on the organization and functioning of the Regulatory Authority for the Postal and Telecommunication Sectors, and Decree No. 98-089 of 16 September 1998 on the interconnection of telecommunication networks. It was these texts which together opened up the sector to competition. The Regulatory Authority for the Postal and Telecommunication Sectors established by the 1998 Act, which is essential to establish a legal and regulatory framework that ensures the free play of competition and development of the telecommunication sector under the best possible conditions, has been operational since January 2000. At that time, the national telecommunication landscape comprised one fixed telephony operator, two mobile telephony operators (one of which, Togo Cellulaire, is a subsidiary of the incumbent operator), an operator specialized in providing Internet access and various ISPs.

CHAPTER FOUR

METHODOLOGY

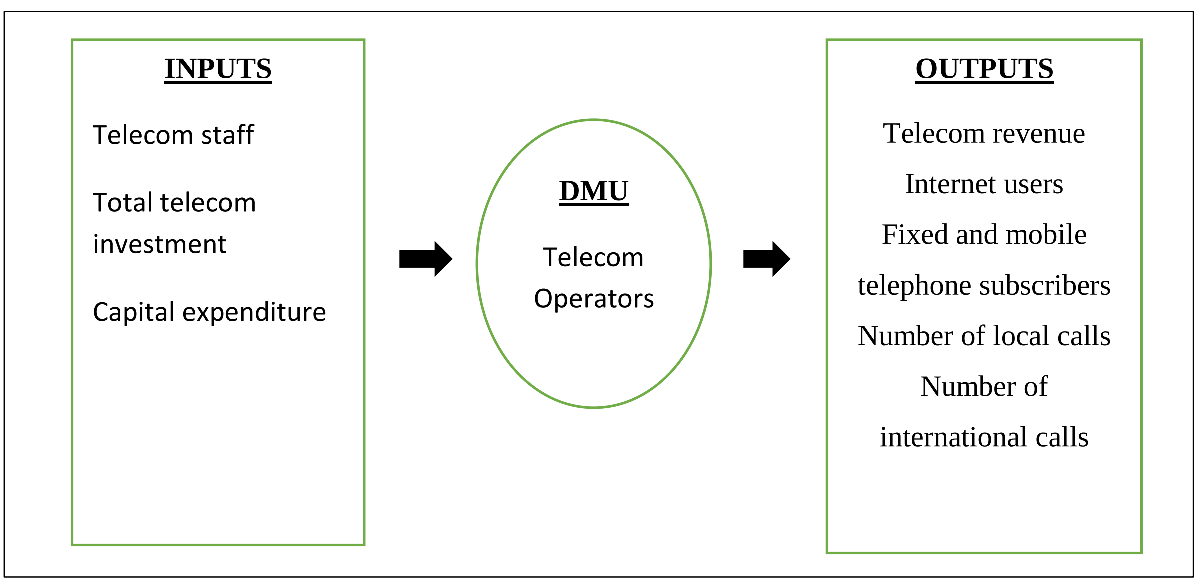
4.0 Introduction

This chapter presents details about the theoretical and conceptual framework upon which this study grounded. It also presents details about selecting appropriate inputs and outputs variables and the data source and variable description in the study. The section continues to specify the stochastic frontier and inefficiency model for this study. Finally, the statement of hypothesis tests the robustness of the model employed.

4.1 Conceptual Framework

Production is the process of converting our limited resources into goods and services using the available technology (Parkin et al., 2003). Production is creating goods and services from the existing resources to satisfy human wants directly or for further production.

Figure 4.1: Conceptual framework



Sources: Author's Constructions

In order words, it shows how resources transformed into goods and services beneficial to humankind. An economic resource used production of a particular good is called input and can be physical or mental (Mansfield, 1975).

In the production process, telecommunication service operators turn inputs (factors of production). The input is divided into broad categories of labor, material, and capital, of which each often includes a narrower sub-division. Labour inputs are telecommunication sector full and part-time employees. Capital often includes total investment, capital investments, optic cables, and base stations.

The choices of output variables for telecom sector efficiency measurement are underpinned by policy-makers views and telecom operator's views. These are some of the output variables employed in the literature; revenue, operating profits, average revenue per user, number of subscriptions, number of international and local calls, market penetrations, internet user rates. Therefore, it is clear that telecom service operators employ multiple inputs and outputs to produce multiple outputs.

4.2 Data Sources and Variable Description

The data used in this analysis consist of nine West African countries: Benin, Burkina Faso, Cape Verde, Cote D'Ivoire, Ghana, Mali, Nigeria, Senegal, and Togo, for the period from 1994 – 2013. Regional and country-level statistics studies of the telecommunication sector in Sub-Saharan Africa tend challenges by lack of microdata as institutions responsible for the sector do not always collect information frequently and consistently. This avoidable situation significantly impacted the complexity of the data mining phase for the research, hence our reliance on only nine countries.

Data collection was from three different sources; the ITU, the United Nations (UN) and the African Telecommunication Union (ATU), World Development Indicators of the World Bank. The International Telecommunication Union provides complete statistical data collected over the years for the telecommunication sector for all countries. The United Nation's database regularly includes data on social and economic indices for a broad set of categories for all countries. The third source, ATU, provides analytic articles and political orientations about telecommunications in the African continent.

4.2.1 Output Variables

The outputs variable consists of two variables: number of mobile subscriptions and telecom sector revenue.

REVEFF: Total revenue in the telecommunication industry was used to measure the sector productivity, including earnings from direct telecommunication services to the public. This indicator has been adopted as the primary output in most studies (see Giokas et al. 2008, Lien & Peng, 2001, Lam & Shiu, 2011, Moshi et al., 2013). The revenue data are express in Million US dollars and at constant (2000) prices to account for inflation.

SUBEFF refers to the subscription to public mobile telephone service (both post-paid and prepaid). Mobile communications have become increasingly popular in recent years. The number of mobile phone subscribers in many countries has exceeded that of fixed-line subscribers (Lam & Shiu, 2010).

4.2.2 Input Variables

STAFEFF: Total number of staff employed by mobile telecommunication network operators for each country. This refers to mobile operators' employees only and not employees employed by resellers.

INVESTEFF: Telecommunication sector investment is used as a proxy for capital. The number of mobile phone subscribers in many countries has exceeded that of fixed-line subscribers. Since most of the new investment in the telecommunication sector is developing the mobile network, the input variables of capital expenditure can serve as a proxy for capital input used in providing mobile services (Lam & Shiu, 2010).

4.3 Theoretical Framework for Stochastic Production Frontier Model

Computing efficiency measure involves estimating a production frontier for the telecommunication sector whose output specified as a function of non-negative random error (u), which shows technical inefficiency and symmetric error (v), noise. Following Aigner, Lovel & Schmidt (1977), Meeusen & Van den Broek (1977), and Symeou (2011), the primary production function is defined as

$$lnY_{it} = X_{it}\beta + V_{it} - \mu_{it}$$

Y_i is the observed output produced by the i-th operator, t is the period, and where $\exp(X_{it}\beta + V_{it})$ is the stochastic variables that determine the most efficiently produced output set and bounds from above the observed output sets of the telecommunications sector. Each $V_i$is assumed to be distributed independently of each μ_i, and both are uncorrelated with the explanatory variables of

X_i. The noise component is assumed to have identical properties to those of the noise component in the classical linear regression model. Specifying the noise term in the model allows for random shocks around the frontier (Kumbhakar & Lovel, 2000 and Symeou, 2011). It also provides superior statistical inferences to other non-parametric frontier analyses which do not (Milners & Weyman-Jones, 2003 and Symeou, 2011)

The main reason for adopting stochastic frontier model than other models is because of its ability to decompose the disturbance term ei into two components; random error, accounting for the deviation owing to factors outside the operator's control of the telecom operators, and the error term accounting for deviation due to inefficiency effect ei factors within the control of the telecom service operators.

4.4 Empirical Model Specification

For any empirical study, the choice of a functional form is vital because the chosen functional form can significantly influence the parameter estimates. Generally, two functional forms of the stochastic frontier model often employed for efficiency measurement in the telecommunication sector include; the Cobb-Douglas and the Translog functional forms. The Cobb-Douglas functional form is easy to implement; however, it imposes a severe restriction on the production elasticities to be constant and the elasticities of input substitution to be equal to one. Other studies that adopted the translog functional form also include Symeou (2011), Daigyo et al. (2011), Uri (2013). The translog functional form is less restrictive, allowing for the combination of squared and cross-product terms of the explanatory variables with the view of obtaining the goodness of fit of the model.

This study adopts the theoretical framework employed by Erber (2010). Following Shepard (1970), Lovell et al. (1994), Coelli and Perelman (2000), stochastic production frontier-based multiple-output distance function specified in Cobb-Douglas functional form.

An output distance function is employed to measure the production frontier. The main advantage of the distance function approach is that it allows for a multiple- input and multiple output technology without requiring price data, which is typically a constraint in working telecommunication industry data. This study will follow Coelli and Perelman (2000) in employing distance functions techniques to estimate the telecommunications sector's multiple-output production technology. An output distance function defined on the output set as $P(x_t)$ as

$$d_t{}^0(x_t, y_t) = min\left\{\delta : \left(\frac{y_t}{\delta}\right) \in p(x_t)\right\} \quad (1)$$

X_t is a vector of inputs; $y_t$is a vector of outputs, and δ is a distance measure. The output distance function is non-decreasing, positively linearly homogeneous, and convex in y_t and decreasing in x_t. For some telecommunications sector *i* defined over *J* outputs and *L* inputs, it takes the form $d_i^0 = d^0(x_{1i}, x_{2i,}, \dots x_{li}, y_{1i}, y_{2i,} \dots, y_{ji})$, where x_{li} is the lth input of sector *i*; y_{ji} is the $jth\ output$. Furthermore, $d_i^0 \leq 1$ is the minimum amount by which the production of all output quantities increased, remaining within the feasible production possibility set for the given input. If y belongs to the "frontier" of the production possibility set, then $d^0(x, y) = 1$.

A Cobb-Douglas functional form for distance function specified following Lovell et al. (1994), Coelli and Perelman (2000), and Erber (2010) since it is flexible, easy to calculate, and permits the imposition of homogeneity. The multiple output distance function is specified in Cobb-Douglas functional form and given by:

$ln\left(\frac{D_{0i}}{y_{ii}}\right) = \alpha_0 + \sum_{j=1}^{j-1} \alpha_j \, lny_{ij}^* + \sum_{l=1}^{l} \beta_l \, lnx_{il} \; + \frac{1}{2}\sum_{j=1}^{j-1}\sum_{k-1}^{j-1} \alpha_{jk} \, lny_{ij}^* lny_{ik}^* +$

$\frac{1}{2}\sum_{l=1}^{L}\sum_{m=1}^{L} \beta_{lm} \, lnx_{il} lnx_{im} + \sum_{j=1}^{J-1}\sum_{l=1}^{L} \delta_{jl} \, lny_{ij}^* lnx_{il} \qquad where \;\; y_{ij}^* = \frac{y_{ij}}{y_{iJ}}, \; i = 1,2, \dots, I \quad (2)$

Equation (2) rewritten in the following functional form;

$-\ln(y_{ij}) = TL(y^*, x, \alpha, \beta) - \ln(D_{0i}) \quad (3)$

Appending the noise term with v_i and the notation lnD_{oi} is changed to $-u_i$. The transformation yields the stochastic frontier function associated with the time trend is express as follows:

$$-ln(Y_{it}) = \alpha_0 + \alpha_T t + \sum_{j=1}^{J-1} \alpha_j \, lny_{ijt}^* + \sum_{l=1}^{L} \beta_l \, lnx_{ilt} + \frac{1}{2}\alpha_{TT}t^2 + \frac{1}{2}\sum_{j=1}^{j-1}\sum_{k=1}^{j-1} \alpha_{jk} \, lny_{ijt}^* lny_{ikt}^*$$

$$+ \frac{1}{2}\sum_{l=1}^{L}\sum_{m=1}^{L} \beta_{lm} \, lnx_{ilt} lnx_{imt} + \sum_{j=1}^{J-1} \alpha_{Tj} \, tlny_{ijt}^* + \sum_{l=1}^{L} \beta_{Tl} t \, lnx_{ilt}$$

$$+ \sum_{j=1}^{J-1}\sum_{l=1}^{L} \delta_{ji} lny_{ijt}^* \, lnx_{ilt} + v_{it} + u_{it} \qquad (4)$$

Where $t = 1,2, \dots, T$ is a time trend, Y_{it} and $y_{ijt}^*$are the output and arbitrarily normalized output for firm i, respectively. Subscripts j, k, index outputs; α, β, δ are vectors of unknown parameters to be estimated; x variables are inputs. Subscript l, m index inputs; v_{it}'s are the error components and are assumed independently and identically distributed as $N(O.\sigma_V^2)$. Following Kumbhakar, Ghosh, and McGuckin (1991), the u_{it} account for technical inefficiency.

Telecommunication revenue is choosing as the output measure used to normalize all other outputs. The study, therefore, specifies the variable for a country I used in equation 4 as follows;

Y_{it} : Telecommunication revenue (REVEFF),

y_{ikt}^{*} : SUBEFF (the number of mobile subscribers) divided by REVEFF

x_{ilt}: STAFEFF (number of staff),

x_{imt}: INVESTEFF (telecom sector investment)

Following Battese and Coelli (1992), the technical inefficiency error term is defined by

$$u_{it} = u_i exp[-\eta(t - T)], \quad i = 1,2, \ldots., I; t = 1,2, \ldots T \qquad (5)$$

Where u_{it} is assumed to be a non-negative truncation of the half-normal distribution $N(\mu.\sigma_{\mu}^{2})$ associated with technical inefficiency in production. u_i is the technical inefficiency effect for firm i for the last period of the sample; η is an unknown parameter to be estimated and represents the rate of change in technical inefficiency. Therefore, a positive value, $\eta > 0$, implies that the technical inefficiency effects decrease over time. One of the advantages of using the error term in equation (5) is that technical inefficiency changes over time, separated from technical change.

The choice of distributional specification concerning the Ui is sometimes a matter of computational convenience. Frontier 4.1 has an inbuilt statistical package used to estimate half-normal and truncated-normal models. LIMDEP can estimate half normal, truncated normal and exponential models. Theoretical considerations may also affect the choice of distributional specification. The half-normal and exponential distribution assumes that most inefficiency effects are close to zero, with associated technical efficiency approaching one. The truncated normal and gamma models allow for a broader range of distributional shapes but, there is a cost of computational complexity because there are more parameters to estimate, and the distributional probability functions for the ui's and vi's may have similar shapes, which can make it challenging to distinguish inefficiency effects random noise (Coelli et al., 2005).

In deriving u from the composed error, the study employed the formula according to Murillo (2004).

$$E\left[\frac{\mu_i}{\varepsilon_i}\right] = \frac{\sigma\lambda}{1+\lambda^2}\left[\frac{fs(\varepsilon_i\lambda/\sigma)}{fc(-\varepsilon_i\lambda/\sigma)} - \frac{\varepsilon_i\lambda}{\sigma}\right] \ldots\ldots\ldots\ldots\ldots\ldots .5a$$

Where $fs(\cdot)$ is the density of the standard normal distribution and $fc(\cdot)$ is the cumulative density function (Murillo-Zamorano 2004). The maximum likelihood estimation will be used likewise in most research works involving technical efficiency. The assumption that the model is half normal means that all efficiency scores are positive. The restrictions imposed on the model produces various interesting results such as the value of $\sigma = (\sigma_\mu^2 + \sigma_v^2)^{1/2}$; $\lambda = {}^{\sigma_\mu}/_{\sigma_v}$ and $\gamma = \frac{\sigma_\mu^2}{(\sigma_\mu^2+\sigma_v^2)}$

Where $\sigma =$ total variation, σ_μ^2= variation due to inefficiency, σ_v^2= variation due to noise

Lambda (λ) is the standard deviation of the inefficiency component to that of the noise component. How high the value of lambda (λ) is; determines how strong the evidence of the presence of inefficiency in the data. Gamma (γ) specifies the variation ratio due to inefficiency to the total variation. With parametric restrictions between 0 and 1, a high gamma (γ) also depicts the explanatory power of inefficiency in total variation (Daigyo et al., 2011). A log-likelihood ratio test was conducted to verify whether the estimation frontier model is robust. This test shows the significance or otherwise of the inefficiency component.

Following Coelli et al. (1998) and given the estimates for equations (4) & (5), the technical efficiencies of production for each firm in the tth year predicted as;

$$TE_{it} = E[(-u_{it})|(v_{it} - u_{it})] \qquad (6)$$

Therefore, the technical efficiency changes between adjacent periods t and s calculated as:

$$EC_{it} = \frac{TE_{it}}{TE_{is}} \qquad (7)$$

4.5 Statement of Hypothesis

There are two hypotheses to be tested with the log-likelihood ratio (LR) test under the null and alternative hypotheses. The LR test statistic is calculated by $-2\ X\ [L(H_O) - L(H_A)]$, where $L(H_O)$ and $L(H_A)$ is the log-likelihood value under the null and alternative hypotheses.

1. Ho: $\alpha_{jk} = \beta_{lm} = 0$, The coefficients of the second-order variables in the translog model are zero implies that the Cobb-Douglas function is the best fit for the model.
2. Ho: $\mu = 0$; the null hypothesis specifies that technical inefficiency has a half-normal distribution.

The null hypothesis is rejected from the above statement of hypothesis if $LR > \chi^2_L$. LR would have approximately a Chi-square distribution if the given null hypothesis confirmed with a degree of freedom equal to the number of parameters assumed to be zero in Ho. When any of the parameters assume a mixed Chi-square distribution, the test's critical values would be obtained from Kodde & Palm (1986).

4.6 Econometric and Statistical Tests

The t-test and likelihood ratio were used to test the statistical significance of the independent variables in equations 4 and 10 at 5% and 1% levels. Provides enough grounds for the acceptance or rejection of country-level and environmental variables as determinants of telecoms sector output and technical efficiency of the telecoms sector.

CHAPTER FIVE

DATA ANALYSIS AND DISCUSSION OF RESULTS

5.0 Introduction

The chapter presents the results obtained from the analysis and the discussion of the result. The results obtained was shown in tables. The chapter consists of descriptive of the variable used in the study, analysis on production function form for the survey, log-likelihood test, and estimate of the stochastic frontier analysis model. The chapter then analyzed and answered the three objectives and questions of this study, including assessing technical efficiency in the telecom sector, the evolution of the technical efficiency levels of the telecommunication sector among the ECOWAS countries, and the determinants of technical efficiency of the telecommunication sector in West Africa.

5.1 Selecting Appropriate Input and Output Variables

Selecting the required inputs and outputs variables constitute the significant task of evaluating the performance of the telecommunication sector. The type of variables depends on choosing the methodology and technical requirement of the desired data and data availability and its quality. Selecting variables was based on the study of available literature to sort out the right indicators from a potential group of parameters suggested in the survey by Resende (2008).

In selecting output variables, two significant views have governed the choice of output variables in studies investigating technical efficiency and productivity growth in the telecommunication sector Giokas et al. (2008); Moshi et al. (2013). These views are the operators' views and policy-makers views. The operators' argument centers on the increase in sector revenue, which means increasing a firm's profits are essential to keep operators in ongoing profitable business Moshi et al. (2013). Studies such as Madden & Savage (1999), Sadjadi & Omrani (2010), Battiston, Campisi &Mancusos (2006), Lam et al. (2010), Yan & Price (2012) applied the operators view as their primary dependent variable. Policymakers regulate and monitor telecommunication providers' profitability and revenue. Policy-makers focus on the increasing penetration of various telecom services. Symeou (2011) and Wallsten (2001), employed policymakers to view variables as their main dependent variables.

However, studies such as Bollou et al. (2001), Giokas et al. (2010) combined both views as indicators of outputs. Additionally, studies, such as Madden et al. (1999), included in their model the quality aspect as an output variable. This study used the combined approach views in selecting the following output variables; the number of mobile telephone subscriptions and total telecommunication revenue.

5.2 Descriptive Statistics

The summary statistics of the variables employed in the computation of mean for technical efficiency shown in Table 5.1. From Table 5.1, we observed that the mean output level (Revenue in 100,000 USD) was 6429.654 USD for the past 20 years. The industries across the nine respective countries recorded a minimum revenue of 204.541 USD against a maximum revenue amount of 71069.800 USD, with a margin of deviation been 12911.82 USD.

Considering mobile subscriptions, the companies recorded approximately 6688 subscriptions with a margin of 17890 subscriptions. For the past 20 years, the annual investment of the telecommunications sector recorded an average investment value of 1917.95 USD with a margin of deviation been 4842.801.

Finally, considering the distribution of the employees in the telecommunication companies across the nine (9) countries, the summary statistics show an average of 3314 employees with a margin of deviation of 4012 employees.

Table 5.1 Descriptive Statistics

Variables	N	Mean	Std. Dev.	Min	Max
Revenue	180	6429.654	12911.82	204.54	71069.8
Mobile Subscriptions	180	6688.378	17890.99	0.02	127246.1
Investments	180	1917.95	4842.80	13.93	48468.3
Telecom Staff	180	3314.361	4012.778	0.40	15.79

5.2.1 Log Likelihood Test

As stated by most empirical literature, the most typical statistical test applied to using the Cobb-Douglas production form has been the log-likelihood test. Hence, the data subject to the log-likelihood test is to justify the appropriateness of using the Cobb-Douglas production form to estimate the parameter. After performing the Log-likelihood test, the summary of the outcome shown in Table 5.2.

Table 5.2 Log-Likelihood Ratio Test

Hypothesis	Log-likelihood Value	P-Value	**Level of Significance**	**Decision**
$H_0 : \beta_0 = \beta_1 = \beta_2 = \beta_3 = 0$	14.0841	0.000*	0.05	Reject the Null Hypothesis

**Significance flagged at 5% level of Significance*

Table 5.2 depicts the log-likelihood test explaining the Cobb-Douglas production functional form for the telecommunications model across the countries. The null hypothesis, Ho is a restriction that the frontier production function cannot be Cobb-Douglas form, hence, $H_0 : \beta_0 = \beta_1 = \beta_2 = \beta_3 = 0$ shows that all the parameters will be equal to zero if applied. From the test, at a 5% level of Significance, all the log-likelihood estimates from the stochastic frontier analysis of the countries' telecommunication companies fell outside this critical value. Hence, based on the justification by the log-likelihood test, enough evidence to say that the parameter estimates are significant given the respective probability value as significantly less than 5 percent (i.e., 0.0000). Therefore, we fail to accept the null hypothesis that the frontier production function is not Cobb-Douglas. Thus, we applied the Cobb-Douglas production form to estimate the variables from the observed data as stated in the study method.

5.2.2 Stochastic Frontier Analysis Results

The parameters of input coefficients and the associated variances obtained from the maximum likelihood estimation using the Cobb-Douglas stochastic frontier production model shown in Table 5.3. They indicate the magnitude of the parameters and their Significance in telecommunications' application of inputs during the period under consideration.

After estimating the model, at a 5% level of significance, the number of telecommunication subscriptions, telecommunication employees, and annual investment has a positive coefficient. These variables significantly affect telecommunication companies' revenue and technical efficiency across the nine countries. Besides, a negative value of the mean in the model signifies technical efficiency at this stage of the operations of telecommunication companies matters but not as significant at a 5% level of Significance. Hence, there was no technical inefficiency in the companies' operations across the countries under study.

Table 5.3 Summary from the SFA model Results.

Variables	Coefficients	Standard Error
Mobile Subscriptions	0.129*	0.016
Annual Investments	0.457*	0.045
Telecom Staff	0.455*	0.057
Constant	5.897*	0.711
Observations (N)	180	
Log-likelihood Value	-147.7649	
Sigma-Squared	0.303	0.073
Gamma Likelihood	0.003*	0.228
Sigma_u2	0.001	0.069
Sigma_v2	0.302	0.032
Ho: No inefficiency component: z = 1.044 P (z) = 0.852		

**significance flagged at 5% level of Significance*

Again, Gamma Likelihood is also a measure of the level of inefficiency in the variance parameter ranging between 0 and 1. From table 5.3, the gamma estimate was 0.003 implies about 0.3% of the random variation in revenue explained by the inefficiency of the telecommunications sector. Therefore, no inefficiency component in the fitted model. Also, using the time-varying model did not take a concave, making it appropriate for the data used for the study.

5.3 Technical efficiency level of the Telecommunication Industry in ECOWAS

To answer objective one, we estimate the telecommunication sectors' technical efficiency level across the countries. The production parameters obtained from the stochastic frontier Cob-Douglas production functional form are express as a fraction of the possible output levels of the companies under study.

We used parameters to predict the technical efficiency score for each revenue level using the conditional expectation of the equation as stated in the methods of this study. As noted in the methodology section, the technical efficiency score of the companies can have an efficiency between 0 and 1. Secondly, the maximum and minimum technical scores are estimated for the sectors in terms of their revenue levels. The mean technical efficiency score for the revenue by the telecommunications was then obtained and multiplied by 100 for conversion into percentage and shown in Table 5.4.

From Table 5.4, Benin recorded a minimum technical efficiency of 34.11% and the highest efficiency of 99.90%. Benin's telecommunication industry operates a 64.50% efficiency level during twenty years out of their total limit of 100% but above the overall mean of 61.73%.

However, the telecommunication companies in Benin still have 35.5% more effort to be put in place in their operations if they have to operate at the total capacity of 100%.

Table 5.4 Summary of Technical efficiency via exp (-E (u | e))

Country	Number of Years	Mean	Std. Dev.	Min	Max
Benin	20	64.48%	18.47%	34.11%	99.90%
Burkina Faso	20	69.21%	16.95%	50.66%	99.90%
Cape Verde	20	49.90%	20.66%	27.35%	99.90%
Cote D'Ivoire	20	60.90%	22.06%	17.90%	99.90%
Ghana	20	58.14%	29.62%	16.67%	99.90%
Mali	20	58.78%	23.51%	7.61%	99.90%
Nigeria	20	54.28%	23.15%	24.51%	99.90%
Senegal	20	72.03%	21.87%	37.73%	99.90%
Togo	20	67.86%	18.01%	31.87%	99.90%
Overall					
Overall Mean	180	61.73%	22.47%	7.61%	99.90%

Moreover, over the twenty years, Burkina Faso recorded a minimum technical efficiency of 50.66% and the highest efficiency, thus a maximum of 99.90%. Burkina Faso's telecommunication industry in Burkina Faso operates within a 69.21% efficiency level above the overall mean of

61.73% out of their total limit of 100%. The telecommunication sector in Burkina Faso still has 30.80% more effort to be put in place in their operations if they have to operate in the total capacity of 100%, with all things being equal.

Over the twenty years, Cape Verde recorded a minimum technical efficiency of 27.35% and the highest efficiency, thus a maximum of 99.90%. The telecommunication sector in Cape Verde operates a 49.90% efficiency level below the industry mean of 61.73% out of their total limit of 100%. The telecommunication sector in Cape Verde still has 50.10% more effort and resources to be put in place in their operations if they have to operate at the total capacity of 100%. Cape Verde is the most inefficient country in ECOWAS.

Cote D'Ivoire, also for the past 20 years under study, recorded a minimum technical efficiency of 17.90% and highest efficiency, thus a maximum of 99.90%. Over the twenty years, the telecommunication companies in Cote d'Ivoire operate within a 60.90% efficiency level out of their total limit of 100%. The telecommunication companies in Cote D'Ivoire still have 39.10% more effort and resources to be put in place in their operations if they have to operate at the total capacity of 100%.

Additionally, Ghana recorded the least technical efficiency to be 16.67%, and the highest efficiency level of 99.90%. Over the twenty years, the telecommunication sector in Ghana operates within 58.14% efficiency level out of their total limit of 100%. Meaning, the telecommunication companies in Ghana still have 41.90% more efforts and resources to be put in place in their operations if they have to operate in the total capacity of 100%, with other factors held constant or other things being equal.

Furthermore, Mali recorded the least technical efficiency to be 7.61%, and the highest efficiency level of 99%. Over the twenty years, the telecommunication sector in Mali operated a 54.78% efficiency level out of their total limit of 100%. Meaning, the telecommunication companies in Mali need 41.20% more effort and resources to be put in place in their operations if they have to operate at the total capacity of 100%.

Over the period under study, Nigeria recorded a minimum efficiency level of 24.51%, with the highest efficiency level being 99%. On average, Nigeria, for the past twenty years, recorded a 54.28% level of technical efficiency. Meaning, the telecommunication companies in Nigeria need 45.70% more effort and resources to be put in place in their operations if they have to operate in the total capacity of 100%, with other factors held constant.

Over the period under study, Senegal recorded a minimum efficiency level of 37.73%, with the highest efficiency level being 99.90%. On average, during the past twenty years, Senegal recorded a 72.03% level of technical efficiency way above the overall mean of 61.73&. Meaning, the telecommunication companies in Senegal need 28.0% more effort and resources to be put in place in their operations if they have to operate at the total capacity of 100%, with other factors held constant.

Over the period under study, Togo recorded a minimum efficiency level of 31.87%, with the highest efficiency level being 99.90%. On average, Togo, for the past 20 years, recorded a 67.86% level of technical efficiency above the overall mean of 61.73%. Meaning, the telecommunication companies in Togo need 32.10% more effort and resources to be put in place in their operations if they have to operate in the total capacity of 100% with other factors held constant or other things being equal.

In summary, it can be said from Table 5.4 that the mean technical efficiency score for the telecommunication companies ranges between about 7.61% and 99%, indicating the scores for the least and most technically efficient telecommunication companies across the nine countries, respectively. Specifically, the mean technical efficiency score for the companies 61.73% significant at a 5% level (one-tail test). Thus, the telecommunication companies within these countries understudy for the period under consideration operated at the efficiency level of 62%. The implication is that the firms' output was more than halfway from their frontier (potential output level) during the period under consideration. This result is similar to Moshi et al. (2010), Madden et al. (1999), Lam et al. 2010 and Symeou (2011). For the telecommunication industry to move close to their frontier, suitable organizational and market structures and skilled human capital are enablers of better use of available technology to improve efficiency.

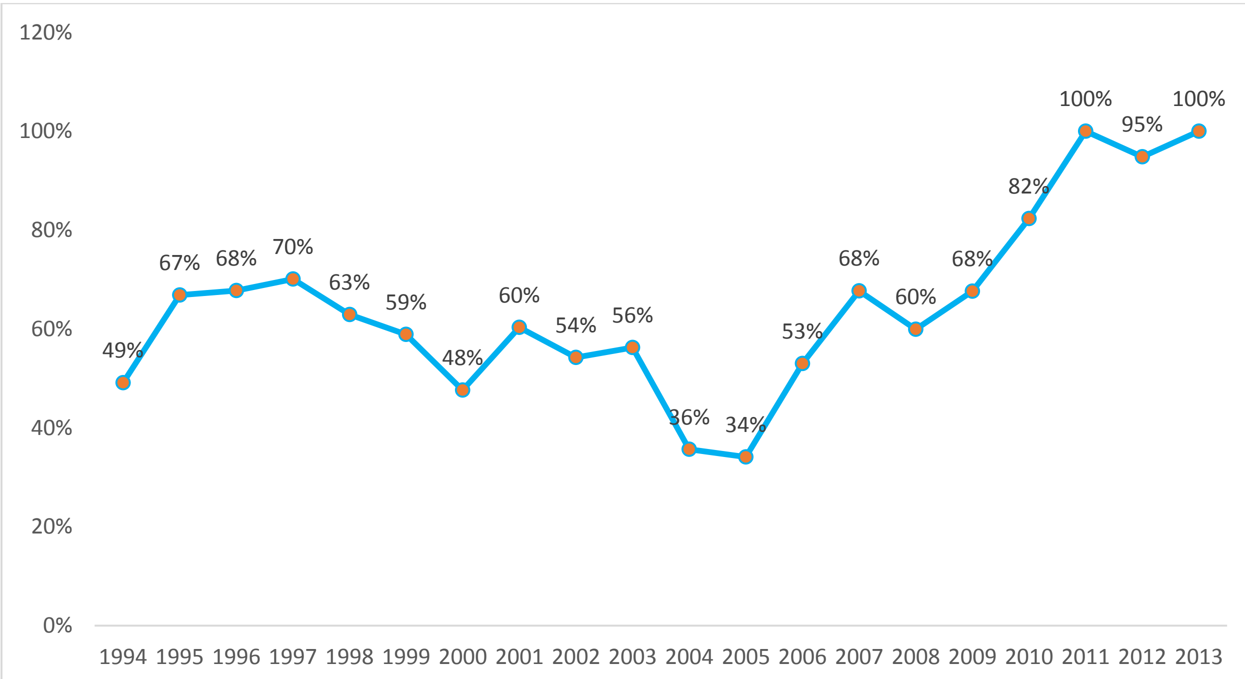
5.4 Evolution of Technical Efficiency level in ECOWAS.

The study sought to determine the evolution of technical efficiency for each country to explore the changes over the period under study. We plot a line graph for each country using the technical efficiency percentages against twenty years.

5.4.1 Benin’s Technical Efficiency Trend

Figure 5.1 gives the efficiency, technological progress, and productivity of the telecommunication operators from 1994 to 2013 in Benin. From the figure, the technical efficiencies of the telecommunication sector operators had experienced volatility in their operation. Over the period, the operators' technical efficiencies kept experiencing an increasing trend. The technical efficiency levels range between 49% in 1994 and 100% in 2013. Meaning operators are still forcing to bring out their best.

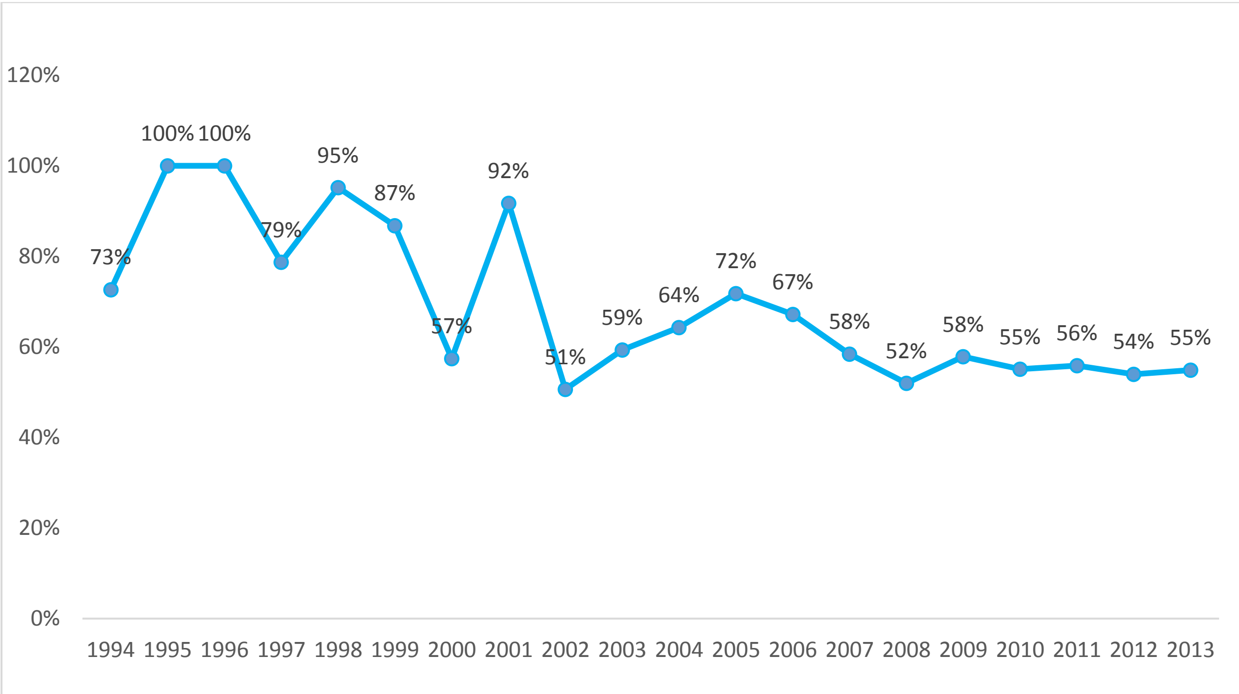
Figure 5.1 Benin's Technical Efficiency Trend (%)



5.4.2 Burkina Faso's Technical Efficiency Trend

Figure 5.2 displays the efficiency, technological progress, and productivity of the telecommunication operators from 1994 to 2013 in Burkina Faso. From the figure, the technical efficiencies of the telecommunication sector operators had experienced some up and down changes over the period. The technical efficiency of Burkina Faso in 1994 was 73%, increased to 100% in 1996, and it became very steady from 2002 with 51% and in 2014 55%.

Figure 5.2 Burkina Faso's Technical Efficiency Trend (%)

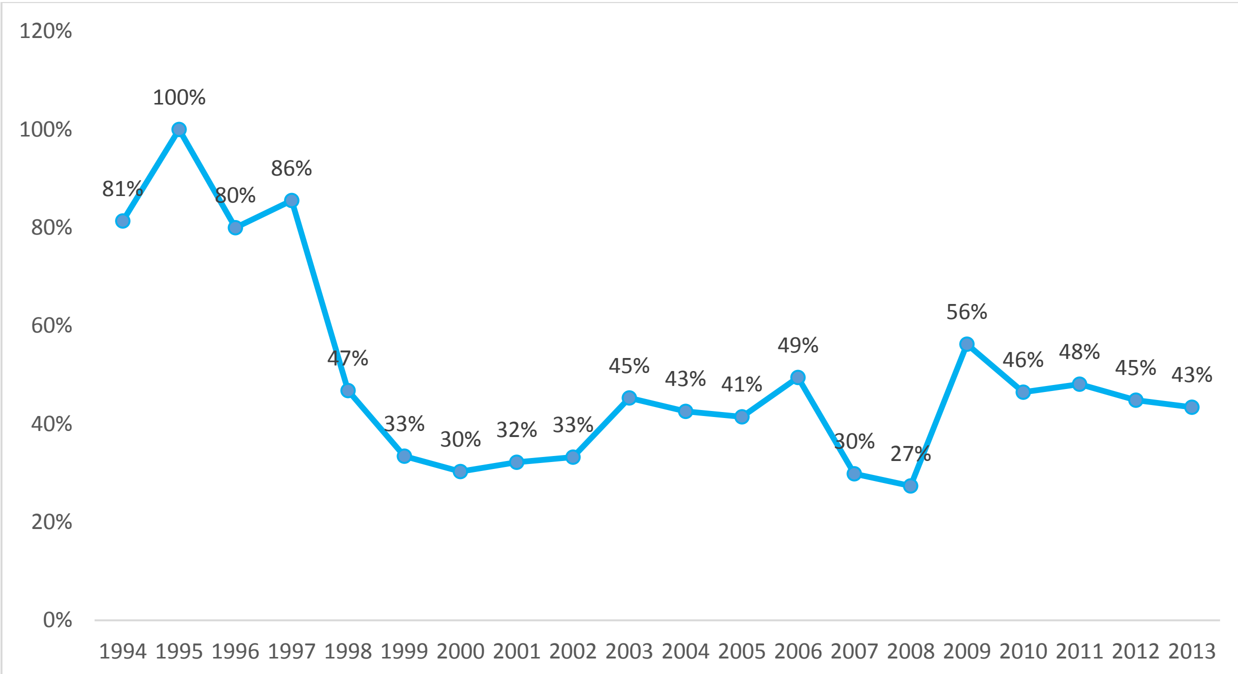


5.4.3 Cape Verde's Technical Efficiency Trend

Figure 5.3 displays the efficiency, technological progress, and productivity of the telecommunication operators from 1994 to 2013 in Cape Verde. From the figure, the technical efficiencies of the telecommunication sector operators had experienced some up and down changes over the period. Over the period, the operators' technical efficiencies kept experiencing a downward trend. The operators are still struggling to bring out their best within the production possibility frontier.

The technical efficiency for Cape Verde was 81% in 1994, increased to 100% in 1995, and starts to decrease to 43% in 2013.

Figure 5.3 Cape Verde's Technical Efficiency Trend (%)

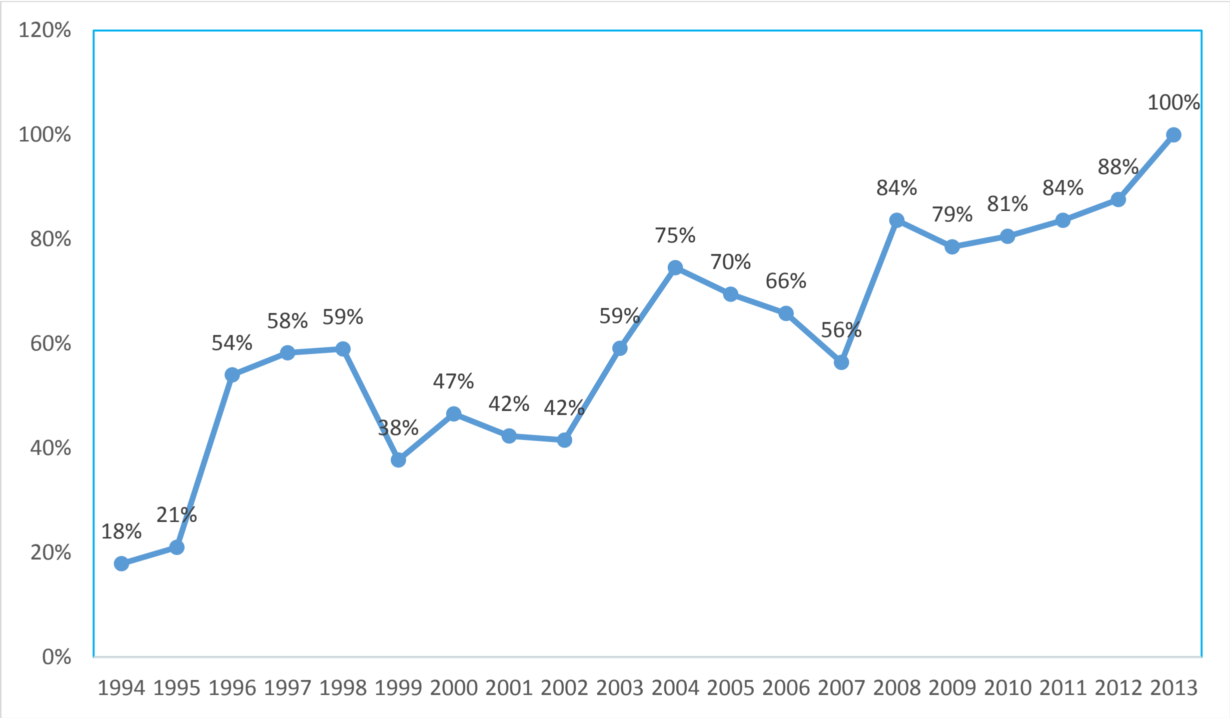


5.4.4 Cote D'Ivoire Technical Efficiency Trend

Figure 5.4 displays the efficiency, technological progress, and productivity of the telecommunication operators from 1994 to 2013 in Cote D'Ivoire. From the figure, the technical efficiencies of the telecommunication sector operators had experienced some up and down movements over the period. Over the period, the operators' technical efficiencies kept experiencing an upward trend. The operators improve upon the existing technologies to bring out their best within the production possibility frontier.

The country's technical efficiency in 1994 was 81%, 75% in 2004, increased to 84% in 2009 and 100% in 2013. These technological efficiency trends contradict the study by Ballou et al. 2010.

Figure 5.4 Cote D'Ivoire Technical Efficiency Trend (%)

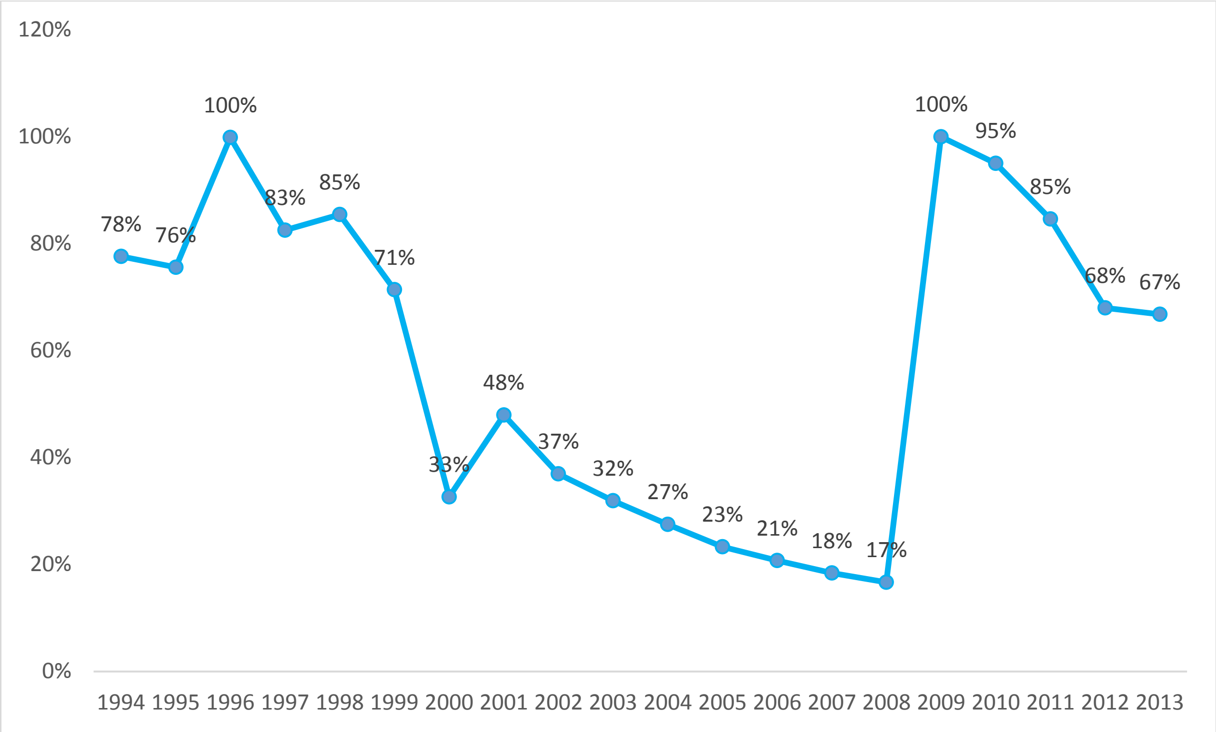


5.4.5 Ghana's Technical Efficiency Trend

Figure 5.5 displays the efficiency, technological progress, and productivity of the telecommunication operators from 1994 to 2013 in Ghana. From the figure, the technical efficiencies of the telecommunication sector operators had experienced some up and down movements over the period. The operators' technical efficiencies kept experiencing an upward trend but a falling trend from 2009 to 2013.

The technical efficiency was 78% in 1994, increased to 100% in 1997, declined to 17% in 2008, increased to 100% in 2010, and declined to 67% in 2013. The operators improve upon the existing technologies to bring out their best within the production possibility frontier.

Figure 5.5 Ghana's Technical Efficiency Trend (%)

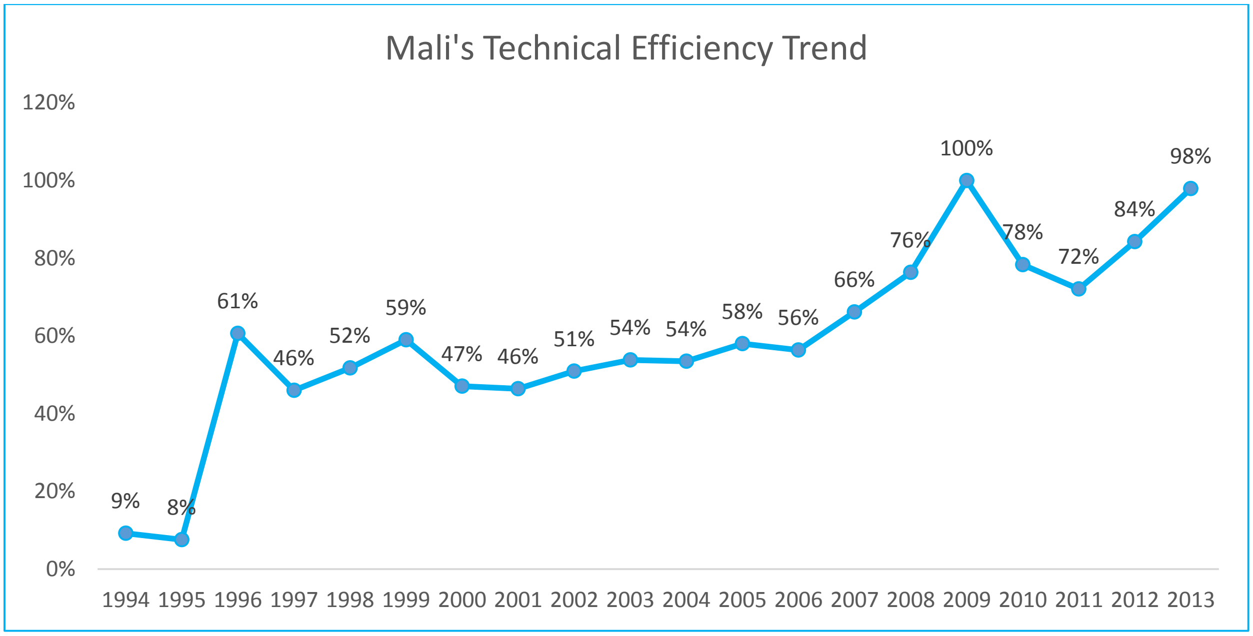


5.4.6 Mali's Technical Efficiency Trend

Figure 5.6 shows the efficiency, technological progress, and productivity of the telecommunication operators from 1994 to 2013 in Mali. From the figure, the technical efficiencies of the telecommunication sector operators had experienced some up and down movements over the period. Over the period, the operators' technical efficiencies kept experiencing an upward trend.

Mali's technical efficiency ranges between 9% in 1994 increased to 61% in 1996, 59% in 1999, 100% in 2010 declined to 72% in 2012 to 98% in 2013.The operators improve upon the existing technologies to bring out their best within the production possibility frontier.

Figure 5.6 Mali Technical Efficiency Trend (%)

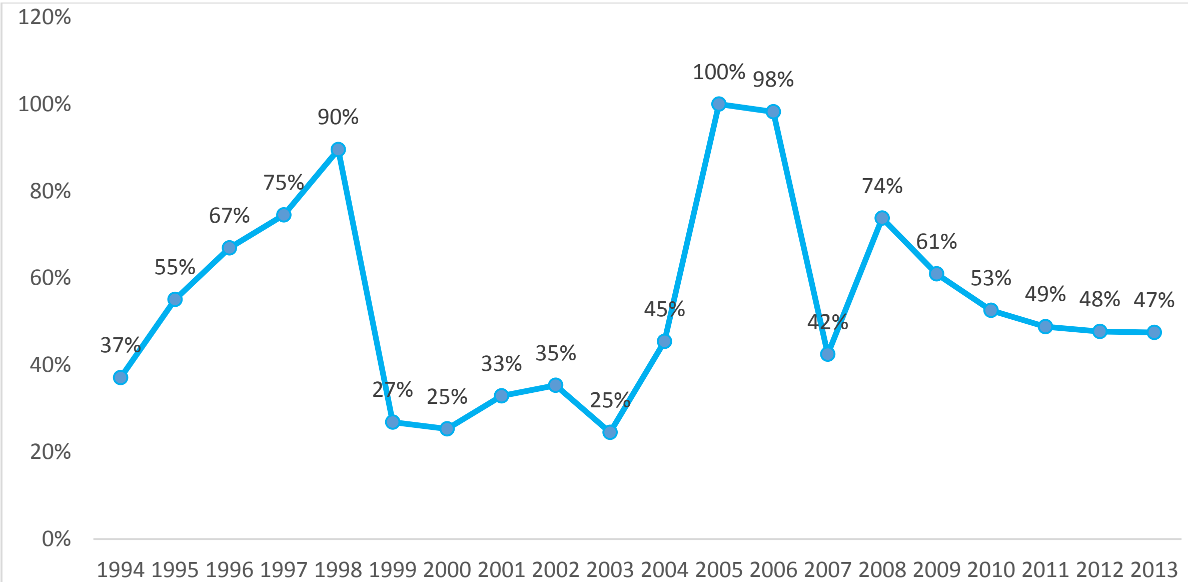


5.4.7 Nigeria's Technical Efficiency Trend

Figure 5.7 shows the level of efficiency, technological progress, and productivity of the telecommunication operators from 1994 to 2013 in Nigeria. From the figure, the technical efficiencies of the telecommunication sector operators had experienced some up and down movements over the period. The operators' technical efficiencies kept experiencing an upward trend over the period.

The technical efficiency was 37% in 1994, 90% in 1998, declined to 25% in 2003, 100% in 2005, declined to 42% in 2007 and 47% in 2013.The operators improve upon the existing technologies to bring out their best within the production possibility frontier.

Figure 5.7 Nigeria's Technical Efficiency Trend (%)

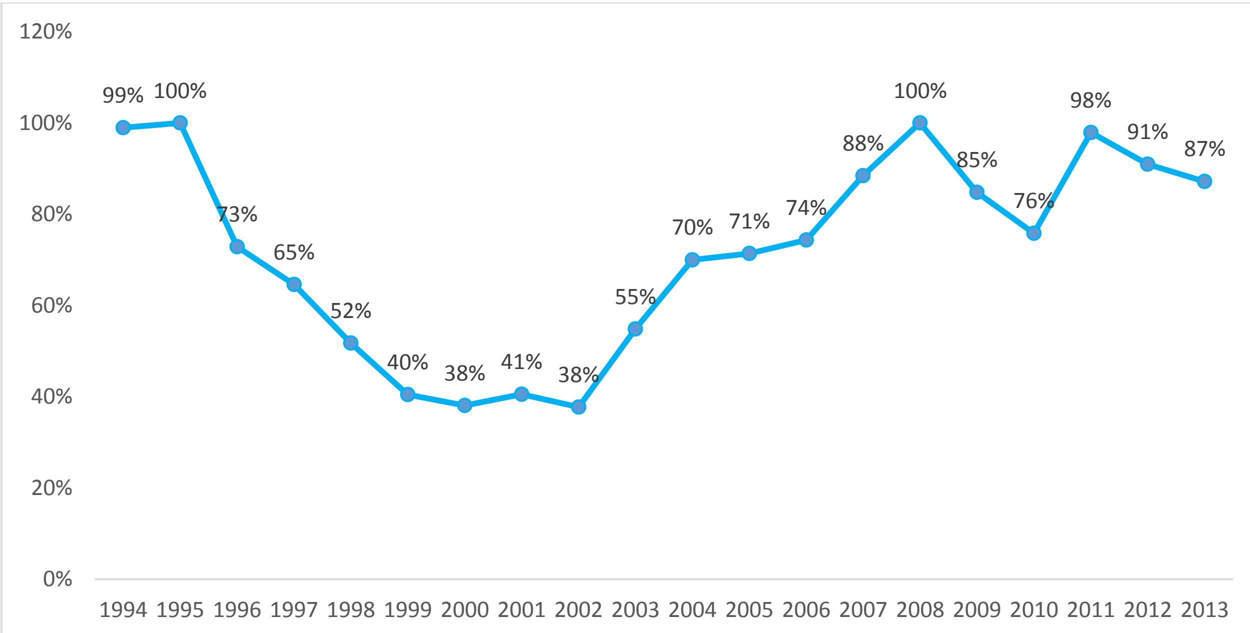


5.4.8 Senegal's Technical Efficiency Trend

Figure 5.8 shows the efficiency, technological progress, and productivity of the telecommunication operators from 1994 to 2013 in Senegal. From the figure, the technical efficiencies of the telecommunication sector operators had experienced some up and down movements over the period. In summary, over the period, the operators' technical efficiencies kept experiencing an upward trend but a fall from 2008 to 2013.

Senegal's technical efficiency has seen a progressive trend, 98% in 1994, declined to 38% in 2002, rose to 70% in 2004, 10% in 2008, and 87% in 2013. The operators improve upon the existing technologies to bring out their best within the production possibility frontier over the period.

Figure 5.8 Senegal's Technical Efficiency Trend (%)

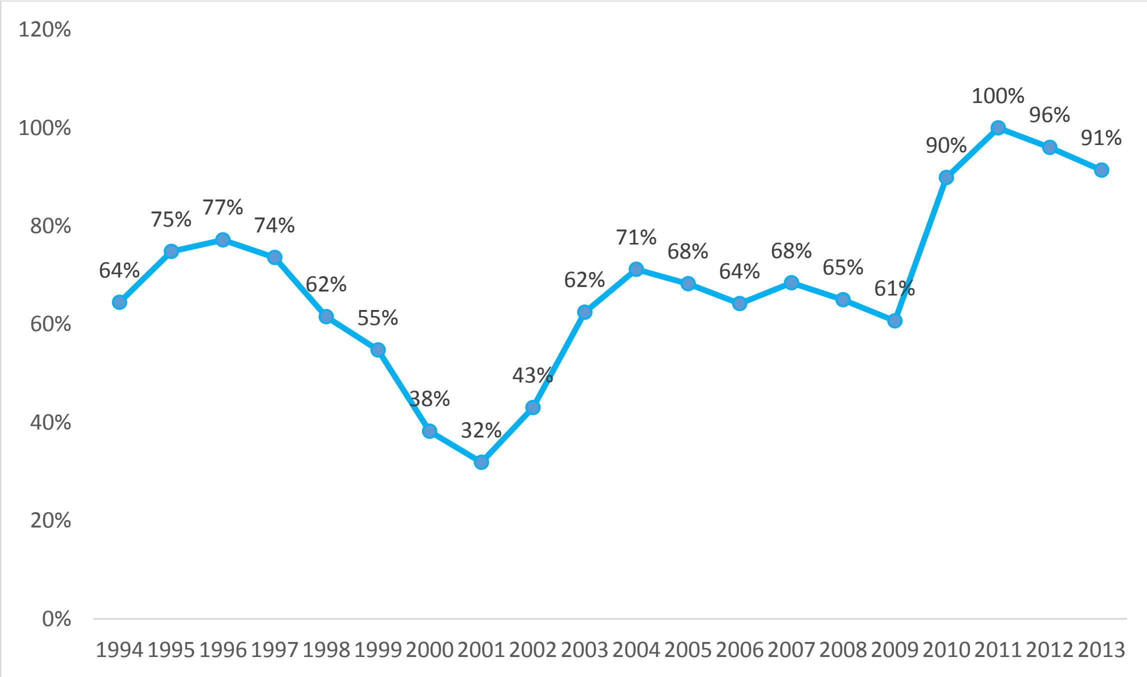


5.4.9 Togo's Technical Efficiency Trend

Figure 5.9 shows the efficiency, technological progress, and productivity of the telecommunication operators from 1994 to 2013 in Togo. From the figure, the technical efficiencies of the telecommunication sector operators had experienced some up and down movements over the period. In summary, over the period, the operators' technical efficiencies kept experiencing an upward trend but rose from 2010 to 2013.

The technical efficiency was 64% in 1994, increased to 77% in 1996, declined to 32% in 2001 and 91% in 2014. The operators improve upon the existing technologies to bring out their best within the production possibility frontier over the period.

Figure 5.9 Togo's Technical Efficiency Trend (%)



In summary, from all the figures, the trend analysis has been a change in the level of telecom operators' technical efficiency over the period under consideration. Based on trend analysis, none of the countries had maintained a consistent technical efficiency level. Besides, Cote D'Ivoire has been the most efficient country in the telecom operators' efficiency, technological progress, and productivity, followed by Mali, Benin, and the least efficient in Cape Verde.

West Africa's telecommunication landscape faces critical challenges that affect the sector's technical efficiency and productivity. Key among these challenges include poor infrastructure (energy and refueling), unpredictable regulations by government and regulators, political instability, high level of consumer retentions, low foreign direct inflows, and the telecom operators' productions.

This study result contradicts the findings in Bollou et al. (2010). Bollou et al. (2010) study results showed that Cote d'Ivoire's progress ratio dramatically declined below 1% in 1998. However, our study results show that Cote d'Ivoire's efficiency ratio in 1994 was 18%, increased to 54% in 1996, and assumed steady progress to 59% in 1998. Even though the political instability affected the telecommunication sector in Cote d'Ivoire in the 1990s, technical efficiency progress never declined beyond 35% over the years. The technical efficiency levels for the countries show a mixed trend, and there has been a progressive growth trend for each nation for the study period.

5.5 Determinants of Technical Efficiency in ECOWAS

To answer objective three of this study, the sectors across the countries have some attribute factors or determinants that are likely to influence the technical efficiency of the telecommunication sector. An Ordinary Least Square (OLS) regression was conducted to test factors that could affect technical efficiency in the Western African telecom sector. We empirically test how the respective predicted technical efficiency mean score responds to a change of mobile subscriptions, annual investments, and telecom employees.

Mobile Subscription (SUBEFF) is an output variable of the telecom sectors that refers to the total number of mobile subscribers. Annual Investment (INVETEFF) shows capital and technology investment in the mobile telecom sector. In contrast, Telecom Employees (STAFEFF) signifies personal (workforce) allocation in the telecom sector.

The following model estimates the determinant of technical efficiency;

$$TE_{It} = \beta_0 + \beta_1 SUBEFF_{it} + \beta_2 INVESTEFF_{It} + \beta_3 STAFEFF_{it} + \varepsilon_{it} \ldots\ldots\ldots\ldots (8)$$

In fitting the OLS regression model, the study used log (SUBEFF (1,000)), log (INESTEFF, in USD (100,000)) and log (STAFEFF (1,000)) as regressors.

Table 5.5 shows that the summary statistics obtained somehow indicate a problem of estimation. The obtained R^2 of 4% means that the estimated regression line explains about 4 percent of the sectors represent technical efficiency levels. The 96% unexplained variation of technical efficiency levels of the countries explained a variable that was not considered.

Table 5.5 Determinants of Technical Efficiency

Variables	Coefficients	Standard Error
logSUBEFF	-0.012**	0.006
logINVESTEFF	0.056***	0.018
LogSTAFEFF	-0.045*	0.023
Constant	0.102	0.235
Observations	180	
R-squared	0.056	

** (10%), ** (5%) and ***(1%) denotes the level of significance on which significance was flagged.*

The F statistic, which is significant at less than 5% significance level, shows that we fail to accept the null hypothesis that the parameters do not explain the dependent variable (mean technical efficiency score). The implication is that the regressors jointly explain variations in the mean technical efficiency of the companies to some extent but cannot predict the technical efficiency levels of the companies. We observed that Annual investment positively impacts technical efficiency with regressor coefficient values of 0.056, significant at the 5% level. However, Mobile

Subscriptions and Employees negatively affect technical efficiency with regressor coefficients of -0.012 and -0.045 and significant at 5% and 10% level of Significance only. This study outcome confirms the findings in the study by Yang et al. (2007) and Moshi et al. (2013).

CHAPTER SIX

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

6.0 Introduction

This chapter presents the study's conclusion by highlighting a summary of the key findings in section 6.2. It also outlines recommendations for policymaking, limitations of the study, and recommendations for further research.

6.1 Summary

Despite the significant expansion and growth of the telecommunication industry in West Africa over the last decades, there has been a lack of quantitative studies on the efficiency and productivity performance of the telecommunication sector in West Africa. The extent to which the efficiency, technological progress, and productivity level have changed with the implementation of the telecommunication sector reforms is yet to be determined. This study demanded the need to fill existing gaps in the literature by estimating the level and analyzing the trend of efficiency and productivity over 20 years period 1994-2013 by using SFA.

In responding to the study's problem statement, the main focus of the research was to empirically investigate the efficiency and productivity of operators in the telecommunication sector in selected West African countries for the period 1994-2013 using stochastic frontier analysis. Specifically, the study sought to address: Firstly, determine the level of technical efficiency in the telecommunication sector during the period under study. Secondly, assess evolution the level of technical efficiency over the period under consideration and evaluate factors that determine technical efficiency and productivity of the telecom operators.

Chapter two of the study reviewed the literature on efficiency measurement. A brief introduction to the theoretical and conceptual framework and followed by the theory of production and stochastic frontier and data envelopment analysis discussed. The chapter then reviewed some empirical studies in the telecommunication sector efficiency measurements by checking works on both stochastic frontier and data envelopment analysis.

In chapter three, a brief background of the nine ECOWAS countries selected for this study, concerning their demographic-economic indicators, telecommunication sector history, and statistics, were discussed.

Moreover, chapter four presented details about the theoretical and conceptual framework upon which this study was grounded. It also gives information on selecting appropriate inputs and outputs variables and the data source and variable description in the survey. The section continues to specify the stochastic frontier and inefficiency model for this study.

Furthermore, Chapter five provided the results obtained from the analysis and the discussion of the results. The results obtained were shown in tables. The chapter consists of descriptive of the variable used in the study, analysis on production function form for the survey, log-likelihood test, and estimate of the stochastic frontier analysis model. The chapters then continued to analyze and answer the three objectives and questions of this study; the estimate of technical efficiency in the telecom sector, evolution technical efficiency levels of the telecommunication sector among the ECOWAS countries, and determinants of technical efficiency telecommunication sector in West Africa.

6.2 Key Findings

At a 5% level of Significance, the number of telecommunication Subscriptions, telecommunication employees, and annual investment had a positive coefficient, which means these variables significantly affect the revenue and technical efficiency of the telecommunication sector across the nine countries.

On objective one, the overall technical efficiency means for the sector 61.73% significant at 5% level. Thus, the telecommunication sector within these countries' understudy for the period operated at an efficiency level of 62%. This result is similar to Moshi et al. (2010), Madden et al. (1999), Lam et al. 2010 and Symeou (2011).

For objective two, Cote D'Ivoire has been the most efficient country in telecom operators' efficiency, technological progress, and productivity, followed by Benin and the least efficient Cape Verde. The mean technical efficiency for the telecommunication companies ranges between 7.60% and 99%, indicating the most minor and most technically efficient telecommunication sector across the nine countries, respectively.

The last objective was to determine the factors that influenced technical efficiency in ECOWAS; annual investment reflects a positive impact on technical efficiency with coefficient values of 0.056, which is significant at the 5% level.   However, Mobile Subscriptions and Employees negatively affect technical efficiency with coefficients of -0.012 and -0.045 and effective at 5% and 10% level of Significance, respectively.

6.3 Conclusion

Based on the study findings, these conclusions are made.

1. Telecommunication Subscriptions, telecommunication employees, and annual investment have positive effects on the revenue and technical efficiency of the telecommunication companies across the nine countries.
2. The technical efficiency score for the telecommunication companies ranges between about 7.60% and 99%, indicating the most minor and most technically efficient telecommunication companies across the nine countries, respectively. The overall mean for ECOWAS is 61.73%.
3. The annual investment reflects a positive impact on technical efficiency. However, Mobile Subscriptions and Employees negatively impact technical efficiency.

6.4 Recommendations

For the countries to become more efficient in the telecommunication sector, policymakers must adopt strategic policies to propel the industry to grow. Policymakers and the operators must cooperate and undertake strategies for mutual benefits such as tax incentives for telecommunication operators facing challenges. Governments of the nine countries must invest in the telecommunication sector infrastructure to expand connectivity.

Management of telecommunication companies across the nine countries should invest more in their capital market by replacing relatively old equipment with new ones. It is also recommended to stakeholders in the industry to take regular maintenance of machinery seriously. When this is done, the operators will be more technically efficient and be more cost-effective in their operations to increase their profits. Furthermore, the employment of skilled labour should be their priority over unskilled labour.

Further studies should consider other external variables that may influence efficiency and productivity of operators in the telecommunication sector in West African countries. Other models like the panel data regression model can be equally applied.

6.5 Limitation of the Study

The study was limited to nine West African Countries, to be specific, nine countries to investigate productivity and the efficiency and of the telecommunication sector for the period 1994-2013 using stochastic frontier analysis. The reason was due to constraints of funds and difficulties in accessing data for the research.

REFERENCES

AFRINVEST (2020), The Nigerian telecommunications industry report. A transformative past, resilient future. Initiation coverage July 2020.

Aigner, D., Lovell, C. K., & Schmidt, P. (1977). “Formulation and estimation of stochastic frontier production function models”. Journal of econometrics, 6(1), 21-37.

Ajetomobi, J. O., Ayanwale, B. A., & SO, B. (2007). “Economic effect of Developments Aid in Nigeria: A Cointegration Analysis”. Pakistan Journal of Social Sciences, 4(1), 1992-1997.

Auguatin Chabossou, (2010). “Benin ICT Sector performance review 2009/2010. Towards evidence-based ICT policy and regulation”. Volume two, policy paper 18,2010.

Badunenko, O., & Kumbhakar, S. C. (2017). “Economies of scale, technical change and persistent and time-varying cost efficiency in Indian banking: Do ownership, regulation and heterogeneity matter?” European Journal of Operational Research, 260(2), 789-803.

Banjoko, S. A. (2002). “Production and operations management. Nigeria”: Pumark Nigeria Limited.

Battese, G. E., & Coelli, T. J. (1992). “Frontier production functions, technical efficiency and panel data: with application to paddy farmers in India”. Journal of productivity analysis, 3(1), 153-169.

Battistoni1 E, Campisi D, and Mancuso P (2006). “European Integration and Telecommunication Productivity Convergence”. Physica-Verlag HD

Bollou, F. (2006). “ICT Infrastructure expansion in Sub-Saharan Africa: An analysis of six West African Countries from 1995 to 2002”. Electronic Journal of Information Systems in

Bollou, F., & Ngwenyama, O. (2008). “Are ICT investments paying off in Africa? An analysis of total factor productivity in six West African countries from 1995 to 2002”. Information Technology for Development, 14(4), 294-307.

Chambers, R. G. (1988). “Applied production analysis: a dual approach”. Cambridge University Press.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). “Measuring the efficiency of decision-making units”. European journal of operational research, 2(6), 429-444.

Coelli, T. (1998). “A multi-stage methodology for the solution of orientated DEA models”. Operations Research Letters, 23(3-5), 143-149.

Coelli, T. J., Rao, D. S. P., O'Donnell, C. J., & Battese, G. E. (2005). “An introduction to efficiency and productivity analysis”. Springer Science & Business Media.

D. Noel Uri, (2001). “Changing productive efficiency in telecommunications in the United States”. Int. J. Prod. Econ. **72**, 121–137.

Debreu, G. (1951). “The coefficient of resource utilization. Econometrica”. Journal of the Econometric Society, 273-292.

Deloitte, G. S. M. A. (2012). “Sub-Saharan Africa Mobile Observatory”; 2012. GSM, London. Developing Countries, 26(5), 1–16.

Djokoto, J. G. (2011). “Inward foreign direct investment flows, growth, and agriculture in Ghana: a Granger causal analysis”. International Journal of Economics and Finance, 3(6), 188-197.

Dwivedi, T. D., Srivastava, V. K., & Hall, R. L. (1980). “Finite sample properties of ridge estimators”. Technometrics, 22(2), 205-212.

Eria Hisali, Bruno Yawe, (2010). “Total factor productivity growth in Uganda’s telecommunications industry”. Telecommunications Policy, Volume 35, Issue 1,2011, Pages 12-19.

Edwin Mansfield, (1975). ‘’Mansfield Microeconomics-Theory and Application. Norton & Company, Second Edition.

Fare, R., Grosskopf, S., Norris, M. And Zhang, Z. (1994) “Productivity growth, technical

Førsund, F. R., Lovell, C. K., & Schmidt, P. (1980). “A survey of frontier production functions and of their relationship to efficiency measurement”. Journal of econometrics, 13(1), 5-25.

Furkan Diskaya, Senol Emir, Nazife Orhan, (2011). “Measuring the Technical Efficiency of Telecommunication Sector within Global Crisis: Comparison of G8 Countries and Turkey, Procedia” - Social and Behavioral Sciences, Volume 24, 2011, Pages 206-218.

Giokas, D., & Pentzaropoulos, G., (2008) “Efficiency ranking of the OECD member stated in the area of telecommunications: A composite AHP/DEA study”, Telecommunication Policy, Vol. 32, pp 672 – 685.

Greene, N., Kass, M., & Miller, G. (1993). “Hierarchical Z-buffer visibility”. In Proceedings of the 20th annual conference on Computer graphics and interactive techniques (pp. 231-238). ACM.

GSMA (2017), The potential of mobile for rural energy access in Mali.

Guermazi, B., & Neto, I. (2005). "Mobile license renewal: what are the issues? what is at stake?". The World Bank.

Guislain, P., Ampah, MA, Besancon, L., Niang, C., & Serot, A. (2005). "Connecting Sub-Saharan Africa: A World Bank Group strategy for information and communication technology sector development". The World Bank.

Helene Smertnik (2014), "Mobile for development utilities. Mobile for smart energy solutions Senegal". GSMA, 2014.

Hisali, E., & Yawe, B. (2011) "Total factor productivity growth in Uganda's telecommunications industry", Telecommunication Policy, Vol.35, pp 12 – 19

Hsu-Hao Yang, Cheng-Yu Chang, (2009). "Using DEA window analysis to measure efficiencies of Taiwan's integrated telecommunication firms". Telecommunications Policy, Volume 33, Issues 1–2, Pages 98-108,

Hu, J. L., & Chu, W. K. (2008). "Efficiency and productivity of major Asia-Pacific telecom firms". Chang Gung Journal of Humanities and Social Sciences, 1(2), 223-245.Information and Communication Technologies (IJMPICT), Vol. 4, No. 4.

https://www.worldbank.org/en/publication/human-capital

https://gsmaintelligence.com/research.

International Telecommunication Union World Telecommunication/ICT Indicators Database – Online Annual Subscription 2015, Article 399-15.

International Telecommunication Union (ITU), Measuring the information society report 2018-volume 2.

Jha, R., & Majumdar, S. K. (1999). "A matter of connections: OECD telecommunications sector productivity and the role of cellular technology diffusion. Information Economics and Policy, 11(3), 243-269.

Jondrow J, Lovell CAK, Materov IS, Schmidt P (1982). "On the estimation of technical efficiency in the stochastic frontier production function model". J Econ 19(2/3):233–238

Katz et al. (2013). "Assessment of the economic impact of telecommunications in Mali. Telecom advisory service, LLC October 2013.

Kessides, I. N., Noll, R. G., & Benjamin, N. C. (2009). "Regionalizing telecommunications reform in West Africa". The World Bank.

Kodde, D. A., & Palm, F. C. (1986). "Wald criteria for jointly testing equality and inequality restrictions". Econometrica: journal of the Econometric Society, 1243-1248.

Koopmans, T. C. (1951). "An analysis of production as an efficient combination of activities. Activity analysis of production and allocation".

Kumbhakar et al. (2014), Kumbhakar S.C., Lien G., Hardaker J.B. "Technical efficiency in competing panel data models: A study of Norwegian grain farming". Journal of Productivity Analysis, 41 (2014), pp. 321-337

Kumbhakar, S. C., & Lovell, C. K. (2003). “Stochastic frontier analysis”. Cambridge university press.

Kumbhakar, S. C., Denny, M., & Fuss, M. (2000). “Estimation and decomposition of productivity change when production is not efficient: a panel data approach”. Econometric Reviews, 19(4), 312-320.

Kumbhakar, S. C., Ghosh, S., & McGuckin, J. T. (1991). “A generalized production frontier approach for estimating determinants of inefficiency in US dairy farms”. Journal of Business & Economic Statistics, 9(3), 279-286.

L. Pun-Lee, L. Teresa, (2005). “Total factor productivity measures for Hong Kong telephone”. Telecommunication. Policy **29**, 53–68

H. Lai, S.C. Kumbhakar (2018). “Endogeneity in panel data stochastic frontier model with determinants of persistent and transient inefficiency”**.** Economics Letters, 162 pp. 5-9

Lam, P. L., & Shiu, A. (2010). “Economic growth, telecommunications development and productivity growth of the telecommunications sector: Evidence around the world”. Telecommunications Policy, 34(4), 185-199.

Lam, PL., & Shiu, A. (2008). “Productivity analysis of the telecommunications sector in China”, Telecommunications Policy, Vol.32, pp 559 – 571.

Li, Y., & Lyons, B. (2012). “Market structure, regulation and the speed of mobile network penetration”. International Journal of Industrial Organization, 30(6), 697-707.

Lien, D., & Peng, Y. (2001). “Competition and production efficiency: Telecommunications in OECD countries”. Information Economics and Policy, 13(1), 51-76.

Lohento, K. (2003). "Civil Society and National NICT Policy in Benin. Assoc. for Progressive Communications".

Lovell, C. K. (1993). "Production frontiers and productive efficiency. The measurement of productive efficiency: Techniques and applications", 3, 67.

M. Resende, (2004). "Price cap regulation, incentives and quality: the case of Brazilian telecommunications". Int. J. Prod. Econ. **92**, 133–144

Madden, G., & Coble-Neal, G. (2005). "Australian residential telecommunications consumption and substitution patterns". Review of Industrial Organization, 26(3), 325-347.

Madden, G., & Savage, S. (1999) "Telecommunications productivity, catch-up and innovation", Telecommunications Policy, Vol.23, pp 65-81.

Malmquist, S. (1953). "Index numbers and indifference curves". Trabajos de Estatistica, 4(1), 209– 242.

Market Publishers (2020). "Benin-telecom, mobile and broadband -statistics and analyses".

Meeusen, W., & van den Broeck, J. (1977). "Technical efficiency and dimension of the firm: Some results on the use of frontier production functions". Empirical economics, 2(2), 109-122.

Milner, C., & Weyman–Jones, T. (2003). "Relative national efficiency and country size: evidence for developing countries". Review of development economics, 7(1), 1-14.

Moriwaki, S., Era, A., & Osajima, M. (2010). "Productivity and Efficiency Analysis of Telecommunications Industries. The Case of Asia-Pacific Countries". Information and Communications Policy Review, 1, E1-E19.

Moshi, G. C., Mwakatumbula, H., & Mitomo, H. (2013). "Regulation, competition and productivity growth in the African telecommunications industry''. International Journal of Managing Public Sector Information and Communication Technologies, 4(4), 17 - 33.

Murillo- Zamorano, L. R. (2004). "Economic efficiency and frontier techniques". Journal of Economic surveys, 18(1), 33-77.

National Communication Authority (2020), Industry information-telecom subscription.

New Partnership for Africa's Development (NEPAD 2002) The African Union Commission

Ogundari, K., Amos, T. T., & Ojo, S. O. (2010). "Estimating confidence intervals for technical efficiency of rainfed rice farming system in Nigeria". China Agricultural Economic Review, 2(1), 107-118.

Oh, D. M. (2010). International Telecommunication Union.

Ongondo, F. O., & Williams, I. D. (2011). "Mobile phone collection, reuse and recycling in the UK". Waste management, 31(6), 1307-1315.

Owusu-Ansah, E., Dontwi, I. K., Seidu, B., Abudulai, G., & Sebil, C. (2010). "Technical efficiencies of Ghanaian general insurers". American journal of social and management sciences, 1(1), 75-87.

Papadimitriou, Athanasios C., and Chrysovaladis P. Prachalias (2009). "Estimating the efficiency of marketing expenses: The case of global telecommunication operators." Journal of Economics and Business 12.2 23-41.

Ranganathan, R., & Foster, V. (2011). "East Africa's infrastructure: a regional perspective". The World Bank.

Riko Hendrawan, Gayuh T Permana, Kristian WA Nugroho (2019) ‘’ Efficiency analysis of telecommunications companies in Southeast Asia using Stochastic Frontier Analysis (SFA) method’’. Jurnal Siasat Bisnis Vol. 23 No. 2, 2019, 104 – 112.

S. Lam, (2008) ‘’Productivity analysis of the telecommunications sector in China’’. Telecommunication. Policy **32**, 559–571 (2008)

Sadjadi, S., & Omrani, H. (2010), "A bootstrap robust data envelopment analysis model for efficiency estimating of telecommunication companies in Iran", Telecommunication Policy, Vol. 34, pp 211 - 257.

Saxena Nigam, V., Thakur, T., Sethi, V.K. et al. ‘’Performance Evaluation of Indian Mobile Telecom Operators based on Data Envelopment Analysis’’. J. Inst. Eng. India Ser. B **93,** 111–117 (2012). https://doi.org/10.1007/s40031-012-0013-0

Schmidt, P., & Lovell, C. K. (1979). "Estimating technical and allocative inefficiency relative to stochastic production and cost frontiers". Journal of econometrics, 9(3), 343-366.

Seo, Daigyo, and Jonghyup Shin. "The impact of incentive regulation on productivity in the US telecommunications industry: A stochastic frontier approach." Information Economics and Policy 23.1 (2011): 3-11.

Suleiman, M.S., Hemed, N.S., and Wei, J. (2017). "Evaluation of Telecommunication Companies Using Data Envelopment Analysis: Toward Efficiency of Mobile Telephone Operator in

Tanzania." International Journal of e-Education, e-Business, e-Management, and e-Learning.

Symeou, P. C., (2011) "Economy size and performance: An efficiency analysis in the telecommunications sector", Telecommunication policy, Vol. 35, pp 426 – 440.

The Little Databook on ICT, The World Bank, 2014.

Uri, N. (2000) "Measuring productivity change in telecommunications", Telecommunication policy, Vol. 24, pp 439 – 452.

Uri, N. D. (2003). ''Technical efficiency in telecommunications in the United States and the impact of incentive regulation''. Applied Mathematical Modelling, 27(1), 53-67.

Viscusi, Aarrington & Vernon, (2005). "Economics of regulation and antitrust". MIT press,2005.

Williams, M., Mayer, R., & Minges, M. (2011) "Africa's ICT infrastructure: Building on the mobile revolution", World Bank, Washington DC.

www.itu.int/ITU-D/ICT/material/Factsfigures2010.pdf.

Yonazi, J. (2013). "Adoption of transactional level e-government initiatives in Tanzania". Dar es Salaam: Clknet Research.

Zhu (2004) J. Zhu ''Imprecise DEA via standard linear DEA models with a revisit to a Korean mobile telecommunication company Operations Research", 52 (2) (2004), pp. 323- 329