Theory, Application and Policy of Efficiency Regulation: the case of the West African electricity distribution sector

Richard Afriyie ODURO

Submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

Collaborative Research by Centre for Environment and Sustainability and Surrey Energy Economics Centre, University of Surrey

October 2018
Abstract

There are narratives based on qualitative and quantitative data that describe the West African Power Sector as very inefficient. In the context of electricity distribution, companies are usually tagged inefficient with various stakeholders justifying that with various analyses, statistics and narratives. Empirical studies establishing such assertions are rather absent or lack a holistic measuring approach. In this work, the acknowledgement of the importance of bench-marking in electricity market regulation is made with the need to further estimate a baseline cost efficiency of the electricity distribution sector of West Africa demonstrated. The aim of this research is to do efficiency studies on the electricity distribution sector of West Africa to comprehend the current state of electricity distribution as well as to understand the underlying causes of inefficiency. Three themes are covered in this thesis. The first theme investigates the theoretical concepts of measuring efficiency and contributes to a longstanding debate regarding the preferred choice of statistical distribution underlying the inefficiency term in the stochastic frontier approach. In this regard, the Burr Type X stochastic frontier model is constructed and tested against other existing models including Normal-Half Normal, Normal- Exponential and Normal-Rayleigh stochastic models. The investigation presents the newly constructed Burr X stochastic frontier model as one that competes with the other models when using cross-sectional data.

In the second theme, cost efficiencies are estimated from an unbalanced panel of 14 electricity distribution companies over the period of 2007-2014 using several panel data models including the pooled model, Pitt & Lee model, true random effects model and true fixed effects model. The results suggest that the EDCs in the West African region operate at an average efficiency level of 52% (pooled normal-Half normal estimate) which appears to validate the perception of many stakeholders. The Nigerian EDCs have a mean inefficiency level of 51% which is the worst among the sub groups considered. The East African comparator (KPEDC in Kenya) recorded an efficiency level of 63% and was outperformed by some West African EDCs. The results demanded an investigation into the underlying reasons for such high inefficiencies in the West African sub-region considering that the sector has experienced significant reform and investment efforts.

In the third theme, using the Electricity Company of Ghana as a case, a Political Economy Analysis (PEA) framework which has the capability of discovering reform opposition and the associated political and economic incentives that unearth informal rules in the industry was employed. Our findings suggest a plethora of possibilities that are encompassed in political and cultural characteristics of consumers, management and political stakeholders who assume overwhelming powers to further influence the governance of the power industry. Perceived inefficiency drivers seem to emanate from financial mismanagement, cultural and attitudinal forces, unsatisfactory regulation, mismanagement of third party contractors, procurements lapses and others. Privatisation seems to be the way forward according to the views of many stakeholders but there are issues surrounding the fear of high cost of electricity as well as downsizing of the utility that could bring hardship to the staff who will be included in such a programme.
Declaration of Originality

This thesis and the work to which it refers are the results of my own efforts. Any ideas, data, images or text resulting from the work of others (whether published or unpublished) are fully identified as such within the work and attributed to their originator in the text, bibliography or in footnotes. This thesis has not been submitted in whole or in part for any other academic degree or professional qualification. I agree that the University has the right to submit my work for plagiarism detection service Turnitin UK for originality checks. Whether or not drafts have been so assessed, the University reserves the right to require an electronic version of the final document (as submitted) for assessment as above.
Acknowledgements

I am greatly indebted to my main supervisor, Professor Matthew Leach, for all the valuable discussions, wise guidance, constant encouragement and support. His vast knowledge has been of great value to me. I would like to express my gratitude to Professor Lester Hunt, Professor Yacob Mulugetta and Dr Mona Chitnis, my other supervisors, who have made many useful inputs in this particular research. I would also like to thank Dr Yaw Bimpeh for accepting to proof read and peruse the mathematical formulae and statistical models used in this thesis.

I cannot forget to appreciate my family who cheered me on constantly while I did this degree. The support and love they offered me cannot be taken for granted. Thanks for your encouragement and understanding.

Many thanks to all my colleagues in the Centre for Environment and Sustainability and the School of Economics for their constant support academically and socially.

Finally, without any doubt, I acknowledge and appreciate the financial support from my sponsors, GETFund (Ghana Education Trust Fund) and the Agricen Group of the University of Surrey.
# Table of Contents

Abstract ........................................................................................................................................... ii  
Declaration of Originality ............................................................................................................... iii  
Acknowledgements ....................................................................................................................... iv  
Table of Contents ........................................................................................................................... v  
List of Figures ................................................................................................................................... ix  
List of Tables ..................................................................................................................................... xii  
Abbreviations and Acronyms ......................................................................................................... xvi  

## Chapter 1 ...................................................................................................................................... 1  
1. Introduction ................................................................................................................................. 1  
1.1 Research Aim, Questions, Objectives and Themes ............................................................... 5  
1.2 Research Methodology ........................................................................................................... 6  
1.3 Thesis Contributions ............................................................................................................... 7  
1.4 Thesis Structure ..................................................................................................................... 8  

## Chapter 2 .................................................................................................................................... 10  
West African Electricity Market and Literature Review ................................................................. 10  
2. Chapter Overview ..................................................................................................................... 10  
2.1 Background to the West African Electricity Industry ........................................................... 10  
2.1.1 Evolution of the Power Industry of Ghana ........................................................................ 11  
2.1.2 Electricity Distribution and Regulation in Ghana ............................................................ 21  
2.1.3 Background to Nigeria Electricity Sector ......................................................................... 24  
2.1.4 Regulation and Efficiency of EDCs in Nigeria ................................................................. 28  
2.1.5 Current State of Nigeria’s Electricity Supply Industry after Reforms ............................ 30  
2.1.6 Electricity Situation in other West African Countries ....................................................... 33  
2.1.7 ECOWAS and Power Sector Regionalisation .................................................................. 38  
2.1.8 Summary on West African Electricity Systems ............................................................... 40  
2.2 Theoretical Framework and Literature Review on Efficiency and Frontier Analysis .......... 42  
2.2.1 Background to Efficiency Concept and its Measuring Techniques ............................... 42  
2.2.2 Understanding Frontier Techniques in Measuring Efficiency ....................................... 44  
2.2.3. Non-Parametric Frontier Techniques (DEA) ................................................................. 48  
2.2.4 Parametric Approaches ................................................................................................... 50  
2.2.5 Stochastic Frontier Model ............................................................................................... 55  
2.2.6 Heterogeneity and Efficiency Modelling ......................................................................... 59
Appendix 4C: Cost Efficiency Measurements for Nigerian EDCs ........................................240
Appendix 5B: Questionnaire used for consumer survey ................................................246
List of Figures

Figure 1.1: Regulatory operational model choices and Structure.................................................................2
Figure 1.2: Thesis Structure................................................................................................................................9
Figure 2.1: Pre-reform structure of the power sector of Ghana.........................................................................12
Figure 2.2: Power Sector Reform and Achievements.......................................................................................14
Figure 2.3: Post-Reform Structure of the Electricity Supply Industry of Ghana.............................................15
Figure 2.4: Final Energy Consumption of Ghana............................................................................................16
Figure 2.5: Final Energy Consumption by Customer Type...............................................................................16
Figure 2.6: Peak Demand Trend of Ghana........................................................................................................16
Figure 2.7: Water Level and Electricity Produced by Akosombo Dam ..........................................................17
Figure 2.8: Average electricity tariff of Ghana................................................................................................18
Figure 2.9: Electricity Generation Trend of Ghana...........................................................................................19
Figure 2.10: Electricity Transmission Losses of Ghana.....................................................................................20
Figure 2.11: Ghana’s Import and Export quantities of Power... .....................................................................21
Figure 2.12: Electricity consumption and losses in the Electricity Supply Industry ....................................22
Figure 2.13: Transmission and Distribution Losses of Electricity Utilities in Ghana........................................22
Figure 2.14: Post-Reform Trading Arrangement for Nigeria’s Electricity Supply Industry............................28
Figure 2.15: Multi-Year Tariff Order (MYTO) for Nigerian Electricity Supply Industry .................................29
Figure 2.16: 2014 Technical and commercial losses in the distribution sector of Nigeria............................30
Figure 2.17: Installed and available capacities, losses in the Electricity Supply Industry of Nigeria (GW) in 2015.................................................................................................................................31
Figure 2.18: Electrical Outages Duration and the Impact on Business sales in Sub-Saharan African Countries ...........................................................................................................................................................................31
Figure 2.19: Electrification rate of West Africa................................................................................................33
Figure 2.20: Transmission and distribution losses and loss rates of sub-Saharan countries in 2012.............33
Figure 2.21: Electricity Access Rates of West African Countries in 2011.........................................................34
Figure 5.23: An Nvivo output of a thematic analysis of the sources of inefficiency in ECG.................174

Figure 5.24: ECG Financial Performance from 2008 to 2013Q2.................................................................179
List of Tables

Table 2.1: Projected Demand ........................................................................................................18
Table 2.2: Power Reforms and Achievements in Nigeria...........................................................27
Table 2.3: Applications of Stochastic Frontier Studies in the Energy Industry........................68
Table 2.4: Applications of Political Economy Analysis in the Energy Sector.............................81
Table 3.1: Standard Deviation of $\sigma_u$ for various SFA models.............................................100
Table 3.2: Standard Deviation of $\sigma_v$ for various SFA models.............................................101
Table 3.3: Mean Squared Error of efficiency estimates for various SFA models.......................102
Table 3.4 Spearman rank correlations between estimated efficiencies of various models ($\sigma_u=0.2$, $\sigma_v=0.6$, n=100)..................................................................................................................107
Table 4.1: Efficiency attributes of 15 EDCs used in this study (2014 data)..................................122
Table 4.2: Descriptive statistics of variables included in the stochastic cost frontier model.......122
Table 4.3: SFA Cost Models .........................................................................................................123
Table 4.4: Efficiency estimates of the stochastic cost frontier panel models............................126
Table 4.5: Efficiency Scores for different segments of the pool....................................................127
Table 5.1: Electricity Consumption by Customer Classes............................................................147
Table 5.2: Items and Constructs used in the Exploratory and Confirmatory Tests......................163
Table 5.3: Goodness of fit of model............................................................................................165
Table 5.4: Convergent Validity Test Results................................................................................166
Table 5.4: Fornell-Larcker criterion for Discriminant validity for Efficiency Attributes and Efficiency Benefits..................................................................................................................166
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE</td>
<td>Allocative Efficiency</td>
</tr>
<tr>
<td>CAPEX</td>
<td>Capital Expenditure</td>
</tr>
<tr>
<td>CRS</td>
<td>Constant Return to Scale</td>
</tr>
<tr>
<td>COLS</td>
<td>Corrected Ordinary Least Squares</td>
</tr>
<tr>
<td>DEA</td>
<td>Data Envelopment Analysis</td>
</tr>
<tr>
<td>EE</td>
<td>Economic Efficiency</td>
</tr>
<tr>
<td>EC</td>
<td>Energy Commission</td>
</tr>
<tr>
<td>ECG</td>
<td>Electricity Company of Ghana</td>
</tr>
<tr>
<td>ECOWAS</td>
<td>Economic Community of West African States</td>
</tr>
<tr>
<td>EPSR</td>
<td>Electric Power Sector Reform</td>
</tr>
<tr>
<td>ERERA</td>
<td>ECOWAS Regional Electricity Regulatory Authority</td>
</tr>
<tr>
<td>FIT</td>
<td>Feed in Tariff</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GRIDCo</td>
<td>Ghana Grid Company Limited</td>
</tr>
<tr>
<td>GWh</td>
<td>Giga Watt hour</td>
</tr>
<tr>
<td>MW</td>
<td>Mega Watt</td>
</tr>
<tr>
<td>MWh</td>
<td>Mega Watt hour</td>
</tr>
<tr>
<td>MYTO</td>
<td>Multi Year Tariff Order</td>
</tr>
<tr>
<td>IPP</td>
<td>Independent Power Producers</td>
</tr>
<tr>
<td>IRS</td>
<td>Increasing Return to Scale</td>
</tr>
<tr>
<td>KV</td>
<td>Kilovolt</td>
</tr>
<tr>
<td>LIMDEP</td>
<td>LIImited DEPendent Variable Models</td>
</tr>
<tr>
<td>NBET</td>
<td>Nigerian Bulk Electricity Trader</td>
</tr>
<tr>
<td>NED</td>
<td>Northern Electricity Department</td>
</tr>
<tr>
<td>NEDCo</td>
<td>Northern Electricity Distribution Company</td>
</tr>
</tbody>
</table>
NERC  National Electricity Regulatory Commission
NITS  National Interconnected Transmission Network
NPV  Net Present Value
OECD  Organisation for Economic Co-operation and Development
OFGEM  Office of Gas and Electricity Market
OLS  Ordinary Least Squares
OPEX  Operational Expenditure
PE  Price Efficiency
PEA  Political Economy Analysis
PNDC  Provisional National Defence Congress
PSRC  Power Sector Reform Committee
PURC  Public Utilities Regulatory Commission
REF  Rural Electrification Fund
RoR  Rate of Return Regulation
SBU  Strategic Business Units
SFA  Stochastic Frontier Analysis
SHEP  Self Help Electrification Programme
SLT  Special Load Tariff
TE  Technical Efficiency
TFP  Total Factor Productivity
VALCO  Volta Aluminium Company
VRA  Volta River Authority
WAPP  West African Power Pool

List of Electricity Distribution Companies Used in the Study

AEDC  Abuja Electricity Distribution Company
BEDC  Benin Electricity Distribution Company
Eko EDC  Eko Electricity Distribution Company
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Company Name and Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enugu EDC</td>
<td>Enugu Electricity Distribution Company</td>
</tr>
<tr>
<td>IEDC</td>
<td>Ibadan Electricity Distribution Company</td>
</tr>
<tr>
<td>IKEDC</td>
<td>Ikeja Electricity Distribution Company</td>
</tr>
<tr>
<td>JEDC</td>
<td>Jos Electricity Distribution Company</td>
</tr>
<tr>
<td>KEDC</td>
<td>Kano Electricity Distribution Company</td>
</tr>
<tr>
<td>Kaduna EDC</td>
<td>Kaduna Electricity Distribution Company</td>
</tr>
<tr>
<td>PHEDC</td>
<td>Port Harcourt Electricity Distribution Company</td>
</tr>
<tr>
<td>YEDC</td>
<td>Yola Electricity Distribution Company</td>
</tr>
<tr>
<td>ECG</td>
<td>Electricity Company of Ghana</td>
</tr>
<tr>
<td>CIE</td>
<td>Compagnie Ivorienne d'Electricité</td>
</tr>
<tr>
<td>CEET</td>
<td>Compagnie d'Energie Electrique du Togo</td>
</tr>
<tr>
<td>KPEDC</td>
<td>Kenya Power Electricity Distribution Company</td>
</tr>
</tbody>
</table>
Chapter 1

1. Introduction
The main socio-economic goal of all the development frameworks designed for countries has been to promote competitive, fast growing, productive economies, which generate sufficient employment for their citizens. Fundamental to the fulfilment of this objective is the provision of reliable and affordable energy to all productive sectors of these economies to stimulate and sustain a long-term steady economic growth as well as clean reliable and affordable energy to citizens. The West African region is not an exception to this concept of developing and executing a plan of providing adequate, reliable and affordable energy for economic development and the general welfare of its citizens. It is therefore not unexpected for the region to experience many reforms and modifications of its power sector in the last three decades.

West Africa has abundant and cheaper energy sources including natural gas, hydro, solar, tidal wind and biomass that can be converted into electricity but regrettably the statistics of access to electricity, per capita electricity consumption and the cost of electricity present a sharp contrast on the grounds. With a demand and supply gap of 46% with only a third of its consumers connected to the grid amidst relatively high cost of electricity of $0.17 per KWh and poor quality of supply, the need for increased efficiency rather becomes a necessity. However, the narratives suggest that the power sector and in particular the distribution sector has remained very inefficient for many decades and have experienced different interventions or reforms that have proven to be unsuccessful. It is therefore important for policymakers in the sub-region to re-look at this problem to improve supply quantity and reliability for the benefits of the population and industrial sector.

Power sector reforms began internationally in the 1980s where there was a drive to introduce competition and private sector involvement into the traditional sector which was dominated by state ownership. Advocates of energy sector reforms believed that once competition was introduced, normally through increase in private sector participation, then there was the likelihood for increased efficiency and reduced end-user tariffs. According to Williamson (1994), this proposition was adopted in the popular Washington Consensus making power sector reforms part of a broader set of policy changes recommended and implemented around the world.
Various models were explored in the phase of reforms as seen in the figure above. Most developed countries have traversed the various phases from a Vertically Integrated Monopoly to a Full Customer Choice where the retail end of the chain is deregulated.

In sub-Saharan Africa and many other developing economies, power sector reforms have been on-going since the 1990s, although at various levels of implementation across the continent. Countries in West Africa have generally explored the transition from state-owned utilities to partially privately-owned utilities and are currently at the phase of private partnership agreements. There have been regulatory reforms starting with making and amending electricity sector laws as well as creating relevant institutions to oversee the expected regulatory tasks. Undeniably, challenges facing the power sector vary across the continent with significant differences between the two distinct regions of sub-Saharan Africa and North Africa, primarily due to disparities in the levels of power sector development. Even within the Sub-Saharan region, energy resource availability and reform outcomes tend to cause some significant differences of the power sectors of various countries.

West Africa continues to have a high electricity supply-demand gap, a situation that has seen many years of expensive and unreliable power supply which seriously discourage investments in the private and industrial sectors.(Chambers, Foresti and Harris, 2012) Most authors including Gnansounou et al.(2007), Edjekumhene, Amadu and Brew-Hammond (2001) and Eberhard et al.(2011) affirm the agenda for power sector reforms as being multidimensional, with the main drivers being the need to improve financial and technical performance of utilities, increase access to electricity and reduce the cost of power to consumers.
A review on electricity sector reforms in West Africa provides key lessons which emanate from political and economic perspectives. Widely held view are as follows:

- Increasing access to electricity has multiple benefits, including health and well-being of citizens (especially women) in their domestic lives and productivity and economic opportunities for small and large enterprises.

- An approach to augment access to electricity could be effected through grid extension conditioned on socio-economic credit or exploring the great opportunity that exists in the use of mini grids with renewable energy options. But any approach to electrification of poorer communities (notably in rural areas) is extremely costly and thus is difficult to finance without specific public funding.

- Rural electrification is of immense political interest. This interest could have both positive and negative impacts on long term, sustainable and fair investment decisions. In one view, political support is essential in order to develop the necessary policy, legal and institutional frameworks for electrification. On the other hand, politics can interfere and cause a detour to uneconomical and unrealistic electrification projects that are not sustainable in the long-term.

- Despite widespread interest in renewable sources of electricity, and their presence in long term plans, they are not typically seen as the main route for expansion of power generation. Some countries have been able to produce the renewable energy act in which renewable energy producers are fairly compensated through feed in tariffs (FIT) but this is at the very infantile stage with renewable energy accounting for less than 1 percent of the energy mix in the sub-region. Thermal power generation still dominates governmental thinking.

- Whilst there is evidently high latent demand for good quality electricity, lack of access and inability to pay high tariffs constrains the investment in infrastructure. The lack of investments in the Electricity Supply Industry has led to high transmission and distribution losses, which feeds back into a downwards spiral of lower reliability, higher prices and dampening of demand. Issues of non-metering and poor fee collection contribute further to high commercial losses. However, the issue of efficiency though highlighted in the countries’ reform policies is not supported by
relevant plans and programmes. There are opportunities to reduce inefficiencies at both the supply and demand levels through programmes to reduce losses and reduce the cost of production, which eventually translates into affordable energy.

Regardless of the level of progress of reforms in the West African Sub-region, it has become quite clear as suggested by Edjekumhene, Amadu and Brew-Hammond (2001) and other authors that the initial pursuit of reforms was not necessarily voluntary but indirectly mandatory. To support the deduction, it is acknowledged that in 1992, developmental and financial support to most of the member countries in the ECOWAS region from multilateral funding agencies practically paved the way for the latter to impose a post-disbursement caveat of mandatory electricity sector reforms. It is quite understandable that the efforts put into the reforms in this phase were not concerted, since they was not the original priority of the countries that were affected. The other reason for an ineffective reform of the early phase was that the intensity of power crisis preceding the early part of reforms was relatively minor due to the structure of the economies (less energy intensive) against the available energy resources at the time. Primarily, the consumption levels were manageable for a less intensive and less populated economy.

A second phase of reforms, in which most of the West African countries find themselves now, has been necessitated by the agitation of stakeholders, particularly civil society, to realise and act on their rights to energy access and security. In certain jurisdictions, some political and non-political factions have staged protests to show their displeasure towards the deplorable state of the electricity sector. The pursuit of the UN Sustainable Development Goals has also added to this activism or impetus and governments are been monitored by interested Civil Society Organisations.

The issues yielding to the perceived unsatisfactory performance of the power sector are seen to be interconnected. As such, any professed solutions will suffer the constraint of the interplay of multiple factors which do not act in isolation. To support this presupposition, a web of causalities could be perceived where underinvestment in the sector contributes to inadequate generation, an inefficient transmission and distribution segment of the market without excluding the effects huge commercial losses have on the financial strengths of West African utilities. For that reason, Antmann (2009) and Eberhard et al. (2011) have highlighted that underinvestment in the West African power sector comes from the following:
- Smaller markets that are unable to offer economies of scale to investors
- Absence of cost-reflective prices
- Failure of counterparties to honour contracts especially governments not paying subsidised portions of prices on time.
- Poor regulation of the electricity market

In this research, the attention is drawn to the above factors especially issues regarding the effective regulation of the electricity supply industry as well as the related inefficiency of the electricity distribution sector. It is believed that in an attempt to promote accessibility and affordability of electricity to a wider West African community the above concerns are crucial and demand close attention. It is important therefore to understand industry practices and the roots of the inefficiency problem, which continue to reduce investment returns or benefits in the power sector, and thus hold development back. In the section following, an outline of the aim, questions and objectives that this research seeks to answer are discussed.

1.1 Research Aim, Questions, Objectives and Themes
This research is intended to afford an understanding of the efficiency concept, its measurement and application in electricity distribution as well as to comprehend the underlying causes of inefficiency in the West African context to support decision making for regulators, management of EDCs and policy makers.

The specific research questions drawn from the above aim are listed below as follows:

- How efficient are the electricity distribution companies of the ECOWAS Block?
- What are the relative efficiencies of electricity distribution companies in the West African Sub-region?
- What are the driving forces culminating into inefficiencies in the distribution sector?
- What regulatory and managerial processes and procedures could be recommended to improve efficiency of electricity distribution companies in the sub-region?

In an attempt to answer the above questions, the research seeks to achieve the following objectives:
• To theoretically and empirically investigate and identify the best approach for measuring efficiency.

• To empirically determine the relative efficiencies of electricity distribution companies in the ECOWAS Block

• To investigate the drivers or causes of inefficiency of distribution companies.

• To recommend policy actions which are internal and external to the operations of the Electricity Distribution Companies of West Africa.

The research is divided into three themes that are designed to achieve the above objectives. The first theme develops a theoretical framework for measuring efficiency while the second theme applies this framework to measure the level of efficiency of the electricity distribution sector of West Africa. The third theme investigates the possible causes and interventions from a political economy perspective. An overview of the different methods applied in the research themes are briefly explained in the section below. Further detail of the methods used in each part of the research are contained within the subsequent core analytical chapters.

1.2 Research Methodology
For theme 1, developing an approach for measuring efficiency that is appropriate for the West African context, a review was conducted of stochastic frontier techniques, with critical debate about the preferred statistical distribution to be assumed for the inefficiency term, as well as whether different distribution types effect changes on the ranking of firms or units analysed. In contributing to the above debate, this study incorporates a Burr Type-X distribution (called Burr X here after) that could augment the stochastic frontier techniques traditionally used for measuring efficiency. Efficiency estimates and parameter estimates from a proposed Normal–Burr x stochastic frontier model as well as those from the existing stochastic frontier models (Normal-Exponential and Normal-Rayleigh) are tested to investigate whether the choice of model affects the efficiency ranking of the firms.

For the second theme, various stochastic cost frontier models are employed to measure cost efficiencies of 14 EDCs in West Africa. Different stochastic frontier panel models run over different distributional assumption are applied to an unbalanced panel of 15 EDCs in Ghana, Nigeria, Togo and La Cote D’Ivoire and a comparator EDC from East Africa.
Finally, for the third theme exploring the causes of the relative inefficiencies identified in the second theme, the Political Economy Analyses (PEA) method is chosen and applied. Using this approach, both quantitative and qualitative data are collected and analysed in order to appreciate the views of consumers, industry and policy experts and other stakeholders regarding the inefficiency problem of the electricity distribution sector. In the quantitative analyses, a structural equation model is used to verify the questionnaires used as well as the perception of consumers and other stakeholders on the inefficiency problem. Using the PEA framework, it becomes possible to investigate the potential incentives and interests of political and economic actors that interact to sustain the inefficiency problem in the sector.

1.3 Thesis Contributions
Contributions to the subject area are twofold. The first is the empirical efficiency studies done on EDCs in the ECOWAS region. There are numerous narratives on the inefficiency of the electricity distribution companies in the sub-region but no empirical work has been done at the block level to support or oppose these assertions. This research provides therefore the first comparative study done on the cost efficiency performance of the Electricity Distribution Companies in West Africa. Policy makers and regulators in West Africa can use the cost efficiency analysis to inform the development of price controls and other regulatory measures. Secondly, the construction, modelling and investigations executed with the proposed SFA based on Burr X is novel to the productivity and efficiency field. This implies that the study joins the novel works by Aigner, Lovell and Schmidt (1977) for Normal-Half Normal, Greene (1990) for Normal-Gamma and by Stevenson (1980) for Normal –Truncated Normal stochastic frontier models. In this regard, the SFA classical models have been augmented by incorporating a competitive stochastic frontier model based on Burr X distribution. The major contributions of this research are captured below as:

Empirical and political economy analyses of the inefficiency problem in the electricity distribution sector of West Africa could support decisions of regulators and policy makers.

Initiation of an important step in measuring the relative cost efficiencies of EDCs which is crucial to both regional and national regulators especially in an infantile regional power market of the sub-region.

Improving on the existing techniques of measuring efficiency by investigating the potential of Burr type-x distribution the famous Stochastic Frontier Model.
1.4 Thesis Structure
This thesis is organised as follows: Chapter 2 reviews the literature and stylized facts of the electricity industry of West Africa as well as providing a review on efficiency measuring approaches.

Chapter 3 represents the first theme of the research: it discusses further the SFA methodologies and constructs an SFA based on Burr type X distribution as well as testing the robustness of the latter.

Chapter 4 represents the second theme: it investigates the relative efficiencies of the EDCs in West Africa using the Panel SFA models based on various distributions.

Chapter 5 represents the third theme: it applies Political Economy Analyses (PEA) to appreciate the sources of inefficiency as well as possible solutions. It employs the PEA framework and executes both qualitative and quantitative analyses in order to reveal the actions of political and economic agents which support or oppose efficiency efforts. This chapter also investigates the reactions of customers to an inefficient electricity distribution sector.

Chapter 6 synthesises all the chapters discussed and captures major findings and their implications on policies governing the efficiency of electricity distribution sector.

Chapter 7 concludes and illustrates contributions made by the study as well as suggestions for possible future work.

The structure of the thesis in figure 1.2 shows the aims, questions, objectives, main research themes, methods, data collected, results and analyses as well as the synthesis of the thesis.

Following this introduction is chapter two which gives an overview of the electricity sector of the West African area as well as reviewing the theory and empirical applications of efficiency measuring techniques.
Figure 1.2: Thesis Structure

<table>
<thead>
<tr>
<th>Theory, Application and Policy of Efficiency Regulation: the case of the West African Electricity Distribution Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AIM</strong></td>
</tr>
<tr>
<td>Understanding the inefficiency problems in electricity distribution sector of West Africa</td>
</tr>
<tr>
<td><strong>STUDY AREA</strong></td>
</tr>
<tr>
<td>Nigeria, Ghana, La Cote D’Ivoire, Togo, Benin (West Africa)</td>
</tr>
<tr>
<td><strong>RESEARCH QUESTIONS</strong></td>
</tr>
<tr>
<td>• How efficient is the electricity distribution sector of West Africa?</td>
</tr>
<tr>
<td>• What are the relative efficiencies of EDCs in West Africa?</td>
</tr>
<tr>
<td>• What factors drive inefficiencies in the distribution sector?</td>
</tr>
<tr>
<td>• What recommendations could improve efficiency in the sector?</td>
</tr>
<tr>
<td><strong>OBJECTIVES</strong></td>
</tr>
<tr>
<td>• To investigate and find best technique to measure efficiencies of EDCs</td>
</tr>
<tr>
<td>• To empirically measure relative efficiencies of the EDCs in the sector</td>
</tr>
<tr>
<td>• To investigate the drivers of inefficiencies in the sector</td>
</tr>
<tr>
<td>• To recommend managerial and policy actions to improve efficiency</td>
</tr>
<tr>
<td><strong>RESEARCH THEMES</strong></td>
</tr>
<tr>
<td>Efficiency Modelling Theory</td>
</tr>
<tr>
<td>Empirical Efficiency Measurement (WA EDCs application)</td>
</tr>
<tr>
<td>Policy (Political Economy Analysis of the Inefficiency Problem)</td>
</tr>
<tr>
<td><strong>METHODS</strong></td>
</tr>
<tr>
<td>MLE</td>
</tr>
<tr>
<td>Stochastic Cost Frontier Analysis</td>
</tr>
<tr>
<td>PEA Framework with Mixed Methods</td>
</tr>
<tr>
<td><strong>DATA COLLECTED</strong></td>
</tr>
<tr>
<td>• Simulated output and input Data</td>
</tr>
<tr>
<td>• EDC Financial Cost Data</td>
</tr>
<tr>
<td>• Technical &amp; Operations Data</td>
</tr>
<tr>
<td>• Regulatory Data</td>
</tr>
<tr>
<td>• Output Data of EDCs</td>
</tr>
<tr>
<td>• Consumer Data</td>
</tr>
<tr>
<td>• Views from stakeholders</td>
</tr>
<tr>
<td>• Electricity policy reforms</td>
</tr>
<tr>
<td>• Policy Roadmaps</td>
</tr>
<tr>
<td>• Regulatory Information</td>
</tr>
<tr>
<td>• Electricity Tariff Structure</td>
</tr>
<tr>
<td>• Gen. Trans &amp; Distribution Plans</td>
</tr>
<tr>
<td><strong>RESULTS &amp;</strong></td>
</tr>
<tr>
<td>• MLE Estimates</td>
</tr>
<tr>
<td>• Burr SFA Test</td>
</tr>
<tr>
<td>• Estimation Results</td>
</tr>
<tr>
<td>• Efficiency Results</td>
</tr>
<tr>
<td>• SEM (Validation)</td>
</tr>
<tr>
<td>• Quantitative &amp; Qualitative</td>
</tr>
<tr>
<td><strong>DISCUSSION</strong></td>
</tr>
<tr>
<td>Theoretical</td>
</tr>
<tr>
<td>Practical</td>
</tr>
<tr>
<td>Policy</td>
</tr>
<tr>
<td>Synthesis</td>
</tr>
<tr>
<td><strong>CONCLUSION &amp; FUTURE WORK</strong></td>
</tr>
<tr>
<td>Key Findings</td>
</tr>
<tr>
<td>Recommendations</td>
</tr>
<tr>
<td>Future Work</td>
</tr>
</tbody>
</table>
Chapter 2

West African Electricity Market and Literature Review

2. Chapter Overview
This chapter first presents an exploration of the structure and regulation of the electricity markets in West Africa on a country by country basis, through critical review of both academic literature and national documents. It looks at available electricity resources, electricity generation capacities, regulatory evolution and an ECOWAS regional power pool agenda. The first part of the review concentrates on the subject matter of Ghana, Nigeria, La Cote d'Ivoire, Togo and Benin as sample countries. These countries are chosen to be adequately representative of West Africa entirely.

The second part of the chapter provides a critical review of the theoretical frameworks for efficiency and frontier analyses. It explores the concept of efficiency and its measurement techniques, with emphasis on the stochastic frontier approaches. In this second part of the chapter, the debate surrounding the preferred statistical distribution assumed for the inefficiency term in the stochastic frontier technique is explored. It is then followed by a discussion of the features or properties of the Burr distribution, as an approach potentially to enhance the robustness of the stochastic frontier model.

2.1 Background to the West African Electricity Industry
As already highlighted, Africa is very diverse and so is the West African region. The people may have a common ancestral line but are very varied in their culture, tradition and laws. This is not different when it comes to the electricity or power industry. There may be commonalities in their approaches but roles, institutions, markets and regulatory environment may be different in many ways. This exploration of the West African Power Sector puts emphasis on the evolution of the power sector, reforms, institutions, stakeholders, and electricity statistics as well as the regional approach to making electricity affordable and accessible to all. The demand-supply gap is highlighted and it is even made more relevant as it is linked to the implications of an inefficient electricity distribution sector. This then lays a firm foundation for the aim of the research. The need for an efficient electricity system, with a suitable regulatory regime, is prime and one of the initial steps is to understand the current sector in detail.
The chapter has its primary focus on understanding the West African power sector: the following sections explore the electricity industry in a selection of the most significant economies, followed by a broader review of the situation in the rest of the region.

2.1.1 Evolution of the Power Industry of Ghana

The energy sector of Ghana commenced its institutionalisation with the creation of a Ministry of Fuel and Power in 1978 in response to the energy crisis of the late 1970s. After the enactment of the National Energy Board (NEB) Law, (PNDC Law 64), the Board was charged with the mandate to formulate policies and plan the energy sector. The NEB’s introduction of the Energy Fund to provide support for the sector was one of the innovative interventions brought on board. This fund was serviced by levies imposed on petroleum products and electricity. (Edjekumhene, Amadu and Brew-Hammond, 2001)

A form of horizontal unbundling emerged when Northern Electricity Department was set up in 1987 as a way to deepen service delivery, increase access and enhance asset management in the northern part of the country and at this point the Electricity Corporation of Ghana lost its distribution charge over the Northern part of Ghana. Upon the introduction of Statutory Corporations Act 461, the Electricity Corporation of Ghana was among the 35 state-owned companies that were converted to public liability companies. The rationale behind this drastic reform was to promote private sector participation and investment, reduce government’s influence on the operations of these institutions, improve financial and technical efficiency and reduce government expenditures in these companies. The then electricity supply industry as seen in figure 2.1 lacked private-sector participation as all the generating and distribution companies were publicly owned entities. In this phase, the electricity tariffs were also set by the individual institutions and approved by government. There were no independent supervisory or regulatory bodies to advise the industry and inefficiency costs were allowed to pass through to consumers.
The less diversified hydro-based power sector was stressed as a result of low levels of rainfall in the late 1980s. The low water levels of the dams which reduced the available capacities of the hydro plants coupled with rising demand was governments motivation to source funding to invest in thermal plants. A condition precedent to access credit facilities from the World Bank (traditional financier), most developing countries were compelled to initiate regulatory reforms to make their electricity markets more attractive to private participation in order to inject competition with the hope of improving efficiency like the Latin American experience. According to Edjekumhene, Amadu and Brew-Hammond (2001), the government of Ghana was not treated differently under the above caveat when they requested for a loan from the World Bank. The Government of Ghana therefore proposed a restructuring policy paper in 1994.

The objectives of the reform included structural changes within the sector to bring about competition in supply, transparency in the regulation of the sector operators, effective commercialization of operations of electricity utilities and encouragement of private investment in the development of the electricity sector. Specifically, the reforms targeted the following objectives:

- Ensuring proper policies and incentives to expand electricity access to spur growth, improve productivity, service delivery and the quality of life, and institute programmes to enhance energy efficiency.
• Regulating the sector to make each part of the sector operate with economic efficiency;
• Delivering electricity and electricity-related services to customers in an efficient and cost effective manner, while ensuring the sector’s financial viability
• Harnessing Ghana’s as well as the region’s rich energy resources for development and making the necessary policy and institutional changes to pass on the economic benefits equitably to the people of Ghana
• Increasing efficiency of asset utilization and thereby determining a realistic level of investments needed to meet energy demand created by growth.

In 1997, in an attempt to achieve transparency in the regulation of the sector, two bodies, the Public Utility Regulations Commission (PURC) and Energy Commission (EC) were formed under the Act 538 and Act 541 respectively (PURC, 1997). PURC is charged with tariff or rate setting and monitoring of quality while the EC is charged with licensing of utilities and providing technical standards and indicative planning.

Mandates of PURC include:

• To provide guidelines on rates chargeable for electricity services
• To examine and approve the rates
• To protect the interests of consumers and providers of utility services
• To monitor the standard of performance of the utilities
• To promote fair competition

The EC’s specific regulatory mandates are under-listed as follows:

• To receive and assess applications and grant licenses to public utilities for the transmission, wholesale supply and distribution of electricity
• To establish and enforce, in consultation with PURC, standards of performance for the relevant public utilities
• To promote and ensure uniform rules of practice for the transmission, wholesale supply and distribution of electricity.
Reforms is ongoing in the Ghana Electricity Supply Industry. Specific objectives or activities were proposed in attempt to achieve the reform objectives. The figure below assesses the level of achievements per proposed task.

**Figure 2.2: Power Sector Reform and Achievements**

<table>
<thead>
<tr>
<th>Power Sector Reform Proposal</th>
<th>Level of Achievements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establishment of regulatory framework</td>
<td>Public Utilities Regulatory Commission (PURC) and Energy Commission (EC) established by separate Acts of Parliament in 1997 to carry out economic and technical regulation respectively.</td>
</tr>
<tr>
<td>Unbundling of VRA</td>
<td>Volta River Development Act (Act 629) was enacted in 2005 leading to VRA’s unbundling into Generation (VRA) and Transmission (GridCo)</td>
</tr>
<tr>
<td>Establishment of Unregulated Market alongside the Regulated Market for IPP’s to sign long term bilateral contracts with Bulk Customers</td>
<td>Bulk Customers classified and framework established for entry into bilateral contract with a supplier of choice and prices are unregulated. Prices at which power is sold to distribution utilities are however regulated.</td>
</tr>
<tr>
<td>Performance contract for ECG and VRA</td>
<td>Yet to be implemented</td>
</tr>
<tr>
<td>Creation of 5 distributional concessions and privatize.</td>
<td>Yet to be fully implemented. One distribution and sale license granted to a private company to operate in an industrial enclave within the franchise area of ECG in 2010.</td>
</tr>
<tr>
<td>Decomposition of ECG into Strategic Business Units (SBUs)</td>
<td>Demarcation has been done but the implementation is mainly on hold</td>
</tr>
<tr>
<td>Competition at generation</td>
<td>A proportion of 75%:25% for VRA and IPPs in terms of generating plant installed capacity.</td>
</tr>
<tr>
<td>Execution of regulatory and technical rules for the grid and creation of wholesale market</td>
<td>National Electricity Grid Code and Wholesale Electricity Market Rules developed but operation of the wholesale market not fully operational. An oversight team has been put in place.</td>
</tr>
</tbody>
</table>

*Source: Sarpong (2013)*
Reforms have caused major changes in the structure of the Electricity Supply Industry in Ghana. There are IPPs operating competitively at the generation level. The transmission company, Gridco, established in 2006, operates Ghana’s National Interconnected Transmission Service (NITS). Generation companies can access the transmission system for onward delivery to Electricity Distribution Companies. Three distribution companies have their operations in three distinct zones which are southern zone, Northern zone and Tema free-zone enclave. Apart from Bulk Consumers (Consumers of 3MVA or with annual consumption of more than 6GWh), other consumers do not have the choice to negotiate pricing or to change suppliers and are charged a universal tariff. The retail end of the chain has not been developed. Creating a competitive retail market has the potential to improve on service quality and efficiency of delivery of power as observed in many developed countries. The current state of affairs of the ESI of Ghana can be deduced in the energy statistics discussed further in this section.

Electricity accounted for 13.7% of aggregate final energy consumed in 2016. This has significantly increased given that 2010 recorded 12%. Nonetheless petroleum and biomass continue to dominate consumption. In 2016, non-residential and special load tariff (SLT) consumers (Bulk consumers of generating companies and SLT consumers of distribution companies) accounted for 55.2% while the residential sector used up about 39% of total final electricity consumed.
Electricity consumption consistently shows an increasing trend with rising peak demand shown in figure 6 below:

**Figure 2.6: Peak Demand Trend of Ghana**

Generational investments have been reactionary to power shortages and fixing crisis but not according to national plans executed in advance to meet projected demand. The sources are dominated by Hydro and thermal with the latter beginning to capture a bigger share of about 55%. The concentration of Hydro sources pose a high risk to the sustainability of the electricity supply system as drought weather causes low water levels which constrains operating plants at full capacities. Figure 2.7 shows the decline of capacity as dam water levels reduce in the Akosombo dam.

**Figure 2.7: Water Level and Electricity Produced By Akosombo Dam**

![Water Level and Electricity Produced By Akosombo Dam](source)

*Source: Energy Commission (2016)*

The trend of demand and supply requires an interrogation as to whether the system can or cannot sustain the future demand. Referring to table 8, by 2022, there will be a surplus generation capacity of 20MW which is inadequate to secure the future from that year onwards. There is a possibility to avoid adding more capacity in the near future if losses in transmission and distribution are significantly reduced. This will reduce the level investments required and finally reduce the cost of power production.
Table 2.1: Projected Demand

<table>
<thead>
<tr>
<th>Year</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected System Demand (MW)</td>
<td>2,646</td>
<td>3,128</td>
<td>3,462</td>
<td>3,712</td>
<td>3,828</td>
</tr>
<tr>
<td>Total Supply Required (Demand + Reserve)</td>
<td>3,308</td>
<td>3,910</td>
<td>4,327</td>
<td>4,640</td>
<td>4,784</td>
</tr>
<tr>
<td>Total Existing Hydro Capacity (MW)</td>
<td>1,120</td>
<td>1,120</td>
<td>1,120</td>
<td>1,120</td>
<td>1,120</td>
</tr>
<tr>
<td>Total Existing Thermal Capacity (MW)</td>
<td>2,362</td>
<td>2,462</td>
<td>2,462</td>
<td>2,462</td>
<td>2,462</td>
</tr>
<tr>
<td>Total Existing Renewables (MW)</td>
<td>22.5</td>
<td>22.5</td>
<td>22.5</td>
<td>22.5</td>
<td>22.5</td>
</tr>
<tr>
<td>Committed Generation Projects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Karpower Phase II</td>
<td>220</td>
<td>220</td>
<td>220</td>
<td>220</td>
<td>220</td>
</tr>
<tr>
<td>CENPOWER</td>
<td>360</td>
<td>360</td>
<td>360</td>
<td>360</td>
<td>360</td>
</tr>
<tr>
<td>Early Power</td>
<td>142</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>GPGC</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>VRA T3</td>
<td>0</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Total Committed Generation (MW)</td>
<td>822</td>
<td>1,100</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
</tr>
</tbody>
</table>


Diversity is an issue as renewables form a negligible part of the generation mix. There is the Renewable Energy Act that is yet to be supported by a Renewable Energy Master Plan but there are small scale projects already springing up in solar and waste to energy. PURC has already designed a Feed-in Tariff arrangement for the different renewable energy types. Funding of renewable energy projects encounters challenges that are quite distinct from funding for other forms of energy generation.

Power outages which called for power rationing and unreliable power (locally called “Dumsor” which literally means “on and off”) from 2012 to 2016 and an accompanying reactionary-investment in new power badges, capacity expansion of existing plants and installation of solar plants. This period caused significant economic derailment as an economy that was initially growing in the region of 11% was dragged to a growth of 3.6%.

Owing to the type of PPAs (Power Purchase Agreement), the average electricity tariff increased over the last three years (2014-2017) from 13 Cents to about 22 Cents.

Figure 2.8: Average Electricity Tariff of Ghana

There has always been an unavoidable debate when it comes to tariffing because of two important stakeholders’ predicament. First, customers are not willing to pay more for the poor quality of service in order that the utilities can provide the required investment to refurbish the supply system. Second, there is a political angle which is a disincentive to government’s support for realistic pricing. Any attempt to support price hikes has a potential to affect the popularity of the party in power. That apart, to win the political will of a particular area, government is pressured and encouraged to coerce the utility companies to take certain investment decisions that may not be economically beneficial to the utility companies and some consumers.

Figure 2.9: Electricity Generation Trend of Ghana

![Electricity Generation Trend of Ghana](image)


According to the Electricity Supply Plan for Ghana Power System, transmitting electricity is achieved mainly through a 161 kV network with a 69 kV network in the Volta region and two 330 kV circuits. Ghana grid is connected to Cote d’Ivoire by a 225 kV tie-line while Togo and Ghana are interconnected by two 161 kV tie-lines. The National Interconnected Transmission System (NITS) consists of approximately 5,207.7 circuit kilometres (km) of high voltage transmission lines which connect generation plants at Akosombo, Kpong, Tema, Bui and Aboadze to sixty four (64) Bulk Supply Points across the nation. The transmission lines involves of 364 km of 330 kV line, 4,636.6 km of 161 kV and 132.8 km of 69 kV lines. Also there is a single circuit 225 kV tie-line of 74.3 km connecting GRIDCo network with CIE of Cote d’Ivoire. (Ministry of Energy, 2017)

Transmission in terms of area covered has improved significantly through the National Electrification Scheme (NES) and the SHEP 4 Programme. As per the Energy Commission
Strategic Plan for 2014, about 75 percent of the total number of communities have been connected leaving about 80,000 communities with an average population of 100. Even though direct access to electricity by individual households in rural communities differ significantly from urban settlements, it is still an indication of significant progress with the 30-year electrification project. However, in terms of technical efficiency, it is rather unfortunate that there is a continuous increase in transmission losses due to the disproportionate replacement of dilapidated transmission facilities emanating from unsuccessful recoupment of revenue which will incapacitate these utilities to replace obsolete capital with modern and high-technological facilities. Below is figure 9 which shows the transmission losses of the grid system.

**Figure 2.10: Electricity Transmission Losses of Ghana**

Financial strength of the transmission utility, GRIDCo, has increased substantially from a loss of GHS 685 Million in 2009 to a profit of GHS235.62 Million in 2011. According to GRIDCo’s annual report for 2011, revenues due to the increased generation and peak demand as well as the increment in tariff by the PURC were the factors that contributed to the enhanced financial position of the company.
Even though electricity supply hardly meets demand for its consumers, Ghana through bilateral and regional agreements, continue to export power to neighbouring countries including Togo, Benin, Burkina Faso and La Cote D’Ivoire. Also, Ghana imports power from La Cote D’Ivoire when necessary. There is an opportunity with Ghana being a major exporter of electricity in West Africa to take advantage of the regional market underway in West African Power Pool (WAPP) Project. In the context of inadequate energy resources, the next section reviews the operations and regulation of distribution utilities in Ghana.

2.1.2 Electricity Distribution and Regulation in Ghana

Distribution of Electricity is faced with challenging issues regarding quality of service and it is the sector that is most criticised. However, this manifestation is not unexpected as it is the closest of the value chain to the majority of consumers (discounting other wholesale purchasers like the mines and VALCO). From Figure 2.12, distribution losses record more than 20%. The ECG accounts for more losses than NEDco and that is expected because of the bigger market share the former has. These losses are substantial and could explain why the industry finds it challenging to manage a maximum peak load in the region 2300MW when an installed capacity exceeds 3000MW.
Thus the solution does not lie entirely in increasing generation capacities but also augmenting technical and economic efficiencies of distribution and transmission companies could increase electricity supply to the end-user at much reduced cost. Limitations of cost recovery inherent in electricity pricing methodologies, unmetering of consumers and uncollected bill payments have contributed to the low investments in the already deteriorated facilities which give rise to huge losses. There have been many reforms on tariffs to recoup the initial investments into thermal generation which required importing fuel at very high cost in the face of the depreciation of the local currency. The tariff increases in the late 1990s was depleted by a surge in inflation and so a further increment was effected to partially correct for high price levels. To help the poor a lifeline rate was set for consumers in the bracket of...
0KWh-50KWh. Now in operation in theory is the automatic adjustment formula which the regulator is not strict on because of interferences from the government among other factors.

In Ghana, the many reforms have as yet to yield significant impact towards the sustainability of the electricity distribution sector. As discussed in the context of many African countries, ESMAP (2005) suggests that the issues surrounding pricing below cost recovery levels and unpaid subsidies have disadvantaged all the companies in the value chain. With ECG (Electricity Company of Ghana) as an example, the efforts made towards improving technical and financial efficiencies have not yielded significant results given that losses are still in the range of 23%-30% for distributed power and an increasing trend in operating profit margin of 32.1% in 2009 to loss margin of 94.5% in 2012. These indicators are expected to improve in the era of increased turnover (customer size) and revised prices but it is not the case with ECG. Quality of service to final consumer is not satisfactory and the company continues to perform poorly against the set targets for reliability and quality of service. Nonetheless the blame cannot be entirely apportioned to the distribution companies since inefficiencies at other points in the value chain have the potential to increase the cost of distributed power. The inefficiencies associated with generation and transmission pass through the chain resulting in higher prices that come with its consequences including power theft and non-payment of bills at the distribution and retail segments.

Regulation of EDCs in Ghana is in the ambit of PURC and the EC. The latter deals with technical regulation while the former deals with the economic regulation. The PURC (set up by Act 538) which is in charge of tariff and customer related issues operate a hybrid Rate of Return (RoR) regulation. Tariff proposals are submitted by the EDCs and the Commission applies their pricing model to ascertain cost recovery with a fair rate of return on their investments. Ideally, the process considers and prevents pass-through cost emanating from inefficient operations of the companies without disregarding compensation for additional objectives such as pursuing targets for national universal access to electricity (PURC, 1999). Tariff is also automatically adjusted by trends of inflation, exchange rates and other variables (PURC, 2011). As expected, in a traditional RoR regulation, there is a function of efficiency where tariffs are adjusted based on the level of efficiency target achieved by the EDC. PURC is also faced with the common short-comings of RoR which includes possible indiscriminate investments and the problem of moral hazard. Hence, PURC’s attempt to cure these
shortcomings by computing tariffs less a productivity factor. Aside that, the tariff calculator incorporates an index of quality of service performance which includes reliability of the supply, customer satisfaction and others though these measurements may not be completely unambiguous.

The efficiency measurements applied to the tariff methodology are unidirectional proxies of efficiency represented by simple ratio measures. They include energy sold per employee, outage per circuit kilometre, operating cost per employee, losses per customer and many more. These proxies are partial measures and not comprehensive enough to represent the entire inefficiency of the EDC. These proxy measures introduce a certain level of unfairness and introduces tariffing defects. For a regional market with various EDCs, this problem is bound to occur and a better efficiency measurement needs to be utilised instead of simple ratios.

Ghana’s future electricity supply requires more investment and the minimum both EDCs and consumers can do is to be more efficient in the distribution and usage of electric power. Tariffing methodologies which employ a comprehensive efficiency estimate cannot be underestimated in the RPI-X function in order to pursue an effective incentive regulation regime. By this, the regulated segment could be incentivised to be more efficient to reduce total waste of electricity.

In the section following the research explores the Electricity Supply Industry of Nigeria. Contextualising efficiency issues in Nigeria is such an important element of our review as it consumes more than half of the total power used in West Africa even with a lower electrification rate. That apart, the review explores the power market development process in order that differences and similarities to the Ghanaian case can be more comprehensible.

2.1.3 Background to Nigeria Electricity Sector
This section commences by giving a brief history of the Nigerian Power Sector Reform. It was 1886 when a Diesel power plant with a capacity of 20MW was installed in Lagos. Other plants of lower capacities began to proliferate in other parts of the country. Then followed the formation of Electricity Corporation of Nigeria in 1951, the establishment of Niger Dams Authority in 1961 and the bundling of these two in 1972 to form the vertically integrated NEPA. In this new agency where power sector monopoly was typified, generation, transmission and distribution were thus under the supervision of a single establishment.
Power challenges exacerbated in the 1990s and as a matter of reforms NEPA was partly commercialised by the appointment of a managing director and subsequent separation of the agency into four autonomous divisions, each headed by an executive director. The 2001 National Electric Power Policy actually set the pace for the reform agenda as it aimed at attracting private sector investment, establishing a transparent regulatory framework, promoting divestment of government investment and enhancing competition and a liberalised electricity market.

In 2005, the Electric Power Sector Reform Act (EPSRA) was enacted which then provided the legal backing for the reform and its related objectives:

- “To provide for the formation of holding company and successive privately owned companies to take over the functions, assets, liabilities, and staff of Nigeria Electric Power Authority (NEPA)
- To develop competitive electricity markets
- To establish the power sector regulatory agency to be known as the Nigerian Electricity Regulatory Commission (NERC)
- To prescribe the procedure for licences and tariffs for power generation transmission, distribution, system operation, and electricity trading
- To prescribe the procedure for consumer protection and licensee performance and enforcement of these obligations
- To stipulate the process for competition and market power
- To provide for the Power Consumer Assistance Fund and Rural Electrification Fund. “

(NERC, 2015)

In order to enhance economic growth, development, and transformation in Nigeria, the main goal of the reform is to increase efficiency, accessibility, reliability, and affordability of quality electricity supply.

Roadmap for Power Sector Reform developed in 2010 and revised in 2013 outlines Nigeria’s plans to accelerate the reforms according to the dictates of EPSRA. The Presidential Action Committee on Power (PCAP) inaugurated in the same year and with the Presidential Task
Force on Power as the executive, was tasked to drive implementation of the reform process with speed.

Again by the dictates of EPSRA, first, an initial holding company (PHCN) was established for the state-owned NEPA which was subsequently unbundled. 18 successor companies emerged from which 11 are distribution companies, 1 being a transmission company (TCN) and 6 generating companies. While the generation and distribution segment of the power sector are completely privatized, the ownership of the transmission process is retained by the federal government but contracted to be managed on behalf of the government by Manitoba Hydro International (MHI). The management contract at the transmission segment was expected to attain improvements in technical and financial efficiency without sacrificing the transfer of skills/knowledge from the contractors to the local employees. By 2013 all the privatised successor companies were handed over. The above constituted the first set of actions for the first phase of the reforms while the establishment of a regulatory body (NERC) for sanity in the market represents the second action. This was followed by the incorporation of successor distribution and generation companies to take over the assets of PHCN. The creation of NBET was the forth and it was established to undertake electricity power trading and management of existing liabilities among the power market players. The creation of a training institute for the purpose of bridging the human capital gap birth NAPTIN which crowns the first phase of reforms.

The second phase is a medium-term horizon with the objective of attracting private sector participation by developing and using a cost-reflective electricity tariff to ensure competitive pricing. It is expected that in this phase, successor power companies would have been up and running (at least with bilateral trade transaction to be commenced). In the third phase, competition is expected to be deepened with a cost-reflective pricing structure and 80% dilution of government ownership of gas fired power plants. Table 2.2 assesses the achievements of reforms in the Nigerian Electricity Supply Industry.
<table>
<thead>
<tr>
<th>Reform Targets</th>
<th>Achievements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of a national policy</td>
<td>A structured and sufficiently robust policy has been successfully developed. The policy is continuously being reviewed and improved on. The most recent is the NREEEP on renewable energy.</td>
</tr>
<tr>
<td>Privatisation of the power industry</td>
<td>PHCN was has been unbundled and 17 private companies emerged for generation and distribution while TCN which not privatised, is under a management contract. Progress of privatisation is high with over 70 licenses issued to independent power producers. However, the expectation of a privatised industry is yet to be realised as the private sector is faced with problems of lack of funding, innovation and leadership in a market where the independent regulator is really not autonomous</td>
</tr>
<tr>
<td>Establishment of legal and institutional framework for effective delivery of reform.</td>
<td>Most of these targets have been met. NERC has been created as an industry regulator responsible for playing the role of a facilitator and enabler of activities in the sector through effective regulation and oversight of all stakeholders in the sector. Other institutions include TCN, NBET, NELMCO, Rural Electrification Agency, Gas Aggregation Company Nigeria Ltd (for growth of natural gas in the power sector) and NAPTIN</td>
</tr>
<tr>
<td>Establishment of a temporary Bulk Trader engaged in the purchase and resale of power and ancillary services from produces until a complete market is established</td>
<td>NELMCO initially was created for the task with NBET taking over subsequently. The Operator of the Nigerian Electricity Market was created for wholesale market settlement and responsible for metering system among generation, transmission and distribution firms. Duplication of roles may be a matter of concern and there may not be better reasons to justify the separation of roles for these two establishments.</td>
</tr>
<tr>
<td>Commercialisation of electricity market</td>
<td>In 2012, the tariffing system (MYTO) was designed and partially implemented in the Transition Electric Market (TEM) by NERC. However, at this stage it is not cost reflective and there are still liquidity challenges in the industry even though there is an agreed limited revenue allocation to the players. Ironically, government is still injecting funds in a rather privatised industry.</td>
</tr>
<tr>
<td>Increasing power generating capacity to a target of 40,000MW by 2020. Increasing rural electrification to 75%</td>
<td>From the trends in growth of generation capacity, this target seems to be over ambitious and may be unrealistic to be achieved even in the medium term.</td>
</tr>
</tbody>
</table>
Figure 2.14 below also shows the structure of the Nigerian Power market which is the product of the reforms. Eleven distribution companies, 6 generation companies (privatised) and one transmission company owned fully by the Federal Republic of Nigeria.

**Figure 2.14: Post-Reform Trading Arrangement for Nigeria’s Electricity Supply Industry**

With 11 electricity distribution companies with limited control over which franchise to operate and bearing in mind the inherent impediments or limitations of the allocated jurisdictions, it is proper to have a very formidable regulatory and pricing regime. The section below provides an understanding of the pricing methodology which is of immense importance to the objectives of this research.

### 2.1.4 Regulation and Efficiency of EDCs in Nigeria

The absence of a cost-reflective electricity tariff has been one of the main deterrents to local and foreign investor participation. MYTO was therefore introduced to correct this irregularity. By the methodology, it allows a minor review every six months and a major review annually. Also, consumers are classified into residential, commercial, industrial, special, and street lighting. MYTO 1 and MYTO 2 produced when the regulator works with basic process found in figure 2.15.
Distribution and commercial losses represent the level of inefficiency in this model and therefore the model gives an incentive for reducing the level of inefficiency of the distributor. Given the inconclusiveness of using unidirectional estimates of efficiency, the regulator may be unfair. MYTO 2 was developed after stakeholders raised concerns and consequently it made provisions for inflation rates, exchange rates, gas supply price, generation capacity, capital expenditure, operations expenditure, and cost recovery and reasonable return. Instead of an annual review in MYTO 1, there is a period of 15 years with a major review every 5 years until the market becomes fully competitive. A feature in the MYTO 2 is the inclusion of fairness and public interest as key factors. The fixed charge that was inherent in the current tariff system has now been excluded in prices of vulnerable customers and those operating in the informal sector. The MYTO methodology utilises a building block approach which is a combination of Price cap and RoR or cost of service regulation. It can be classified as a form of incentive regulation. The building block approach determines cost of providing electricity services and equate price to reasonable return to capital invested. Since the regulator expects an improvement in performance in terms of efficiency, financial viability and quality of service, the MYTO incentivises distribution companies to over perform the projected targets built in the tariff path. Three building block elements are considered in the methodology and they are Return on capital, Return of Capital and Operating Costs. The firm is thus compensated for its obligations to debt or equity providers, depreciation due to run down of
capital, fuel, and variable and fixed operating & maintenance, overheads and administration costs.

There are some challenges with regulation and the implementation of the MYTO methodology in the transition electricity market. Some of the issues are typical to many markets. For example even in the matured electricity markets, lack of a uniform reporting framework (including accounting standards) and monitoring performance of industry players still exist as challenges to the regulator. Specifically to the Nigerian Electricity Market, the difficulty of incentivising investments in generation is a major problem to the distribution companies that always draw in government to redeem the situation making it less ambitious as a privatised market.

In the next section, the discussion is centred on how reforms and policy changes including the MYTO regime have changed or influenced the statistics of the electricity supply industry.

2.1.5 Current State of Nigeria’s Electricity Supply Industry after Reforms

Figure 15 provides a summary of the losses across Nigeria’s power sector. It is evident in the figure that the Nigerian Electricity Supply Industry has had significant investment, but is unable to effectively utilise capacity to the full. About 69% of the installed capacity of generating plants are unavailable. Huge losses are incurred during transmission and distribution. As high as 46% accounts for the distributional technical, commercial and collection losses can be appreciated in figure 2.16.

**Figure 2.16: 2014 Technical and Commercial Losses in the Distribution Sector of Nigeria**

Source: NERC, Advisory Power Team
Power supply at the required quality remains a serious challenge for Nigeria despite her abundant energy resources. According to the 2013 GDP, Nigeria had the largest GDP close to US$510 billion and overtaking South Africa. Many firms experience on average 196 hours of outages per month which amounts to 8 days of unreliable power (figure 2.18). These firms and upper income consumers generate their own energy for their commercial and domestic operations (IEA, 2014). Even with the expedience of prosumers, about 8% of sales is lost annually by businesses in Nigeria.
According to Power Africa, out of the 6800 MW generating capacities, only 3600 MW is available due to gas supply constraints and seasonal hydro crisis. Putting it in context, Nigeria’s generating capacity compared with South Africa’s installed capacity of 40000 MW (0.78KW per capita) reveals gross underinvestment given that the latter has only a third of the population of the former.

At 125 kWh per capita, electricity consumption is one of the lowest in the world. The presupposition demonstrates the magnitude of demand and supply gap that exists in the electricity market. This gap seriously impedes the growth of the non-oil sector and, as a result, job creation and poverty reduction.

According to the African Development Bank (2010), out of the 45% of the population that have access to electricity, only about 30% of their demand for power is being met. The power sector is plagued by recurrent outages to the extent that some 90% of industrial consumers and a significant number of residential and other non-residential customers provide their own power at a huge cost to themselves and to the Nigerian economy.

ECREE (2014) shows Nigeria’s national electrification rate to be 48% which is less than that of Cote D’Ivoire, Ghana, Cape Verde and Senegal (figure 2.19). Given that Nigeria is the biggest consumer in West Africa, this statistics show the extent of the problem at the sub-regional level. The landscape of electricity generation, transmission and distribution has serious challenges but there are also huge investment opportunities to be realised should the stakeholders take a collective action to make the current reforms work.

In addition, while privatisation of the generation and distribution sectors is expected to increase supply and reduce inefficiency, the future of the Transmission Company of Nigeria is disturbing as investments in the system is not keeping pace with current and future installed generation capacity in the time of increasing demand. That apart, according to the Advisory Power Team (2018), distribution companies have not shown a clear improvement in operations and sustaining the sector liquidity maybe impossible without government’s urgent intervention. In summary, the reforms should be monitored closely to ensure that no part in the value chain is ignored to avoid a pass-through effect in the system that eventually impairs any progress made.
2.1.6 Electricity Situation in other West African Countries

Generally, West Africa is endowed with natural resources and has a high energy potential, however, installed capacity is around 10,640 MW of which only around 60% (6,500 MW) is fully functional to meet demand. It is therefore not surprising to a high section of the economy that is unserved with electricity and continue to use biomass or thermal generators. According to the AfDB (2011), total demand is growing, reinforced by an increasing rate of population and urbanisation, assessed to be about 22,000MW, far more than the actual generating capacity. This supply and demand gap is exacerbated by high commercial and technical losses estimated at 21.5% in West Africa in 2010 (ECREEE, 2014).
Most West African countries rely heavily on thermal power and obsolete power plants, which means that electricity costs in West Africa are among the highest in the world. An average of 17.9 Cents per KWh is higher than that of South East Asia and other parts of the world dominated by developing countries. High prices, low electricity access rates, unreliable supply of cheaper energy sources (natural gas), and climate change effect on relatively cheaper hydro power plants and high technical and commercial inefficiency have led to nearly 173 million of the West African population without access to electricity. (Refer to figure 2.23 below)
The electricity generation and distribution facilities in countries like Liberia and Sierra Leone were seriously damaged during recent military conflicts and construction has been disrupted. They are still seeking opportunities to rebuild their infrastructures with the help of the international community. Other countries in the ECOWAS region are without coastal access, such as Mali, Burkina Faso and Niger, which do not possess important energy resources and are likely to be dependent on electricity imports; and small countries of the coastal region (Benin and Togo) which already have established an integration of their bulk electricity supply that can serve as an antecedent to an integrated regional approach. Cote D'Ivoire, Senegal and Guinea have significant electricity resources and are contributing to the WAPP or have the potential to do so.

La Cote D'Ivoire has high prospects of natural gas and so about 75% of the country’s electricity plants are fuelled with natural gas. Senegal, unfortunately relies on crude oil while Guinea has hydro power that is extremely underutilised or underexploited. There is significant progress in La Cote D'Ivoire’s electricity market with increasing generating capacity and improved regulation. The country was the first in sub-Saharan Africa to turn to the private sector to expand its electricity generation capacity when the government, after opening up electricity production to competition, established Compagnie Ivoirienne de l’Électricité (CIE) in 1990 and granting it a concession covering the purchase, transmission and distribution of electricity. A second restructuring phase launched in 1998 was mainly geared towards the financial stability.
or enhancement of profitability in the ESI of Cote d’Ivoire—this time primarily focused on making the sector more profitable. A last reform was launched in 2011, when the state-owned company Société des Énergies de Côte d’Ivoire (CI-ENERGIES) was created to plan and manage investments in the power sector. Hitherto, the production of power was open to the private sector, but the transmission, distribution, import and export activities of electricity remained a State monopoly as per the Electricity Law of 1985.

The current authority in charge of regulating the electricity sector is the Autorité Nationale de Régulation du Secteur de l’Electricité (“ANARE”). The Electricity Code gives greater independence and authority to the ANARE by specifically providing that the regulatory authority is an independent legal entity with financial autonomy. The authority is in charge of overseeing the compliance with the laws, regulations and obligations under authorizations and conventions in force in the electricity sector; proposing electricity tariffs to the State as well as the tariffs to access the national grid; protecting users and consumers of the public services and as well as their rights; arbitrating disputes between operators or between operators and the State; and advising and assisting State in regulating the electricity sector. The Code addresses matters relating to contract terms and tariffing both in their quest to creating an industry that has reasonable technical and commercial losses and affordable prices.

Togo and Benin have a slightly complex electricity market built out of collaborations and partnerships with agents within and out of each of the countries. The VRA of Ghana, CIE of La Cote d’Ivoire and TCN of Nigeria are the major suppliers of electricity to Togo and Benin. In Togo, however with the funding aid from the IFC there has been an established IPP. Contour Global is an independent power producer which was established in 2010 with a 25 year concession arrangement. CEB (Communauté Electrique du Benin) is responsible for purchasing and selling power to the distribution companies of these two countries. The CEB delivers power to Benin’s distribution company, the Société Béninoise d’Energie Electrique (SBEE), Togo’s distribution company, the Compagnie d’Energie Electrique du Togo (CEET), and to large industrial customers. In Togo, the CEET (Compagnie d’Energie Electrique du Togo) which is the distribution company with some in-house generators distribute electricity to the lowly grid-connected urban and peri-urban areas (about 30% electrification rate on the
average). Rural electrification is extremely low at 5%. The Electricity supply industry is seen in the figure below.

**Figure 2.24: How the Electricity Supply Industry in Togo and Benin is Organised**

![Diagram of Electricity Supply Industry in Togo and Benin]

Source: SOFRECO (2010)

Regulation of the market is overseen by Ministry of Energy and a special set up called ARSE (Autorité de Réglementation du Secteur Electricité) set up in 2000 to advise the energy ministry on definition and implementation of subsector regulations and tariff proposals and decisions. Aside, advising on procurement activities it manages potential conflicts with concessionaire and consumers. However, given that CEB operates under a special code (Code Benino-Togolais of Electricity), ARSE’s supervision does not extend to it. The existing national regulations are not explicit with tariff setting and there is no well-defined methodology. Low access to electricity in rural areas and the lack of promotion of renewable energies in order to bridge the demand and supply gap requires specific policy and requisite plans. End use prices are still very high in the range of 19-21 US cents while technical and commercial losses are reported in excess of 24%.

The deliberation and the facts presented in the sections above suggest that the West African region has as yet to have an efficient electricity industry. Also, owing to the different strengths of the various member countries regarding energy resources, the ECOWAS commission is pursuing a regional energy integration agenda endorsed by an energy protocol in 2003. In the next section, the objectives, plans, regulation and possible limitations of the agenda are discussed.
2.1.7 ECOWAS and Power Sector Regionalisation

In 2003 and according to the ECOWAS (Economic Community of West African States) protocol on energy, all member states shall co-ordinate and harmonise their policies and programmes in the field of energy. Member countries are to ensure effective development of energy resources as well as establish adequate co-operation mechanisms with the view of ensuring a security supply of energy in the sub-region. It is explicit this Energy Protocol that the alliance is dedicated to promoting the development of new and renewable energy in the frame work of policies regarding diversification of energy sources. However, paramount of all is to join forces to ensure that countries that have adequate supply of energy are able to support other countries that lack capacity to even generate and supply energy sufficient enough to run their economies. The need for regionalisation has been based on the variation that exists in the different countries in terms of availability of energy resources as well as the recognition that through regionalisation, trade in energy and other commodities could deepen among member countries. The ECOWAS block intends to reduce the electricity supply deficit through the power pool concept by correcting issues of mismatch in the demand and supply of electricity, inadequate installed and available capacities of member states and the highly unsteady price of fuel and the inadequacy of tariff that compensate players fairly. Solutions to complement these problems aforementioned are viewed by the ECOWAS block as seen below:

- Development of generation and transmission infrastructure by encouraging private public partnerships
- Establishment of a regional market
- Establishment of regional regulator or regulatory framework.

Studies conducted by Gnansounou, Bayem and Bednyagin (2007) and others have justified the benefit of regionalisation by comparing the level of investments needed in two different strategies namely the integrated approach and the ‘autarkical’ strategy which consists of inadequate expansion of national power generation systems and the exchanges of electricity between the countries in sub-zones. They conclude that “integrated strategy which involves a total regional integration with the whole West African zone as one region is recommended in this article as it enhances fast retirement of the obsolete power plants and the integration of new investment projects.
On the other hand, the potential of regional power sector integration has been investigated by ESMAP (2010), which considers the lack of political will to be a key obstacle and it is envisaged that member states may ignore the wider regionalisation plans and concentrate on national plans as a result of challenging economic conditions of these less endowed countries. Barnett (2014) appreciates the aforementioned in his section of political economy of power pools by highlighting the intensive capital requirements as a deterrent to survival of the pools.

The establishment of the West African Gas Pipeline and the West African Power Pool projects by ECOWAS initiated the agenda for regional integration of the entire energy sector of the region even though prior to their set-up, there were bilateral/tripartite agreements and projects that linked and caused trade between countries.

**Figure 2.25: Import and Export of Electricity in the West African Power Sector**

![Import and Export of Electricity in the West African Power Sector](image)

**Source: ECREEE (2015)**

The regionalisation concept has been developed with a master plan and a regulatory body to ensure sanity and fairness among the market players. The master plan for 2012 to 2015 was explicit on their achievements and awaiting or pending priority projects. There are on-going projects in generation and transmission initiated by WAPP. There are various funding strategies and partners for each or a set of projects. They rely on external donors and private partnership for the execution of these projects. For the distinguished WAPP zone A (Cote d’Ivoire, Ghana, Togo, Nigeria, Niger, Burkina Faso, Benin and Niger) and WAPP zone B (Mali, Senegal, Guinea, Guinea-Bissau, Gambia, Liberia and Sierra Leone), there is a significant level of interconnection among countries especially in the former. For the Zone B, the only connection that exists is that between Mali and Senegal which enables power transmission
from the Manantali hydropower plant and SOGEM generation plant. For Zone A, all the countries are interconnected except for Niger which is only connected to Nigeria. However, among the priority projects for the near future includes the complete connection of Zone A and Zone B to allow for a complete regional trade. As per the plan, 5 exchange points are to be established to permit adequate control and scheduling of generation and transmission in the region. These exchange points are to be regulated by the ECOWAS Regional Electricity Regulatory Authority (ERERA) which was established in 2008 by a supplementary Act A/SA.2/1/08. This is charged with regulation of electricity exchange points and to assist regulatory institutions in member countries.

Aside investments being made by individual countries, WAPP intends to invest into maintaining an emergency supply by investing into a number of generation facilities. It is estimated in the update of WAPP’s master plan authored by TRACTBEL in collaboration with the Sector Ministries of member states that a global investment outlay of US$26.5 Billion is required to finance these regional priority projects for the period 2012-2025. These projects include 33 generation projects amounting to a sum of US$20 billion and 26 transmission projects showed with an estimated cost of US$6.5 billion. These typical project finance facilities proved viable with a positive NPV of US$12.1 billion for the entire region over the period 2012-2025.

2.1.8 Summary on West African Electricity Systems
The preceding sections presented an array of factors leading to the poor electricity supply in the various countries. In spite of the disparities between the countries, the West African Power Pool intends to create a regional market and envisage an improvement in the quality of service as well as regulate energy trade across this region. The issue of underinvestment, high technical and commercial losses are very important as far as these reforms are concerned and would be of prime interest to avert these challenges. Regulation of utilities in the ECOWAS sub-region could utilise incentive or benchmarking regulation which requires benchmark measurements including efficiency estimates and other parameters for price controls. Adopting a uniform way of measuring and comparing efficiency of utilities in the West African Power Pool could be a step in the right direction. Economic efficiency, technical efficiency and financial efficiency are some of the indicators to start tracking for peer reviewed pricing or tariffing regimes of the electricity sector. It is expected thus to answer the
question: what drives energy efficiency in distribution companies of West Africa (since most losses are made at the distribution sector). Another question regarding how economic energy efficiency or technical efficiency relates to financial efficiency of utilities in the WAPP could be probed into much further. Of great relevance to the above critical investigations is to provide confidence to investors and member states with the sole motive to revealing the benefits of regional integration reforms and regulation in order to make them more committed to the electricity industry integration agenda of ECOWAS.

Another important common issue, but varying in terms of application, is the subsidisation of electricity in the entire region which has been a set-back to potential investors and leads to the inefficient use of energy by the segment of the economy who are in the high income bracket. It is true that Governments make up the difference in tariffs but may take longer time as these member states struggle to meet their normal budgetary expenses. Such prolonged repayment of subsidies manifests itself in the continuous financial weakness of national utility companies and IPPs with the former expected to even be worse of as governments are mostly the sole or majority shareholder.

Even though experiences of many developed competitive markets have given rise to lower prices of electricity, it is still important given the longstanding ‘investor and member country fears’, to be able to model the possible competitive pricing outcomes of WAPP so as to minimise the uncertainties regarding total commitment of investors and member states.

While agreeing to the grave importance of the potential investigations discussed above, the significance of a robust efficiency measuring technique in regulation at both the national and regional levels cannot be stressed enough. Even more important, is the application of benchmarking regulation in the electricity market which calls for a fair, robust and uniform or standard methodology to measure relative efficiencies which allows for both discretionary and non-discretionary parameters. Non-discretionary factors may include those beyond the control of management. Such factors include economic, regulatory, geographical, climatic and other conditions that can affect the cost and quality of service performance of utilities as discussed in Growitsch, Jamasb and Wetzel (2010). Thus the use of simple ratios such as customer to sales ratio, energy sold by employee, output per circuit kilometre and operating cost per employee may be disadvantageous to some firms due to their inability to control certain factors outside their realm. An example with regards to non-discretionary factors such
as markets with naturally low customer densities is normally beyond the control of the utility company. An all-encompassing and robust relative efficiency measuring technique is thus required in the commonly used benchmarking regulation.

The next section explores the concept of efficiency after which a survey of the different techniques used in measuring efficiency is executed. This is done with the focus of presenting an adequate background to enhance the understanding of extensions and applications of existing models in chapters three and four respectively.

2.2 Theoretical Framework and Literature Review on Efficiency and Frontier Analysis
The objective of this part of the review is to uncover the foundations of the efficiency concept, the essence of measuring it and the techniques used in measuring it. The review also highlights the various extensions built on the core and primary techniques with the focus of finding aspects of further investigation to enhancing their robustness. In this regard therefore, the literature reviewed transcends generic productivity measuring models to extended stochastic frontier models and to latent models. The section considers reviews on both parametric and non-parametric techniques with this section treating in detail the stochastic frontier technique. The Stochastic frontier is shown to be well suited to the focus of this research. The specifications of functional forms and the distribution of the inefficiency term in the SFA model are discussed in the end. The Burr distribution is introduced and its potential performance reviewed against the prominent distribution types into the classical or existing methodologies. This becomes relevant as the review proceeds to explore the application of Burr distribution on the stochastic frontier models in chapter 3.

2.2.1 Background to Efficiency Concept and its Measuring Techniques
Surveys done by Greene (2007) and Kumbhakar and Lovell (2000) suggest that literature on efficiency measurement is voluminous with many more researchers still investigating and extending existing models for improvement. This level of interest is due to the subject matter’s importance but also to its widespread application across all productive sectors. The efficiency concept has been looked at in many respects and Patterson (1996) executes the concept as well as its measurement in terms of energy efficiency from the engineering perspective to the production perspective. Fried, Lovell and Schmidt (2008) distinguishes between efficiency and productivity by giving an exposition on the way the concept has evolved from one to the other. They used the variations in the domestic performance of US
airlines to highlight the possible sources of these variations and settle on the variation of productive efficiency as the underlying reason. By examining or analysing the differences in productive efficiency in managing resources and services of these airlines and their impact on their financial performance, they brought meaning to productivity and defined it as the ratio of output and input (output/input). Productivity change can be easily calculated as the ratio of the change in output and change in input. These two measurements are simple but could get quite complicated when there are multiple inputs and multiple outputs which is usually the case. While studying the resource and output trends in the United States post 1870, Abramovitz, (1956) concludes that variations in productivity is a residual famously referred to as “measure of our ignorance”. Minimising measurement error in the design of output and input indices has been the main effort in ousting this residual and Solow (1957) among others as reported in Stone (1980) were the early proponents of this remedy. The variation in this residual is attributed to differences in production technology, scale of operation and operating efficiency and this assertion is supported by the US Department of Labour’s Statistics (2005) and the OECD (2001). Operating efficiency is paramount in our discussion among the three sources of productivity variation and it is in the interest of any analyst to understand its contribution to productivity from a cross-sectional interaction (production point) as well as its inter-temporal contribution to changes in productivity. At this point the discussion begins to settle on the efficiency of a producer to be a comparison between observed values and optimal values of its inputs and outputs. Yet, three problems are fundamental to this measurement which includes: first, which outputs and inputs are relevant and need to be included; the next concerns how multiple outputs and inputs can be weighed and compared; and the last relates to how the technical or economic capability of a producer is ideal?

The works of Knight (1933), upon facing the first problem, settled and proposed the definition of productivity to be a ratio of useful outputs and useful inputs. Discussions on what variable to include as useful ensued between Leibenstein (1966) and Stigler (1976) in the argument regarding X-efficiency. An extension of the argument was the link between omitted variables and productivity differences and also the connection between a complicated model and its practicability. These linked issues still had to account for weighing these variables to allow for comparability which then introduced market prices and the other issues of how to treat price
levels of years and in different jurisdictions and the more complicated case of no price information. A case of no competitive market prices and the existence of controlled prices or monopolistic prices in the markets in some of the analysed units can only add to the difficulties of weighing variables. The question relating to “at what level of potential of a producer is an optimal producer was even a much more difficult issue to address. As suggested by Fried, Lovell and Schmidt (2008), the lack of a solution to this very challenge, a very important part that really is driven by efficiency seem to have been unattended to for a relatively long period of time.

The relationship between productivity and efficiency has been exposed adequately and thus the next section will continue the discussion on the approaches used to measure efficiency.

2.2.2 Understanding Frontier Techniques in Measuring Efficiency
From a general production philosophy, producers are considered efficient if they produce the highest possible output given the inputs they actually employ or whether they produced that output at the lowest cost. Optimality as found in many economic concepts is the back-bone of defining efficiency. Studying efficiency and productivity measurement is grounded in the understanding of production, production functions and productivity. As suggested by Sena (2003) and others, since the high levels of efficiency and productivity are desirable goals for any economy, defining and measuring them in approaches that follow economic theory and provide valuable information for management and policy makers are very important. Out of the different methods it appears that those based on the notion of best practice frontier have dominated literature and practice. Literature often than not ascribes the success of these frontier methods to their ability to incorporate economic theory and the ease of rationalising and operationalising the concept of efficiency from these frontier methods in providing handy information for decision. Thus the measurement of economic efficiency has been strongly hinged on the use of frontier functions and it is therefore not surprising to encounter most efficiency literature acknowledging the works of Farrell (1957). Michael J Farrell with a primal idea from Koopmans (1951) and Debreu (1951) adopted a frontier approach to measure technical efficiency and price efficiency of agricultural units in the United States of America. It was asserted that technical efficiency reflects a firm’s ability to maximize its output from a given combination of inputs. It was argued on the other hand that price efficiency is indicative of the usage of optimal quantities of inputs with their respective prices. Evolution of the
nomenclature along the path of furthering the discussion, one of which is that of Kopp (1981) termed Farrell’s price efficiency as allocative efficiency which, combined with technical efficiency yields economic efficiency.

At this point and for the purpose of modelling, it is compelling to discuss the different efficiency types as in technical, allocative and economic efficiency using a functional form, the usual Cobb Douglas function of production.

Technical Efficiency (TE) according to Coelli and Perelman (1996) could be input or output oriented in that the key indicator is how much we need to proportionally reduce input to produce a fixed quantity of output. Different approaches have been used to illustrate how the different efficiency types could be identified on a production frontier, however, the one by Coelli (1996) is appreciated for its clarity. He considers two firms P and Q using inputs, X1 and X2, to produce one output, Y with a constant return-to-scale production function.

**Figure 2.26: Concept of Technical and Allocative Efficiency Measurement**

On the premise of constant returns to scale (CRS), as Farrell (1957) defines the technological possibility sets using the unit isoquant YY’ representing the minimum combination of inputs needed to produce a unit of output. Thus, under this framework, every firm with a package of inputs along the unit isoquant is considered as technically efficient while those above and to the right of it, such as firm P suggests a firm that is technically inefficient since the input package that is being used is in excess of the minimum that is required technically to produce a unit of output. The technical inefficiency of producer or firm P is measured by the distance RP on the ray OP and the distance denotes the amount by which all inputs can be rearranged without reducing the amount of output produced in its technically inefficient state. Thus the
technical inefficiency level associated to firm P can be expressed by the ratio $RP/OP$ and thus arriving at a technically efficiency of $1-RP/OP$ which is the same as the ratio $OR/OP$.

A cost minimisation behavioural objective can be assumed if information on market prices is known. According to Murillo-Zamorano (2004), by letting input price ratio reflect the slope of the isocost-line $CC'$ and employing the unit-isoquant in figure 2.26, allocative inefficiency can also be derived. In this case, the suitable distance is given by the line segment $SR$, which is measured as a ratio $SR/OR$. Considering the least cost combination of inputs given by firm $R'$, the above ratio indicates the cost minimisation that a producer would be able to reach if it moved from a technically but allocatively inefficient input package of firm $R$ to a both technically and allocatively efficient one of firm $R'$. Therefore, the allocative efficiency (AE) that illustrates the producer at package $P$ of firm $P$ is measured by the ratio $OS/OR$.

Together with the concepts of technical efficiency and allocative efficiency, overall efficiency which is later conceived as Economic Efficiency subsequent to Farrell (1957) can be measured in equation (2.1). $OS/OP$ therefore defines Economic Efficiency (EE) as below:

$$ EE = TE \times AE = \frac{OR}{OP} \times \frac{OS}{OR} = \frac{OS}{OP} \quad (2.1) $$

The geometric distance as far as EE is concerned is defined by $SP$ and could be subjected to analyses of cost reduction. The applied concept of frontier economics as described above is viewed in the context of an input-oriented scheme. Fare, Grosskopf and Lovell (1985 and 1994) provide an explanation of the same frontier concept for an output-orientated approach to analysing efficiency. In order to verify the coherence in both approaches, Fare and Lovell (1978) show that under CRS, there is no dissimilarities in the technical efficiency measurements from either an input-oriented or an output-oriented approach. However, such equivalence has been rejected in the case of variable return to scale (VRS) in the works of Førsund and Hjalmarsson (1979) as well as Kopp (1981) in the case non-constant returns to scale. Where the behavioural objective has differed from cost minimisation, allocative efficiency in an output oriented problem has been measured from a revenue maximisation perspective in Fare, Grosskopf and Lovell (1985 and 1994) and Lovell (1993). An analysis of allocative efficiency on the basis of profit maximisation was executed by Kumbhakar (1987), Fare, Grosskopf and Lovell (1994) and Grosskopf and Weber (1997) on the assumption of both cost minimisation (input oriented model) and revenue maximisation (output oriented model).
Greene (2007) argues that efficiency techniques based on revenue and profit functions have received less utilisation in literature unlike production, cost and distant functions. He attributes that to the need for many assumptions about producer and market behaviour when using either revenue or profit functions frontiers. Also, he suggests that while cost and production functions are reflective of the optimisation behaviour of individual firms, in the case of a profit function it requires additional assumptions of market structure and price setting. Greene (2007) also attributes the less utilisation of profit and revenue functions to the high data demands of these techniques as compared to cost and production techniques.

From the above works, it can be perceived how the simple frontier approach of (Farrell (1957) has evolved into other alternative ways specifying production possibility sets from the various perspectives discussed. It is also admissible that distant function approach has also emerged and spread widely after the primal frontier work of Farrell. Since the main aim is to develop a framework where a frontier can serve as a point of reference or benchmark with which producing units or firms can be compared with, it is not surprising that over the last fifty years there has been varied tried and tested approaches at constructing, calculating and even estimating these frontiers. Nonetheless, these approaches can be classified and distinguished by a parametric or non-parametric criterion.

In the parametric approach, functional forms of the frontier are predefined or pre-established apriori while in the non-parametric approach, the functional form is deduced or calculated from the sample observations in an empirical way. Most of the literature used in the estimation of economic efficiency have utilised either parametric or non-parametric approaches. There are different opinions as to which is a better approach and till date the method of choice remains a debate with an unyielding result. The proponents argue for and against the two approaches based on their disadvantages and advantages. For example Berger (1993) and others prefer the parametric approach whereas Seiford and Thrall (1990) are advocates of the non-parametric approach. Further advances that try to combine both methods utilises Bayesian analyses and Bootstrapping theory which treats stochastic noise in the non-parametric approach as well as providing flexible functional forms in parametric methods. Sticking to the objectives of this chapter (literature review), emphasis will be placed on the basic models of non-parametric approach and further review the basic and more complex models of the parametric approach in the next section.
2.2.3. Non-Parametric Frontier Techniques (DEA)

Building on the Farrell (1957) basic model of single-input/output efficiency measure, Charnes, Cooper and Rhodes (1978) generalised it into the multiple-input/output case and remodelled it as a mathematical programming problem. Later in 1981, this was then termed Data Envelopment Analysis. From that time onwards there have been various improvements and empirical applications of this technique in productive efficiency literature even though they were originally born in the operations research arena for measuring and comparing relative efficiencies of a group of decision making units (DMUs). In the non-parametric approach, the objective is to define a frontier envelopment surface for all sample observations. The most efficient DMUs determine the surface and therefore any DMU that do not lie on it are considered the inefficient ones. A striking difference between the non-parametric and the parametric approaches is the lack of consideration for statistical noise in the former.

The CCR model of basic DEA is presented in the figure below:

**Figure 2.27: The Basic Model of DEA**

In this model, three assumptions are made: a constant return to scale (CRS), convexity of the set of feasible input-output combinations and finally, strong disposability of inputs and outputs. Murillo-Zamorano (2004) explains the estimation of efficiency in figure 2.27 by viewing the convex hull as an isoquant line where DMUs lying on it are assumed to be using the same proportions of inputs to produce various amounts of a single output. This isoquant (DG) is estimated by DEA techniques from data on the population of five DMUs producing various amounts of a single output by utilising different amounts of inputs. Thus the DMUs which are A, B, C, D, E and G produce Y from a combination of X1 and X2. Going by a much simpler analysis of measuring the level of inefficiency is by comparison of a DMU to a single referent DMU on the isoquant line. For example, technical efficiency of DMU A, would be
determined by the ratio OA*/OA where A* is a linear combination of referents B and C (known as ‘peer group’). A* and A are considered to use equal proportions of inputs since they lie on the same ray. Similarly, the efficiency of DMU E is estimated by the ratio OC/OE. The segments DC, CB and BG which form the frontier envelope all the performances of other DMUs not on the isoquant which is indeed not 1 since it is rather a linear approximation. Also, the points F and A* are not real DMUs but hypothetical units estimated as weighted averages of inputs.

In essence, the individual efficiency scores are calculated by using mathematical programming techniques. Here, the solutions to the problem must satisfy an inequality constraints for the purposes of increasing or decreasing certain outputs or inputs without changing the expected amounts of inputs or output. Through mathematical programming formulation, the DEA calculation are designed to maximise the relative efficiency scores of each DMU subject to the constraint that the set of weights obtained by the programme for each unit must also be feasible for all the other units in the sample. For example, with N homogenous units with an input –output vector of m inputs and s outputs, for each unit off the efficient frontier and with μj representing the weight of each unit within the peer group, then a vector \( \vec{\mu} = (\mu_1, \ldots, \mu_N) \) can be defined. The efficiency scores can be calculated by the following mathematical programming formulation.

\[
\text{TECRS} = \min_{\mu} \psi \nu_0 \tag{2.2}
\]

Subject to
\[
\sum_{j=1}^{n} \mu_j X_{ij} \leq \psi X_i^0 \quad i = 1 \ldots m
\]
\[
\sum_{j=1}^{n} \mu_j Y_{rj} \geq Y_r^0 \quad r = 1 \ldots s
\]

The solution to the above mathematical programme is that for each DMU analysed, the yield is at least the same level of output (refer to second constraint) but consumes just a proportion (\( \psi \)) of each of the inputs utilised by the DMU (refer to first constraint). The technical efficiency scores are determined by the optimal \( \psi^* \) which is arrived by the linear combinations of referents that for each DMU minimises the value of \( \psi \)

A dual version formulation can be obtained as a maximum rate of weighted outputs to weighted inputs subject to the constraint that the similar ratios for each unit be less than or equal to one or unity. An emerging problem for the initial dual formulation solution was the
population of infinite number of solutions to the maximisation problem as discussed and corrected by Coeli, Rao and Battese (1998)

DEA with much flexibility has been extended from its basic model to much complex models from models that treat non-discretionary variables to models that deal with multiplier sets, to models that introduce multiplicative measures of relative efficiency by using multiplicative envelopment surfaces. There are also extensions in relation to measuring allocative efficiency from price information with a choice of a behavioural objective such as cost minimisation, revenue maximisation or profit maximisation. For panel data analyses, an example is the window analysis founded by Charnes, Clark, Cooper and Golany (1994).

With the deterministic property of DEA being its main weakness, recent literature has shown it is possible to define a model that allows for the determination of statistical properties of the non-parametric frontier estimators. Grosskopf (1996) seem to be the most revered in this area where he provides a survey of statistical inference in non-parametric, deterministic frontier models. Bootstrapping techniques are also efficient in dealing with the statistical inference problem of non-parametric models and this arose subsequent to the application of asymptotic results. In the recent developments, Sengupta (2000) and Huang and Li (2001) have constructed more refined stochastic DEA models with the latter discussing the relationships of their constructed stochastic DEA models by applying the theory of chance constrained programming and subsequently testing the model on some classical DEA models.

### 2.2.4 Parametric Approaches

In this section, the review begins by understanding with least squares regression based estimation of frontier functions in order that the journey in the parametric efficiency approaches could be well explored. Considering the production model, \( f(x_i, \beta) \), being linear in the logs of the inputs and the left hand side of the estimating equation representing the output variable, then,

\[
\ln y_i = \alpha + \beta^T x_i + \varepsilon_i \tag{2.3}
\]

In this model, the following is assumed:

\[
\varepsilon_i = -U_i;
\]
\( \varepsilon_i \) is assumed to be independent of all model variables and in addition, it is non-zero (negative) mean and has a constant variance as well as an ordinary regression noise (disturbance)

\[
E[\varepsilon_i|X_i] \leq 0
\]

\( x_i \) is the set of functions of inputs embedded in the empirical model.

\[
\ln y_i = (\alpha + E[\varepsilon_i]) + \beta^T x_i + (\varepsilon_i - E[\varepsilon_i])
\]

\[
\ln y_i = \alpha^* + \beta^T x_i + \varepsilon_i^*
\]

The model is reduced therefore into a classical linear regression one. Since \( \varepsilon^* \) is the difference between a random variable (constrained to be always negative) and its mean, normality is therefore disallowed. Regardless, the OLS is a robust estimator of non-normality and thus the model’s parameters can be estimated consistently except for the constant term. Unfortunately, in this model, the constant term is rather the most important parameter in estimating the residuals or by extension \( E[u_i|X_i] \).

\[
e_i = \ln y_i - \alpha^* - b^T x_i = -u_i + E[u_i]
\]

\( b \) is the vector of the least square coefficients by regressing \( y \) on \( x \) and on a constant, \( \alpha^* \)

At this stage it is possible to estimate consistently with \( e_i - e_m \) for \( u_j - u_m \) as the former is an unbiased, pointwise estimator of the latter.

A ratio estimator \( \exp(e_i)/\exp(e_m) \) similarly can estimate consistently

\[
\frac{TE_i \exp(E[u_i])}{TE_m \exp(E[u_m])} = \frac{TE_i}{TE_m}
\]  (2.4)

Had the task been comparison of firms, the frontier aspect of this technique will be inconsequential and one could rely on the OLS estimates. To further advance the model for inclusion of a frontier and having in mind that the deficiency of the OLS model is the displacement of the constant term, the two methods proposed are the Corrected Ordinary Least Squares (COLS) and Modified Ordinary Least Squares (MOLS).
COLS solves the constant displacement problem by shifting the estimated production function upward until all other residual points are below one referral point or residual. A corrected OLS constant is achieved eventually as seen in the model below:

\[ a_{COLS} = a^* + max_i e_i \]

\[ e_{i_{COLS}} = e_i - max_i e_i \] (2.5)

It is expected that all the COLS residuals will agree with the theoretical restriction. COLS technique is therefore a parametric approach that applies ordinary least squares in the estimation of a production function or cost function where the error term is adjusted to be either negative or positive. The adjusted line or constant then becomes the efficient frontier. The limitation of this method even though it is used in some regulatory regimes for price reviews as in the UK (OFGEM) include the specification of the functional form of a production function, the lack of distinction between noise and efficiency. In addition, Coelli and Walding (2006) perceive COLS as providing an average efficiency measure rather than a frontier efficiency.

With Modified OLS, the approach requires a parametric model of the distribution of the efficiency term. Greene (2007) suggests that using the mean for the estimation of \( u_i \) is rather useless (it is zero by design) even though the OLS residual are pointwise consistent estimates of their population counterparts, \( -u_i \). With a constant displacement of the OLS intercept, the variance and any higher order central moment of the OLS residuals is capable of producing a consistent estimation of even deeper model parameters by employing method of moments. Thus the \( E(u_i) \) is thus estimated by the variance of a certain distribution. The efficient frontier is thus formed by displacing the OLS constant by an estimation of \( u_i \) which is also linked to estimates of variances or higher moments. It is noteworthy that in the case of a cost function and unlike the production function that has been looked at so far, the estimated cost frontier will lie under the data points and not above.
COLS and MOLS are frontier functions in which deviation of an observation from the theoretical maximum is attributed solely to the inefficiency of the firm under review. They are generally termed deterministic frontier functions whose slope parameters are estimated and are consistent with OLS. They are termed deterministic because the inefficiency term \( u \) contains the entire stochastic component of the model. Aigner and Chu (1968) advanced this aspect of the efficiency literature by suggesting a log-linear production function in which the Technical efficiency (TE) component is a random disturbance \( U \) which is in the 0-1 range. They arrived at a basic Cobb-Douglass production function model:

\[
Y = AX_1^{\beta_1}X_2^{\beta_2}U_i
\]  
(2.6)

\[
\ln Y = \alpha + \sum_{k=1}^{k} \beta_k X_{ki} + \varepsilon_i
\]  
(2.7)

\[
= \alpha + \sum_{k=1}^{k} \beta_k X_{ki} - u_i
\]

Given that \( \alpha = \ln A, X_{ki} = \ln X_{ki}, \varepsilon_i = \ln U_i \).

Aigner and Chu (1968) recommended and applied two methods of computing the parameters that would restrict \( u_i \) to be non-negative: linear programming and quadratic programming methods.
The third (SFA) which is extensively explained subsequently is dissimilar due to the way the frontier is constructed. In SFA specification, maximum output that the producer can achieve is assumed to be determined both by the production function as well as random external elements such as luck or unexpected disturbances in the associated market. The estimates of \(-u_i\) is produced by slack variables associated in the constraint. An average technical inefficiency can be arrived at by the following statics.

\[
\text{Average Technical Inefficiency} = \frac{1}{N} \sum_{i=1}^{N} \hat{u}_i \quad (2.8)
\]

Or

\[
\text{Average Technical Inefficiency} = \frac{1}{N} \sum_{i=1}^{N} e^{-\hat{u}_i} = \bar{E} [TE_i] \quad (2.9)
\]

Applications of these models can be seen in studies done by Forsund and Hjalmarsson (1979) and Forsund (1992) where the authors adopted a generalised production function and minimised the sum of the residuals with additional constraints. In these studies, economies of scale and technical efficiency were the main foci and were determined as such. Greene (2007) brings to attention that in the programming procedures, deterministic models are assumed a statistical model and this makes the properties of the “estimators” ambiguous since it relies on the process that actually generates the data. Matters concerning the lack of naturally produced standard errors of coefficients required for making inference is also discussed as a disadvantage of these models. Schmidt (1976) describes Aigner-Chu’s optimisation approach to have the propensity to be construed as a log likelihood estimation and thus appear as having a statistical pedigree but insist since the model does not satisfy all the log likelihood conditions, statistical inference assumed on standard maximum likelihood estimator results may be distorted.

Stochastic Frontier Model (SFM) as a parametric technique is widely used in many forms. It uses econometric approaches where the error term is decomposed into an inefficiency term and a random noise term. The literature on SFA has moved from the cross-sectional models to various panel-data models with different assumptions on the probability densities of the composite error term. The classical SFA worked on by Aigner, Lovell and Schmidt (1977) requires specification of the functional form as well as the distribution of the inefficiency and noise terms. Battese and Coelli (1992) and Battese and Coelli (1995) suggest that SFA is more robust with large number of observations. The pros and cons of each SFA method are explicit.
in this section making the choice one makes to be linked with one’s chosen objective. For the purposes of the modification of the SFA model as well as it being the main technique being employed in chapter 4, more probing is done on it in the next chapter.

As suggested earlier in this section, the Stochastic Frontier Approach (SFA) has metamorphosed from cross-sectional estimation to panel estimation with various methodologies of estimations. Kumbhakar and Lovell (2000) show this evolution in their book titled “Stochastic Frontier Analysis” where they show the various techniques used in stochastic frontier techniques. From time-invariant panel models to time-variant panel models, there have been considerations of fixed and random effects each giving unique results in practice. Important and common to these different approaches has been the assumption of the underlying distribution of the decomposed error term into the noise error term (v) and the inefficiency error term (u). This has attracted different assumptions as much as the modification of the SFA model and yet the debate is ongoing as to whether it matters or not. The next section discusses the above and introduces Burr distribution as a potential modifier of the SFA model.

2.2.5 Stochastic Frontier Model
Aigner, Lovell and Schmidt (1977), Meeusen and Van Den Broeck (1977) and Battese and Corra (1977) concurrently developed a Stochastic Frontier Model that, besides incorporating the efficiency term into the analysis also captures the effects of exogenous shocks beyond the control of the units under review. This type of model also accounts for the presence of stochastic elements in the production and modelling processes as well as in the measurement of the engaged variables.

Utilising the Cobb-Douglas case and in logarithmic forms, the single-output stochastic frontier can be represented as

\[ Y_i = \beta_0 \sum_{n=1}^{N} \beta_n \ln X_{ni} + V_i - U_i \]  

(2.10)

Where \( V_i \) represents the random noise and one-sided inefficiency term is represented by \( U_i \).

The error term representing statistical noise is assumed to be identical independent and identically distributed. With respect to the one-sided (inefficiency) term, various statistical distributions have been assumed in the literature, the most frequently used being the half-normal, exponential, and truncated from below at zero. In so far as the two error terms are
assumed independent of each other and of the predictor variables with an assumed distribution, a likelihood function can be defined. Executing a maximum likelihood estimation then becomes the next logical step to determine the parameters of the joint distributions of \( V \) and \( U \).

Regardless of the distribution chosen, for efficiency measurement analysis, the composed error term needs to be decomposed. Jondrow, Lovell, Materov and Schmidt (1982) showed that for the normal-half normal case, the expected value of \( u_i \) conditional on the composed error term, \( e_i \) is

\[
E[u_i | e_i] = \frac{\sigma \lambda}{1 + \lambda^2} \left[ \frac{\phi(\lambda \sigma)}{\Phi(\lambda \sigma)} - \frac{e_i \lambda}{\sigma} \right]
\]  

(2.11)

With \( \phi(\cdot) \) being the density of the standard normal distribution, \( \Phi(\cdot) \) the cumulative density function, \( \lambda = \sigma_u / \sigma_v \), \( e_i = v_i - u_i \) and \( \sigma = (\sigma_u^2 + \sigma_v^2)^{1/2} \)

The technical efficiency of each unit was computable once Jondrow, Lovell, Materov and Schmidt (1982) obtained the conditional estimates of \( u_i \) found below as:

\[
TE = 1 - E[u_i | e_i]
\]  

(2.12)

A substantial level of debate regarding the right point estimator given the pioneer work done by Jondrow, Lovell, Materov and Schmidt (1982) has developed. First, many others proposed and preferred the \( \text{Exp} \{ -(u_i | e_i) \} \) as opposed to \( 1 - E[u_i | e_i] \) since the latter is just a first-order approximation whiles the former is a more general infinite series.

i.e. \( \text{Exp} \{ -(u_i | e_i) \} = 1 - u_i + u_i^2 / 2 - u_i^3 / 3! \cdots \)

An additional alternative point estimator of technical efficiency was developed by Battese and Coelli (1988) which is supposed to be a preferred estimator for values of \( u_i \) not close to zero.

It is expressed as:
\[ E[\text{Exp}(-u_i|e_i)] = \frac{1-\phi(y+(y e_i/\delta))}{1-\phi(y e_i/\delta)}.\exp(y e_i + (\delta^2/2)) \quad (2.13) \]

Where \( \delta = \frac{\sigma_u \sigma_v}{\sigma} \) and \( \gamma = \frac{\sigma_u^2}{\sigma^2} \)

Notwithstanding the type of point estimator used, there exist a shared essential defect. Although they are all unbiased, they are not consistent estimators of technical efficiency given that \( \text{plim} E(u_i|v_i - u_i) - u_i \neq 0 \) a situation Greene (1993) found very unfortunate.

However, as the recent literature has shown, it is possible to get confidence intervals for any of the three alternative technical efficiency point estimates commented on above. Murillo-Zamorano (2004) highlights that Hjalmarsson, Kumbhakar and Heshmati (1996) suggest technical efficiency estimator for the JMLS while Bera and Sharma (1996) proposed that for Battesse and Coelli (1988). Subsequently, Horrace and Schmidt (1995,1996) derive upper and lower bounds on \( \exp(-u_i|e_i) \) based on lower and upper bounds of \(-u_i|e_i\) respectively. Horrace and Schmidt (1996) describes a method for calculating confidence intervals for efficiency levels. In 1995, the same authors further advanced by conducting multiple comparisons with the best methodology.

Jondrow, Lovell, Materov and Schmidt (1982) also computed the expected value of \( u_i \) conditional on the composed error term in a model based on exponential distribution. Their exposition is seen below:

\[ E[u_i e_i] = (e_i - \theta \sigma_v^2) + \frac{\sigma_v \phi[(e_i - \theta \sigma_v^2)/\sigma_v]}{\phi[(e_i - \theta \sigma_v^2)/\sigma_v]} \quad (2.14) \]

Where \( \theta = 1/\sigma_u \)

There are two main shortfalls of the proposed half-normal and exponential distribution used for the inefficiency term. First, Stevenson (1980) suggests that there was no need to restrict the mean to zero since artificially high technical efficiency levels since the conditional technical inefficiency scores will concentrate in the neighbourhood of zero. Stevenson (1980) therefore argues that there could be over estimation in the efficiency levels when using the model of Aigner, Lovell and Schmidt (1977) and thus the zero mean condition in the half normal and the exponential models were unnecessary. The other drawback which is quite a generic problem with most SFA models is the pre-determined shape of the distribution of disturbances. In an attempt to address these limitations, Stevenson (1980), proposed and produced efficiency analyses using a model based on a truncated distribution.
Green (1980a) and Green (1990) demonstrate an attempt at solving the deficiencies of the half-normal and exponential models. In the former, a frontier deterministic model was rather constructed based on gamma distribution as seen below:

$$y = f(X, \beta) - \mu \text{ Where } \mu \sim G(\Theta, P)$$

Meaning $$f(\mu) = \frac{e^\theta}{\Gamma(P)} \mu^{P-1} e^{-\theta \mu} \text{ and } \mu \geq 0, \Theta, P > 0$$ (2.15)

In Greene (1990), gamma distribution was applied to the stochastic frontier model:

$$y = f(X, \beta) + v - \mu; \text{ Where } \mu \sim G(\Theta, P) \text{ and } v \sim N(0, \sigma^2)$$

He executed a maximum likelihood estimation of the parameters of the composed error. A consistent method-of-moment estimator as well as the decomposition of the error term into the efficiency term and the random noise term were described in that piece of work.

Sharing the perspectives of other authors, Murrillo –Zamorano (2004), amplifies the nature of the complexity relating to the various estimation procedures and suggest that it might outweigh the benefits. This might be one of the reasons that makes fixed shape models the most prevalent and might not be reasons of being the most predictive and robust model. Users of such models may have prioritised simplicity over robustness. On the other hand, researchers who have preference for quality or robustness may find it appealing to investigate which SFA distributional model gives the best results. In connection with that dilemma, our motivation to investigate further this subject matter rather puts us in the latter category of researchers as this study experiments the use of Burr type-x distribution on the stochastic frontier model. Section 2.2.9 elaborates the issue of whether the type of distribution really matters.

The next section explains the concept and types of heterogeneity that may arise in an attempt to model and benchmark production units that usually possess unique attributes since most of the firms operate in different terrains with different characteristics. This task is imperative because heterogeneity is a natural and survival condition just like the concept of productivity. Also with regards to the industry in which our empirical studies is conducted, heterogeneity is naturally inherent in these monopolies as they promoters of the distribution sector do not choose their area of operation which are by default different in many regards. The last reason
is that in the literature of frontier economics, there has been many advancement in modelling heterogeneity such that this review cannot afford to ignore.

2.2.6 Heterogeneity and Efficiency Modelling
Heterogeneity can be classified into observable and unobservable heterogeneity. The former refers to heterogeneity that is contained in the measured variables. This would include specific shift factors that operate on the production or cost function with the potential of also entering the inefficiency distribution. It is also possible as explained by Alvarez, et al. (2005) that observable heterogeneity may also influence through the scaling property in the form of heteroscedasticity. It is also likely to have heterogeneity located in the different parts of the model as discussed above.

Unobserved heterogeneity, on the other hand, get involved in the model as ‘effects.’ Greene (2004) argues that behaviour of unobserved heterogeneity is normally seen as fundamental issue of panel. Unobserved heterogeneity could in principle and mostly reflect variables that are omitted in the model. However, aside omitted variables that are production factors (measured in either quantity or prices), any other variables ought to be grouped and identified differently. Unobserved heterogeneity are typically features that do not change over time that enter the model and may or may not be related to the variables in the model. On this subject matter, Greene (2004) performs a satisfactory analyses while attempting to distinguish between the two and constructs models of Stochastic frontier embedded with the possible heterogeneous conditions discussed above.

Based on the above appreciation of heterogeneity, understanding true technology is crucial in the accurate measurement of performance. The proposition that a range of production technologies exist in an industry is generally accepted, in principle, but rarely in the execution of empirical analyses. Estimation of the technology rests on the assumption that all producers in the sample use the same technology.

With this view, where there is a multiplicity of technologies, a fairer representation of productivity potential involves identification of these technological variations across the candidates being analysed. For example, electricity distribution companies in the energy industry may use different technologies. It is thus possible that the production or distribution technology assumed may not be representative for all the firms under review. The estimated technology can fail to represent a “true" technology of a particular firm which has the
potential to introduce some bias or unfair measurement. Economies of Scale, elasticities of substitutions and other measures of production structure could be misleading when a single or aggregate technology is imposed on all the firms being surveyed.

The significance for firm specific characterisation in the construction of production frontier is that if the unobserved technological differences are unaccounted for during estimation, they may be captured inappropriately as inefficiency. According to Parameter and Kumbhakar (2004) the incorporation of a priori information to fragment the sample so that homogeneity of technology and efficiency is maintained could be one simple way of incorporating heterogeneity. The importance of heterogeneity in production technology has since been recognised in the applied field of efficiency. Mester (1996) in the analysis of US savings and loans banks based on ownership type (public or private) and Altumbas, Evans and Molyneux (2001) whose analysis on banks considered differences in organisational structure were among the early writers in the subject matter. Other authors including Mester (1996) and Bos and Schmiedel (2007) engaged in splitting and accounting for heterogeneity based on geography. After an extensive review on the type, sources and classification of heterogeneity in panel data models, the next section explores in detail the model specifications and other extensions applied to the Stochastic frontier Approach. The section examines the evolution of the stochastic panel models which systematically infuse heterogeneity and construct significant extensions of the basic panel models discussed earlier.

2.2.7 Panel Stochastic Frontier Modelling and its Extensions

The cross sectional models discussed above have shown some inconsistencies although unbiased. The Stochastic frontier continued to evolve with the introduction of the panel models to correct some of the deficiencies of cross sectional models. The advantages of panel data in stochastic frontier analyses come in three ways as supported by Pitt and Lee (1981) and Schmidt and Sickles (1984).

The strong assumptions of distributions and independence of error terms are not necessary in the case of panel unlike in cross sectional frontier analyses. For example, when employing maximum likelihood estimation for a cross section data, apart from the specification of the distributional type, there is a strong requirement for the technical efficiency term to be independent of the regressors. This lacks practicality as there could be a policy incentive that affects the utilisation of a certain variable of production whiles it also impacts on the
inefficiency of the producer. A compelling policy to increase labour intensity may also affect the efficiency of a firm.

The second advantage of panel frontier is that when evaluating the performance of a producer, it can be estimated consistently. Due to the structure of cross sectional data, the producer’s behaviour over time cannot be investigated. Panel stochastic frontier provides this avenue where the analyst can observe changes over time and even assess the performance of a producer or a unit before and after a particular intervention is introduced into the production process.

At this point of the evolution of the stochastic frontier panel models, three shortcomings are faced by the analyst when observing producers at several points in time. The practicality of an unavoidable case of correlation of the inefficiency term with input levels which is substantiated above may be unwarranted in certain cases. For example in the case of Huang and Liu (1994) who constructed the inefficiency term to include functions of the inputs (x). The issue of assumption of normality for the noise term and other forms of distributions for the inefficiency term is yet another assumption that may or may not be relevant.

Finally, the fundamental question of whether inefficiency varies with time or not presents another area of investigation. On this matter, Greene (2007) indicates that in the case of a cross section, it is really a moot point but to say that inefficiency is fixed over time is rather very important in the analysis of panel data. The consensus seems to be that by intuition, the longer the panel, the better is the estimator of time invariant inefficiency regardless of how it is computed in the model. However, he suggests that it is also true that the longer is the observation time period, the less tenable the assumption of a” fixed inefficiency over time” is.

Evidenced earlier, the shortcoming of panel data, the succeeding section exposes the various solutions or techniques (not simple though) used to address the issues. It begins with time-invariant panel models to time-variant models which addresses specifics of the panel constant term leading to sub-models of random effects and fixed effects.

2.2.7.1 Time Invariant Models

These are models which may assume technical inefficiency as specific to an individual assessed unit and time invariant. This implies that inefficiency may be different for different
firms but also supports the notion of no learning over time as these inefficiency levels do not change with time. This review commences with the basic linear fixed effect model where there is no distribution assumption on $u_i$ and the inefficiency term is allowed to be correlated with the regressors and with the normal noise term $v_{it}$

$$y_{it} = \alpha + \beta' x_{it} + v_{it} - u_i$$  \hspace{1cm} (2.16)

If $\alpha_i = \alpha - u_i$

$$y_{it} = \alpha_i + \beta' x_{it} + v_{it}$$  \hspace{1cm} (2.17)

$\hat{\alpha} = \max \{\hat{\alpha}_i\}$

$\hat{u}_i = \hat{\alpha} - \hat{\alpha}_i$

With either $N \to \infty$ or $T \to \infty$ $\beta$ can be consistently estimated. However, consistency of the estimates of $u_i$ will require both conditions- $N \to \infty$ and $T \to \infty$. (Greene, 2004)

Where $\alpha_i$ represent producer-specific intercepts. As in the case of COLS, OLS estimation is used to estimate the parameters.

The cost function model equivalent of measuring relative productive efficiency is defined as:

$\hat{\alpha} = \min \{\hat{\alpha}_i\}$

$\hat{u}_i = \hat{\alpha} - \hat{\alpha}_i$

Examples of studies that have utilised fixed effects models in literature include Tandon, Murray and Lauer (2000) and Hollingsworth and Wildman (2002).

In the linear random-effect model, the $u_i$ are randomly distributed with a constant mean and variance and are assumed to be uncorrelated with the regressors and with $v_{it}$.

$$y_{it} = \alpha + \beta' x_{it} + v_{it} - u_i$$

Considering $\alpha^* = \alpha - E(u_i)$ and $u_i^* = u_i - E(u_i)$

$$y_{it} = \alpha^* + \beta' x_{it} + v_{it} - u_i^*$$  \hspace{1cm} (2.18)

Estimation of the model is done using a two-step generalised least squares (GLS) method where $\alpha^*$ and $\beta$ are estimated by Feasible GLS. $u_i^*$ is estimated in the second stage from either the residuals or the best linear unbiased predictor (BLUP)
The panel data models and techniques discussed so far do not have to assume a distribution in the specification as well as the estimation of their frontier functions. Nevertheless, for efficient estimation of the parameters and the technical efficiency scores of the units under analysis, maximum likelihood techniques could be applied as discussed in the cross-sectional models. The normal-half-normal panel model equivalent of that Aigner, Lovell and Schmidt (1977) was derived by Pitt and Lee (1981). In this model, they interpreted the random effects as inefficiency instead of heterogeneity with the difference between their model and classical panel random effect being the incorporated half-normal assumptions for the individual specific effects. The short coming of the model was mainly the capturing of any unobserved time invariant firm specific heterogeneity as inefficiency. Schmidt and Sickles (1984) added to the extension of the model by using the Generalised Least Squares (GLS) estimator for fixed effects while Battese and Coelli (1988) further extended Pitt and Lee’s analysis to derive the normal-truncated stochastic frontier panel data model after which, Battese, Coelli and Colby (1989) applied maximum likelihood techniques to analyse an unbalanced panel data.

Murillo-Zamorano (2004) explains the difficult task of choosing one of the three time invariant models as a preferred one since each one has dissimilar properties and impose different necessities on the data being analysed. In terms of the efficiency scores and the ranking of the units been assessed literature reveals no significant differences in the outputs of these three time invariant panel models. Rather, Kumbhakar and Lovell (2000) suggest that these approaches are likely to produce similar efficiency rankings at the top and bottom of the distribution.

By intuition and from the notion of more innovation over time, it is anticipated that technical efficiency could be time variant as the time dimension becomes larger or the period becomes longer. The next section discusses time–varying technical efficiency in stochastic frontiers using fixed, random and maximum likelihood techniques.

### 2.2.7.2 Time-Varying SFA Panel Models

Dissimilar to time invariant model, the panel models that are time varying allow for the technical efficiency to change over time.
\[
y_{it} = \alpha_t + \beta' x_{it} + v_{it} - u_{it} \tag{2.19}
\]
Making \(\alpha_t = \alpha_t - u_{it}\)
\[
y_{it} = \alpha_{it} + \beta' x_{it} + v_{it} \tag{2.20}
\]
In the earlier time fixed SFA models, the very advantage of panel data being the ability to analyse data over time is overlooked. However, in a more recent random effects models attention is given to include time-variant inefficiency. It will be unfair to disregard the works of Cornwell, Schmidt and Robin C. Sickles (1990) and Coelli (1992) as they are the most popular with contributions in this stead. As noted by other authors Farsi and Filippini (2008) though a very good addition, in both models, firm-specific heterogeneity is treated as inefficiency which is problematic especially if they are correlated with the regressors or explanatory variables. Greene (2004) suggests that there is a possibility for the random effect model to be affected by a bias in heterogeneity while the fixed effects model may be consistent (for cost frontier slopes) but may usually overestimate the inefficiency variances. Cornwell, Schmidt and Sickles (1990) using the assumption of “no correlation between the random effects and a sufficient number of the explanatory variables” corrects this by applying an instrumental variables methodology extending the works of Hausman and Taylor (1981). By this approach, they develop a model that considers heterogeneity in slopes as well as intercept.

Another feature that runs through all the models accounting for heterogeneity is that they are unable to separate the sources of these heterogeneous factors and the inefficiency at the firm or production unit level. Further extensions have been able to tackle this very important constraint in reaching a much more accurate efficiency estimators. Though few in the literature, sufficient contributions come from Polachek and Yoon (1996) and Greene (2002). The former authors rather used a simplistic approach on the stochastic frontier by incorporating firm specific dummies. It was clear as stated by Greene (2002) how numerical impediments contributed to the delay of such models. The larger the number of firms the harder it is to capture all the firms specific dummies even though it is not unsurmountable. Following his critique he proposed solutions for both random and fixed effects models and called them True Fixed Effects and True Random Effects models while alerting that “True” did not bear a sense of actuality or correctness of a model but to cause a distinction between the
classical cases and effects treatment in his extended model. These models are well discussed and applied to the electricity distribution sector of West Africa in chapter four. However, it must be emphasised that many more techniques have been invented which look at the probable presence of heterogeneity in the input factors, the distribution of the inefficiency term and exogenous factors. The common place being the presence or absence of heterogeneity across firms but also the location of the same in the model, production process or otherwise. Also, subsequent to disputing that the heterogeneity of firms will always be located in the mean of the efficiency term, other models that allow heteroscedasticity in u and v at firm level have become extended models. Caudill and Ford (1993); Caudill et al (1995) Hadri (1999) and Wang (2002) are some of the applied examples. The possibility of omitted variables as a set-back on the advancement of the models discussed so far motivated Mundlak (1978) to capture the correlation between the individual effects and the regressors in order to reduce heterogeneity bias. Another area of analysis on the efficiency estimation and heterogeneity of TFEM and TREM distinguishes between transient and persistent parts of the productive model. It is assumed that all time-persistent inefficiency is absolutely absorbed into the constant term in both models. Practically, they explain that inefficiency could be overestimated if the production process is characterised by a certain source of inefficiency that can result in time-invariant excess of inputs. Foundation of this concept was produced by Colombi (2010), Colombi et al. (2011, 2014), Kumbhakar and Tsionas (2012) among others. However, it was Filippini and Greene (2014), who empirically modelled transient and permanent efficiency using the Simulated Likelihood Approach.

2.2.8 Applications of SFA Techniques
In this section, there are some examples of empirical work executed using some of the techniques discussed above. There are many more that cut across different industries. Significant work has been done on the airline, banking, health, railway, education, network (gas and electricity) etc. For the purpose of the empirical work and the objectives of this thesis, it is a motivation to consider applications in the energy industry. SFA applications have been applied mostly for benchmarking regulation in utility companies. There are many studies or applications that estimate productive or cost efficiency in electricity and gas distribution networks. Furthering these models in chapter 4, the role of efficiency measurement and firm ranking will be elaborated to give more meaning to regulatory economics.
SFA has also been applied in energy demand models where energy is treated as a production factor used together with other inputs to produce energy services. Here, an energy demand frontier is established to indicate the minimum amount of energy that is needed to produce a level of energy service (Filippini and Hunt 2011, 2013). The inefficiency levels are inferred from the deviations from the frontier which is contained in $u$ (a non-negative random term). These models have advanced to consider the effect of rebound on the efficiency levels. Here, rebound refers to the decrease in the unit cost of energy services when the energy system becomes more efficient which then leads to a reduction in the price to consumers who respond by increasing their demand and consequently netting off some efficiency gains. This linkage of energy demand functions and rebound was first announced by Orea et al. (2014)

A review of the literature in Africa has not exposed any works done on SFA as far as it is known. However, an analysis done using DEA on regional units of the main electricity distribution company of Ghana was executed by Sarpong (2013, unpublished). SFA methods have been applied across different sectors including energy, agriculture, health, bank etc. in many other jurisdictions apart from Africa and this work draws experiences from them.

In the light of the different schools of thought on the advantages and disadvantages of the parametric and non-parametric approaches, Farsi and Filippini (2009) applied the three approaches to 52 utilities in the Swiss electricity sector. The results showed lower efficiency estimates for the COLS with the average efficiency estimates of SFA and DEA being similar. Further, there was a higher correlation between estimates of COLS and SFA than between estimates of these parametric estimates and the non-parametric DEA approach. Their results suggested that, efficiency ranking of firms could vary considerably depending on the approach used.

Pardina and Rossi (2000) investigate performance development of 36 Latin American distribution utilities between 1994 and 1997 using SFA. In this study, there was no evidence of catching up among the utilities sector during the period. Their findings also suggest improved performance among the utilities operating in countries which have implemented power sector reforms. Whilst those in countries without such reforms have increased their labour share, the study finds that utilities operating in a reformed power sector have increased their capital share. The increase in capital share by these companies could be attributed to the investment in capital to improve technical efficiency as well as allocative
efficiency. Addition of capital could continue until optimal levels are reached, above which the utility would be inefficient.

Filippini et al. (2004) adopted the Stochastic Cost Frontier approach on Slovenian electricity sector where the companies were estimated to be cost inefficient. Another finding was the presence of increasing return to scale suggesting the opportunity for economies of scale which also calls for merger of relatively small-sized firms.

Pollitt (1995) examines the effects of the public versus private ownership on performance through an international comparison of electricity generation, transmission, and distribution utilities using DEA, COLS, and SFA models). There was no strong evidence that performance is affected by ownership. His findings suggests that RECs in the UK were not less efficient than US distribution utilities prior to privatisation.

In the table below, some examples of SFA applications are provided in the energy sector.
<table>
<thead>
<tr>
<th>Author</th>
<th>Data</th>
<th>Inputs</th>
<th>Outputs</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pardina and Rossi (2000)</td>
<td>36 Latin American Dist Utilities 1994-1997 Data</td>
<td>Unit Sold No. of employees Transformer Cap. Service Area Network Size No. of Residential Sales</td>
<td>No. of Customers</td>
<td>SFA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Having discussed the applications of the stochastic frontier, the moot issue of which underlying distribution used for the inefficiency term is the most appropriate is re-visited. In the section below, the discussion is even further advanced to debate whether the choice of a certain distribution really matters.

2.2.9 Does the Underlying Distribution Matter?
Typical specification of SFA is normal distribution, $N(0, \sigma^2_V)$, for the noise and some specified one-sided distribution for $u$, such as Expo($\lambda$) or $|N(0, \sigma^2_U)|$. These parametric models are well described and distinguished in the survey conducted by Kumbhakar and Lovel (2000). Adequate fitting of the data to the underlying assumption of the probability density distribution of the noise term and or efficiency term is the motivation of these modifications as authors perceive that data may not be really distributed normally. With this view, the classical SFA could lead to over or under estimation of efficiency. Testing different shapes of distribution from exponential, truncated, half normal, gamma to Rayleigh was expected to produce significant differences in results. Green (2005) and Kumbhakar and Lovell (2005), suggest that little has been done to empirically test if the difference in efficiency scores from the various modifications are significant or not to the ranking of firms on efficiency. Yet, Green (2005) agrees by arguing that even though no analytical studies have been done to confirm the impact the different distributions have on efficiency ranking, the various models of varying distributions have been robust as per their specifications. Kumbhakar and Lovell (2000) report estimates based on the cost frontier estimated in Greene (1990) using the Christensen and Greene (1976) electricity data. Kumbhakar and Lovell obtained rank correlations for estimates of inefficiencies from the four known distributions that ranged from a low of 0.7467 (exponential and gamma) to a high of 0.9803 (half normal and truncated normal). Green (2005) admits that their results based on the same data used in Christensen and Greene (1976) are considerably stronger. However, the author associates the strong evidence of the impact of the distribution types and their corresponding correlation rankings to the difference in specifications (translog cost function against translog production function) and the algorithm (simulation based estimator against the Brute Force Estimator) used.

Kumbhakar and Lovell (2000), agree that it is apt for sample efficiency means to be sensitive to the underlying distributions and that many empirical studies have confirmed the sensitivity
of mean efficiency. However, the authors suggest that it is unclear how the distribution chosen could change the ranking in efficiency of the sample firms.

The review at this point appeals for models which are more accommodative to fit different data types and shapes of distribution density of the error term or the inefficiency term. Reviewing literature in other areas other than energy such as applied reliability studies in health services and insurance companies, make use of burr distribution in their model specification. It is thus possible to look into how burr distribution could be utilised to enhance SFA models. Preceding this compelling task will be to examine the feature and applications of Burr distribution in the next section.

2.2.9.1 Features and Applications of Burr Distribution

Burr (1942) introduced twelve different forms of cumulative distribution functions for modelling data. Among those twelve distribution functions, Burr-Type X and Burr-Type XII received the maximum attention. However, its application was put in recess until Cox (1961) initiated an investigation to identify the best distribution for data. This attempt thus advanced the argument and theoretical research into the subject matter. He constructed a problem in terms of a significance test to measure the departure of the observed data from a null distribution in the direction of an alternative distribution. In his other paper, Cox (1977) declares that formulating other distribution representing the direction of the departure from the null distribution is weaker than embedding the null distribution in a family of competing models, each of which could be the true representative of the observed data. It implies that considering general family of distributions could fit data if none of the individual competing models is appropriate.

From Cox’s discussion in terms of survival analyses or reliability studies where he suggests that a general family of parametric distributions should be given the first option for robustness, it is in order to employ Burr distribution on SFA in the estimation of technical efficiency. Given the most common distribution fits to be half-normal and truncated for SFA, experimenting with Burr distribution could improve on the robustness of the model. The strengths of Burr Distribution is confirmed by Rodriguez (1977) who suggests that it covers large range of distribution shapes useful in real world applications. For example, the Type XII distributions include characteristics of the normal, lognormal, gamma, logistic, and exponential distributions as well as other characteristics associated with the Pearson family
of distributions. Also, the peculiarity of the variables of data sets in certain jurisdictions like Africa with many shocks and structural breaks in observations adds to the motivation of this investigation. There could be a wide deviation from normality and other forms of distribution which may make the derived model of the stochastic frontier insensitive to energy efficiency measurements. In essence, there is a possibility of underrating or overrating energy efficiency measurements when the true distributions of underlying parameters deviate from the assumed distributions.

**Figure: 2.29: Different Density Functions of Burr XII (c, k, α) Distribution with Different Values of α and Fixed Values of c and k**

![Figure 2.29: Different Density Functions of Burr XII (c, k, α) Distribution with Different Values of α and Fixed Values of c and k](image)

*Source: An output from the study*

The figure above illustrates the different density functions of Burr XII with one varying parameter and two fixed parameters. The various shapes of distribution can be seen to be contained in Burr distribution indicating that it forms a family of various distributions. A detailed account of Burr XI distribution is important to the research. As such, the section following will explore the foundations of the distribution and how it can be assimilated into the SFA model.

Examples in Okasha and Matter (2015); Surles and Padgett (2001) show that Burr-type distributions are one of the very popular distribution families for modelling lifetime data as well as modelling phenomenon with monotone and unimodal failure rates. Korkmaz et al. (2017) suggests that Burr distribution is very versatile and confirms that a variety of uncertainties can be modelled by it. It has several applications in actuarial science, economics, finance, life testing, survival analysis and telecommunications because of its heavy tail properties. Burr XII especially, has been appraised for hydrological applications and it proves
to be very useful given its flexibility and ability to adequately adapt many different shapes of frequency curves and flow duration curves (FDC). The appraisal yields that the disadvantage of Burr XII distribution among other three parameter distributions is that the practical applications are hampered due to the difficulties in implementing and controlling the estimation procedure.

According to Das and Nath (2016), the three-parameter Burr XII distribution was originally used in the analysis of lifetime data and is becoming increasingly useful in the context of actuarial science. They agree that a typical attribute of the occurrence of large but infrequent claims necessitates the need to fit and use a statistical distribution characterised with heavy tails and a rightward skew. In this regard, different distributions such as Pareto, Weibull and Burr are suitable candidates for loss modelling in motor insurance.

The above discussion on the features and applications of Burr distribution offers adequate revelations that provides the basis to research on the incorporation of Burr distribution into the stochastic frontier model.

So far, the measuring techniques have been discussed extensively in this chapter. It is realised that there is an opportunity to improve on the stochastic frontier model by considering a more flexible Burr distribution based on its features and potentials discussed above.

Considering that this study employs a multi-disciplinary approach and tools to achieve the set objectives discussed in chapter one, it is appropriate to depart from the frontiers of efficiency measurement to review the political economy analysis tool which will be found useful in chapter five the study seeks to understand the inefficiency problem of the electricity distribution sector of West Africa. In section 2.3, the underlying theory and its applications in the energy landscape is explored.

2.3 Theory of Political Economy Analysis
Preceding the explanation of the PEA framework is an important undertaking to explain the political economy approach to development used in many disciplines and popularised by the view of the development community. Considering John Arndt’s position on linking the political economy paradigm to theory building in marketing in Arndt (1983) it is not out of place when it comes to explaining the paradigm and its connection with the development work.
To start with, according to Bagozzi (1974), paradigms can be explained as statements in science that answer questions and attempts to indicate rules followed in giving meaning to result findings. Kuhn (1962) had previously simplified what paradigms mean by stating that they “provide models from which emerges particular articulate traditions of scientific research.” The interpretation is that paradigms are not theories and thus may rise and fall since they lack testable propositions and law-like generalisations. They are thus foundations from which theories may evolve. An understanding of the paradigm of microeconomics is crucial as it builds a good foundation for alternatives of Political Economy Analysis. This paradigm may be argued to be one of the dominant view in contemporary social sciences as it is well elucidated by Arndt (1983). He also admits that the core mission of this paradigm concerns prices, market establishments and income distribution among others. Apart from microeconomics being given an entrenched position in Economics, its traits of optimality and cogent logic continues to make it applicable in other related fields. Riding on its tenet of efficient allocation of resources, it has been applied to various fields including marketing, business management, engineering, industrial ecology and even at the national levels of reforms. In spite of the valuable role played by the microeconomic paradigm in providing normative decision rules or models for practitioners, a common view shared by social scientist and development partners is that it is inadequate in providing positive theory to solving problems that involve many interest groups within and outside organisations. For solving problems that go beyond the maximisation of returns of one actor to build a theory of organisations involving many actors, there will be the need to develop a paradigm that considers interests as well as potential conflicts within and between organisations to impact the shaping of external relationships. The political economy approach could therefore complement the typical microeconomics paradigm to bring an understanding to problems with the motive of reaching sustainable solutions.

Due to the variability in the political economy paradigm, the choice of organisational approach of political economy is the one which brings to light the foundations of PEA which the section intends to explicate. Political Economy is considered by Stern and Reve (1980) as one that understands social systems as “comprising interacting sets of major economic and socio-political forces which affect collective behaviour and performance. “ The Marxian tradition in development theory in the time of Lenin’s imperialism is an example of the
application of political or political economy tools to development. In addition, Adam and Dercon (2009) accede that the use of political economy was apparent in the structuralist economics tradition which led the discussions on economic development in Latin America for nearly four decades. This presupposes that the concept of political economy has been used in the past except to say in neo classical development economics the emergence of the new political economy of development is more evident. It is not surprising therefore that the diagnosis and recommended policy actions of the “development problem” by international agencies such as the World Bank, the IMF, ADB, OEDC and others show traces of political economy. A case in point is the capital-shortage diagnosis at a time where low incomes and the significant low private and social returns characterised the developing world between the 1950s and 1970s with which the short-term capital inflows through governments as an approach to development assistance had little success especially in Africa. Critiques of foreign aid including Peter Bauer (1974) were quick to suggest that failure of the countries comes from the view taken to sacrifice inclusive economic development for more acquisitive objectives. At this stage, international development partners came to the realisation that low levels of growth and development are symptomatic of weightier concerns regarding political and institutional foundations on which societies are constructed and that resonates the choices of economic policies. Traditions of African political economy had been conveniently suggested by Robert Bates (1986) and Richard Sandbrook (1985) as the main attribute embedding institutional failures in systems where the use of patronage, opposing regulatory agencies and weakening of competing centres of political power as “coherent” strategies of African leaders.

This “institutional failure” diagnosis brought to the attention of international development agencies to consider a range of policy instruments that uses aid flows but with the object of moving the political equilibrium to enforce transparency and accountability on political groups and elites. The emergence of good governance in international engagements as an alternative laid a foundation for macroeconomic policy choices, investment options and trade reforms to contest with a wide range of concerns regarding Governance, regulation, corruption and institutional foundations of policy. The concept of good governance is defined by the Swedish Government as “a good system of government encompassing the state’s way of exercising its political, economic and administrative powers”. SIDA (2002) suggests that the
institutions and processes should be based on principles of rule of law and should show traits of responsibility, integrity, openness and efficiency.

The UNDP definition relates to governance for sustainable Human Development and it is defined as “characterised by participation, transparency and accountability, efficiency and purposefulness, equality and justice, and the rule of law. Good governance should ensure that political, social and economic priorities are based on a broadly common view in society and that the poorest and most vulnerable groups have an influence over decisions on the division of development resources”

The World Bank defined governance as “a predictable, open and enlightened policy formulation (i.e. transparent processes), a public sector characterised by a professional ethos, the rulers’ executive branch taking responsibility for their actions and a strong civil society’s participation in public undertakings, all on basis of a society founded on the rule of law”. The good governance methodology or diagnosis had been the back-bone or guiding principle for many recommended policy actions by the development community until recently when a second thought was given to its relatively unsuccessful results in some jurisdictions.

The confusion of how certain good and tested reforms which worked well in certain regions, countries or even communities failed to yield expected results opened up the discussion for more inputs. In these discussions, recent literature including IDS (2005), IDS (2010) and Grindle (2011) equally critiqued the good governance approach and suggested that the classical good governance approach is based on normative assumptions that enhanced governance and institutional models practiced successfully elsewhere can be simply transferred to the developing world to yield similar results. These critiques proposed an approach that does not only impose good practice but one that considers measures befitting to the political and social context. The Political Economy Analysis as an alternative to the good governance approach provides an understanding on state-building as well as managing or limiting conflicts, managing economic rents, understanding the formal and informal institutions and lastly, appreciating the form and structure of political competition.

A reflection on this issue has called for investigating how political processes within which such projects or programmes are implemented. As Barnet (2016) indicates, the unintended focus has been rather “what needs to be done” and not “how to make it happen” in the development community. He suggests that generally the solutions have been designed
around the suspected issues of the lack of political will or vested interest against reforms, lack of competent policy implementers and others. The motive of understanding the underlying factors that promote or inhibit the expected outcomes could be unveiled as long as these investigations go beyond the existing policy and take a deeper view on other factors that characterise the incentives and potentials of agents against positive change. A Political Economy Analysis is therefore one of the requisite tools required to traverse this very critical stage of policy design and implementation. According to the DFID (2009), PEA is described as multi-disciplinary field of enquiry which seeks to put together the insights of the old political economy with ‘new institutional economics’ and understanding of social processes, cultural norms and ethnicity. The Economic Co-operation and Development (OECD) provides another explanation which could enhance the understanding of the major components of Political Economy Analysis. In their view “Political Economy Analysis is concerned with the interactions of political and economic processes in a society: the distribution of power and wealth between different groups and individuals, and the processes that create, sustain and transform these relationships over time.” By this definition, the negotiation or bargaining manifested as interest groups compete over their rights to resources cannot be ignored. In the same vein, the economic process or reward implications is not overlooked in the definition as one of the motives of contesting the rights over resources not reduced to just ownership but also the economic incentives which contributes to their societal influence affecting also the political choices made in the society. ADB (2013) propose that the dynamics of political and economic processes can therefore be challenging to disentangle from the success or failure of policies. In support of the use of PEA, Barnett, Stockbridge and Kingsmill (2016) suggest that the use of PEA should help to understand why socially and economically desirable plans and policies exhibit some difficulties to implement by policymakers to yield expected results.

There are different PEA frameworks and the structure of each framework is based on what the PEA is attempting to achieve. Country level PEA is centred on general macro scale analysis of a policy, issue or a problem. Sector focused PEA deals with identifying specific barriers and opportunities in a particular sector. Within a country or a particular sector, PEA can be employed to understand a certain problem with policy or reform. As discussed earlier, the
development community agencies have developed varied frameworks that seek to cover the different PEA applications.

Referring to figure 2.30, PEA can be carried out at the country level and at the sector level.

Figure 2.30: Types of Applications of Political Economy Analysis

Source: DFID (2009)

At the country level, DFID’s Drivers of Change (DOC) approach is one of the earliest tools used in analysing political economy by a donor agency. A macro-scale question of how policy benefit the poor and the vulnerable in a sustainable way is the main principle behind the approach. Many of countries have been explored with this approach and the drivers of change analysis on Ghana by Booth et al. (2005) is a popular example. The analytical framework is set out to determine possible drivers of change within the country’s structural features, institutions and agents.

Structural features cover the country’s economic and social structures, natural resources, demographics etc. while the formal and informal rules form the country’s institutions. The agents’ section of the analysis determines the drivers of change embedded in political leaders, political parties and trade unions as well as external actors including foreign governments and even donor partners.
There were some initial limitations of the above framework. First, the lack of guidance allowed for inconsistencies in the methodology and quality. Also, the inability for the framework to translate findings into practical and operational actions added to its limitations. The politics of development approach was therefore designed to resolve these problems.

There are other PEA frameworks developed by other development agencies. The Netherlands Foreign Affairs use the Strategic Governance and Corruption Assessment (SGACA). Power Analysis is the framework developed by SIDA. “Problem Driven’’ approach is the framework of the World Bank used for Country, Sector and Project PEA.

Sectoral PEA concerns understanding the incentives and constraints that influence actors or change agents in a particular sector and to use such knowledge to enhance the explanation of why reforms fail. It could be applied to sectors such as education, health, water, power, Agriculture etc. DFID provides tools for sectoral and issue-based political economy.

Problem driven which is stated as a level of PEA in the DFID topology is rather contested by ODI (2012) as being applicable to all the levels discussed including the two levels in the former’s typology shown below:
They suggest that in place of the problem driven level in DFIDs classification, a representation of specific policies or projects will be more coherent in the typology of PEA. It is further highlighted that efforts in distinguishing between levels of application of PEA is by no means to suggest that the different levels should be treated as alternatives but should be seen as complementary. This is because in practice the issues in different levels interact with the different levels.

The World Bank’s approach to PEA is well detailed in the problem driven framework supported by ODI (2013) and well detailed in Fritz et al. (2009) seen in figure 2.32 below:

**Figure 2.32: Problem-Driven Political Economy Analysis Framework**

<table>
<thead>
<tr>
<th>What vulnerabilities/challenges?</th>
<th>Evidence of poor outcomes to which GPE weaknesses appear to contribute.</th>
<th>Eg: repeated failure to adopt sector reform and poor sector outcomes. Continuous food insecurity. Corruption continues to undermine the business climate even after anti-corruption law.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governance and Political Economy Analysis</td>
<td>Institutional &amp; governance arrangements &amp; capacities</td>
<td>What are the associated institutional set-up and governance arrangements?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mapping of relevant branches of gov’t, ministries, agencies &amp; their interaction. Existing laws &amp; regulations. Policy processes (formal rules &amp; de facto).</td>
</tr>
<tr>
<td></td>
<td>Political economy drivers</td>
<td>Why are things this way? Why are policies or institutional arrangements not being improved?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Analysis of stakeholders, incentives, rents/rent-distribution, historical legacies &amp; prior experiences with reforms, social trends &amp; forces (eg ethnic tensions) and how they shape current stakeholder positions and actions.</td>
</tr>
</tbody>
</table>

**Source:** Fritz *et al.* (2009)

Barnett, Stockbridge and Kingsmill (2016) provide a framework that simplifies the political economy analysis and further provide the sources of political economy signals along the value chain of the power sector of Africa in figures 2.33 and 2.34 below:
It is believed that the problem in the power sector is a vicious circle. The fact that the power sector runs on a system implies a problem in one part could be caused by another part or could affect other parts. Therefore, it is important to always have a holistic view of the activities of the supply chain with the objective of identifying possible sources of rent extraction, interest and political economy. For example, awarding less value for money contracts will push cost of production high would compel consumers to pay for higher tariffs or government to subsidise tariffs. Such interactions in the system and the related transmitted effects compounds the inefficiency problem in the power sector. Solving
inefficiencies in one part of the chain is only part of the solution but not a complete solution as inefficiencies in the other sector can reintroduce same in that sector. Barnett et al (2016) analogue that by saying “It does not matter where the toothpaste tube is pressed as long as the tooth paste rent comes out.” Inefficiencies could therefore be introduced in the whole system due to the inefficiencies of one or two parts of the chain. They suggest that procurement activities, inefficient pricing or costing as well as less productive staff form a common grounds for rent extraction in all parts of the value chain.

The literature on political economy analysis abound at least within the last twenty or so years. There is therefore a significant number of empirical work in the literature of political economy analysis which is unsurprisingly dominated by the writers from donor agencies in the development economy. The world bank, SNV, DFID USAID are main contributors in this field. The Policy Practice and other consultancies have also written extensively on policy briefs explaining the concept of PEA at various levels and in different jurisdictions and sectors as well as applying the technique in various fields. The table below details some of the PEA studies in the energy industry.

**Table 2.4: Applications of Political Economy Analysis in the Energy Sector**

<table>
<thead>
<tr>
<th>Authors</th>
<th>Title</th>
<th>Key Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnett et al. (2016)</td>
<td>Political Economy of Africa’s Power Sector</td>
<td>Donors to help build technical and financial capacity but be more flexible</td>
</tr>
<tr>
<td>Barnett (2014)</td>
<td>Political Considerations relevant to Energy and Economic Growth</td>
<td>All energy systems, private or public need some form of regulation and are governed by important tax and subsidy regimes linked with lobbying, rent seeking with winners and losers</td>
</tr>
<tr>
<td>Nwajiaku-Dahou (2012)</td>
<td>The political economy of oil and 'rebellion' in Nigeria's Niger Delta</td>
<td>The systematic smuggling of refined oil products across porous West African borders by state officials responsible for endemic shortages in the downstream sector has been common practice in Nigeria for decades, as has under-invoicing by oil companies, and pipeline tapping by oil-company employees past and present</td>
</tr>
<tr>
<td>Authors</td>
<td>Title</td>
<td>Key Findings</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
<td>--------------</td>
</tr>
<tr>
<td>Obi (2010)</td>
<td>Oil as a ‘curse’ of conflict in Africa: peering through the smoke and mirrors</td>
<td>The resource curse perspective cannot fully explain conflict in African oil states. It is argued that the class relations, contradictions and conflicts rooted in the reduction of the continent and its resources to transnational processes and elites ingrained in globalised capitalist relations may be a befitting explanation from a political economy perspective.</td>
</tr>
<tr>
<td>William (2010)</td>
<td>Making a liberal state: ‘good governance’ in Ghana</td>
<td>The construction of a liberal state involves a establishing of the state as a governmental agency with the capability to institute reforms on its society.</td>
</tr>
<tr>
<td>Stiftung (2013)</td>
<td>Powering Africa thorough Feed-in-tariffs</td>
<td>The overall costs of Refit project development and the lack of affordable financing options are major constraints to Renewable Energy FiT</td>
</tr>
<tr>
<td>Energy Group, Africa Region (2013)</td>
<td>Energizing Economic Growth in Ghana: Making the Power and Petroleum Sectors Rise to the Challenge</td>
<td>A common challenge to the power and petroleum sectors revolves around unplanned investments, unsatisfactory performance of energy enterprises and unsustainable pricing policies.</td>
</tr>
</tbody>
</table>

2.4 Summary
Chapter two is structured to give an extensive background to the electricity industry of West Africa in the first part. This is important for the purposes of giving the necessary foundation to the investigations done in chapters four and five. This chapter examined the state of electricity along the power supply chain of various West African countries and illuminated on their marker structure, regulatory regimes or models and challenges. It revealed that the persistent problems that necessitated reforms hinge on the inefficiency of the power sector. It was revealed that the region continues to have a supply and demand gap with high prices of electricity making a significant section of the population unable to access electricity. Also, that if the system could not add to the generation capacity or reduce the cost of electricity,
the least it could do was to reduce the level of inefficiency. That task continues to be looked at by national policy reformers as well as regional policy reformers giving it a significant level of attention. However, properly estimating the level of inefficiency is probably the first step to minimising it but unfortunately, the literature also revealed the lack of a holistic model for measuring efficiency of the operations of utilities in the value chain and that simplistic ratios that are less representative of the overall efficiency are used instead.

Understanding the concept of efficiency, theoretical underpinnings of frontier economics and the various techniques for measuring efficiency is the general motive of part two of the chapter. Specifically, the main aim was to narrow down on the Stochastic Frontier Approach (SFA) or technique for modelling efficiency. Different sub-models have been discussed in this section with the future benefit of being applied in our empirical study of estimating the efficiency of electricity distribution companies in West Africa. In the end, the moot issue of which distribution underlying the inefficiency term in the SFA technique is resurrected with much credence to Burr Distribution as a likely contender. In order to lay a good foundation for further analysis in chapter five, it was also prudent to explain the political economy analysis framework while reviewing the underlying theories and applications accordingly. Having successfully executed the objectives of the chapter, this research proceeds to chapter three to investigate the potentials of Burr type x as an assumed distribution of Stochastic frontier approach.
Chapter 3
Formulation and Analyses of the Normal-Burr X Stochastic Production Frontier Model

3.1 Introduction
As discussed in chapter two, the Stochastic Frontier Model, primarily was developed to measure technical efficiency of production units. In the model, these production units (firms, regions, countries, etc.) are assumed to produce according to a common technology and are considered efficient when they lie on the frontier as they produce the maximum possible output for a given set of inputs. Otherwise, the firms are relatively inefficient which could be due to structural problems or market imperfections and other factors which cause firms to produce below their maximum attainable output. Aigner, Lovell, and Schmidt’s (1977) and Meeusen and van den Broeck (1977), who independently proposed the stochastic frontier model simultaneously accounts for statistical noise and technical inefficiency.

The stochastic frontier model is usually estimated by a maximum likelihood estimation, which requires distributional assumptions of the error terms. Most often, it is assumed that the noise term follows a normal distribution with zero mean and constant variance. For the estimation of the technical inefficiency term, other distributional assumptions have been proposed in the literature and they include a one parameter half normal introduced by Aigner et al. (1977) and exponential by Meeusen and Van den Broeck (1977). For the two parameter distributions, Stevenson (1980) constructed the stochastic frontier model based on truncated normal while Greene (1980, 1990) introduced the gamma distributions. There is no theoretical justification for the selection of any particular distributional form over the other (Coelli, Rao and Battese, 1998).

All the inefficiency distributions in the literature have different strengths and weaknesses. For instance, the exponential and half-normal distributions have a mode at zero, suggesting that a high percentage of the firms under study are perfectly efficient. The distributions like truncated normal and gamma distribution could have non-zero modes. Thus they are more flexible than exponential and half-normal. However, according to Ritter and Simar (1997) it may be difficulty and if not inept to identify the best estimate of the values of the two gamma parameters. The choices of models used in the stochastic frontier in the literature seem to be somewhat arbitrary.
In this work, Burr X distribution is proposed to be the assumed distribution of technical inefficiency term in the SFA model. The potential of Burr X distributions has been discussed in the chapter 2 and it is expected to be more flexible with the ability to encapsulate the already known and assumed distributions for the inefficiency term (i.e. half normal, truncated, exponential, gamma and Rayleigh). Burr X is known to have some interesting relations with the Rayleigh, Gamma and Weibull distributions. It is also related to the recently proposed Exponentiated exponential and Exponentiated Weibull distributions.

The rest of the chapter is outlined as follows: Section 3.2 introduces the stochastic frontier model for cross-section; Section 3.3 discusses the specification of the Burr X distribution in detail; section 3.4 illustrates the maximum likelihood estimation of Burr parameters; section 3.5 presents the designing stage of the Normal-Burr X SFA followed by log likelihood estimation of the proposed model in section 3.6. Sections 3.7, 3.8 and 3.9 respectively present efficiency estimation of the proposed model, results of the Monte Carlo simulations and conclusion of the chapter.

### 3.2 Model Specification

The original stochastic frontier production for cross-sectional data had an error term which had two components, one to account for the usual random noise \((V)\) and another to account for technical inefficiency \((U)\). This model can be expressed as:

\[
Y_i = \beta X_i + (V_i - U_i) 
\]

where for any \(i = 1, \cdots, n\); and:

- \(Y_i\) is the production function (or the logarithm of the production) for \(i\)th firm.
- \(X_i\) is a \(k\)x1 vector of (transformations of the) input quantities of the \(i\)th firm.
- \(\beta\) is a vector of unknown parameters.

Furthermore, for \(i = 1, \cdots, n\), \(V_i\) is the random error term or noise assumed to be identical and independently normally distributed with mean 0 and variance \(\sigma_V^2\); \(U_i\) is a non-negative random variable which is assumed to account for technical inefficiency and often assumed to be identical and independent normally distributed with mean 0 and variance \(\sigma_U^2\). In the model (1) \(V_i\) and \(U_i\) are also assumed to be independent of one another. Technical efficiency
is defined as \( \text{TE}_i = \exp(-U_i) \), and the point of the model is to estimate \( U_i \) or \( \text{TE}_i \). The value of \( \exp(-U_i) \times 100 \) is the percentage of the maximum possible output obtained by a producer \( i \). This original stochastic production frontier specification has been modified and extended in the literature as discussed in chapter two. Aside the four main distributional assumptions discussed earlier, recent engagements in this field of research have introduced other distributional assumptions including Weibull by Tsionas (2007) and Rayleigh constructed independently by Oliviero (2014) and Hajargasht (2014). Model specification (3.1) has also been modified to accommodate panel data and time-varying technical inefficiencies.

In order to modify the stochastic frontier production model given in equation (3.1) by allowing the technical inefficiency term \( U_i \) to have two-parameter Burr type \( x \) distributions, section 3.3 provides the distributional functions of Burr \( x \).

3.3 The Burr \( x \) Distribution

Burr (1942) introduced twelve different forms of cumulative distribution functions for modeling data. Among those distributions, Burr Type \( x \) and Burr Type \( x \) are the most popular ones. Several authors consider different aspects of the Burr Type \( x \) and Burr Type \( x \) distributions and these examples could be seen in Ahmad, Fakhry and Jaheen (1997), Jaheen (1995, 1996), Raqab (1998), Rodriguez (1977), Sartawi and Abu-Salih (1991), Surles and Padgett (1998) and Wongo (1993). For a review for the two distributions the readers are referred to Johnson, Kotz and Balakrishnan (1995). Recently, Surles and Padgett (2001) introduced two-parameter Burr Type \( x \) distribution and named as the generalized Rayleigh distribution. The two-parameter Burr \( x \) distribution has the following cumulative distribution function:

\[
F(x) = \left(1 - e^{-\frac{x^2}{\sigma^2}}\right)^\alpha \text{ for } x > 0; \, \alpha, \sigma > 0
\]

where \( \alpha \) is the shape parameter and \( \sigma \) is the scale parameter of the distribution. When \( \alpha = 1 \) and \( \sigma = \sigma \sqrt{2} \), the Burr type \( x \) reduces to the Rayleigh distribution. If the random variable \( X \) has a Burr \( x \) distribution then it has the density function:

\[
f(x) = \frac{2\alpha x}{\sigma^2} e^{-\frac{x^2}{\sigma^2}} \left(1 - e^{-\frac{x^2}{\sigma^2}}\right)^{\alpha-1} \text{ for } x > 0; \, \alpha, \sigma > 0
\]  

(3.2)
When \( \alpha \leq 1/2 \) the Burr X distribution has a decreasing probability density function and when \( \alpha > 1/2 \) density function is a right-skewed unimodal. The Maximum likelihood estimators for the parameters of the Burr X have been obtained by Kundu and Raqab (2005).

The Burr X is a member of a more general class of distributions known as the Exponentiated Weibull family. The Burr X distribution covers large range of distribution shapes useful in real world applications. For example the Type X distribution includes characteristics of the normal, Rayleigh, gamma, Weibull, and exponential distributions, so that a wide variety of distributions may be approximated by a Burr X. The Maximum likelihood estimators for the parameters of the Burr type X is given by Kundu and Raqab (2005). The versatility and flexibility of Burr X distribution makes it an attractive tentative model for technical inefficiency term in stochastic frontier production analysis. The graph below shows Burr type X distribution densities for several values of the shape parameter (\( \alpha = 0.1, 0.25, 0.5, 1.2 \))

![Burr Type X Distributions with various Scales for its Parameters](image)

**Source: Produced by the Author**

Burr X is quite similar in nature to the other two-parameter families like Weibull, gamma or generalized exponential family. Raqab and Kundu (2006) studied the relationship of Burr X with Weibull, Gamma and Generalized Exponential while Lio et al. (2014) studied the control charts for monitoring Burr X. Smith et al. (2015) studied the higher order inference for stress–strength reliability with independent Burr X. The kth non-central moment for the Burr X distribution is defined in Surles and Padgett (2005)
\[ \mu_x^{(k)} = \alpha \sigma^k \Gamma \left( \frac{k}{2} + 1 \right) \sum_{i=0}^{\alpha-1} (-1)^i \binom{\alpha - 1}{i} \frac{1}{(i + 1)^{\frac{k}{2} + 1}} \]

Where \( \Gamma() \) is a complete gamma function. Therefore putting \( k = 1 \); the means are obtained as:

\[ \mu_x^{(1)} = \alpha \sigma \Gamma \left( \frac{1}{2} + 1 \right) \sum_{i=0}^{\alpha-1} (-1)^i \binom{\alpha - 1}{i} \frac{1}{(i + 1)^{\frac{1}{2} + 1}} \]

For example, when \( \alpha = 1 \), that is for a Rayleigh distribution, the mean value of \( X \) is

\[ \mu_x^{(1)} = \sigma \Gamma \left( \frac{1}{2} + 1 \right) = \sigma \sqrt{\frac{\pi}{2}} \]

The variance of \( X \) is

\[ \text{var}(X) = \mu_x^{(2)} - \left( \mu_x^{(1)} \right)^2 = \frac{2 - \pi}{2} \sigma^2 \]

The mode of the density function can be estimated as \( \sigma \gamma \) where \( \gamma_0 \) is the solution of the non-linear equation:

\[ 1 - 2\gamma^2 - e^{-\gamma^2} (1 - 2\alpha \gamma^2) = 0 \]

3.4 Maximum Likelihood Estimation Burr X Parameters

Kundu and Raqab (2005) obtained the Maximum likelihood estimators for the parameters of the Burr X and If \( \{X_1, \cdots, X_n\} \) denotes a random sample from Burr X, then the log-likelihood function, \( L(\alpha, \sigma) \), can be written as:

\[
L(\alpha, \sigma) = \ln 2 + n \ln \alpha - 2n \ln \sigma + \sum_{i=1}^{n} \ln x_i - \frac{1}{\sigma^2} \sum_{i=1}^{n} x_i^2 + (\alpha - 1) \sum_{i=1}^{n} \ln \left( 1 - e^{-\frac{x_i^2}{\sigma^2}} \right) \]

The maximum likelihood estimators for \( \alpha \) and \( \sigma \) can be obtained by taking the derivatives of equation (3.3) with respect to both \( \alpha \) and \( \sigma \) to result in two equations. The resulting equations can be set equal to 0 and solved to obtain the maximum likelihood estimates (MLE) of \( \alpha \) and \( \sigma \).
\[ \frac{\partial L}{\partial \alpha} = \frac{n}{\alpha} + \sum_{i=1}^{n} \ln \left( 1 - e^{-\frac{x_i^2}{\sigma^2}} \right) = 0 \] (3.4)

\[ \frac{\partial L}{\partial \sigma} = 2n\sigma - \frac{2}{\sigma} \sum_{i=1}^{n} x_i^2 + \frac{2}{\sigma} (\alpha - 1) \sum_{i=1}^{n} \frac{x_i^2}{1 - e^{-\frac{x_i^2}{\sigma^2}}} = 0 \] (3.5)

From equation (3.4), it is possible to obtain the MLE of \( \alpha \) as a function of \( \sigma \), denoted by \( \hat{\alpha}(\sigma) \) as found below:

\[ \hat{\alpha}(\sigma) = -\frac{n}{\sum_{i=1}^{n} \ln \left( 1 - e^{-\frac{x_i^2}{\sigma^2}} \right)} \]

Putting \( \hat{\alpha}(\sigma) \) into equation (3.3), the profile log-likelihood of \( \sigma \) can be written as (ignoring the constant):

\[ L(\hat{\alpha}(\sigma), \sigma) = -n \ln \left( -\sum_{i=1}^{n} \ln \left( 1 - e^{-\frac{x_i^2}{\sigma^2}} \right) \right) - 2n \ln \sigma - \frac{1}{\sigma^2} \sum_{i=1}^{n} x_i^2 - \sum_{i=1}^{n} \ln \left( 1 - e^{-\frac{x_i^2}{\sigma^2}} \right) \]

The MLE of \( \sigma \) can be obtained by maximizing \( L(\hat{\alpha}(\sigma), \sigma) \) given above with respect to \( \sigma \). This can be done by differentiating \( L(\hat{\alpha}(\sigma), \sigma) \) with respect to \( \sigma \), equating it to 0 and then solving for \( \sigma \).

3.5 The Normal-Burr X Stochastic Frontier Analysis

In this section, the stochastic frontier production model given in equation (3.1) is modified by allowing the technical inefficiency term \( u \) to have a two parameter Burr x distribution defined in equation (3.2). Thus the probability density function for the technical inefficiency term \( u \) can be written as

\[ f_u(u) = \frac{2\alpha u}{\sigma_u^2} e^{-\frac{u^2}{\sigma_u^2}} \left( 1 - e^{-\frac{u^2}{\sigma_u^2}} \right)^{\alpha-1} \text{ for } u > 0; \alpha, \sigma_u > 0 \]

From the model specification (3.1) it is assumed that statistical noise term \( v \) has a standard normal probability density function:
\[ f_\nu(\nu) = \frac{1}{\sqrt{2\pi\sigma_\nu}} e^{-\frac{\nu^2}{2\sigma^2_\nu}}, \quad \sigma_\nu > 0 \]

Given the independence assumption, the joint density function of \( \nu \) and \( u \) is the product of their individual density functions,

\[ f(\nu, u) = f_\nu(\nu)f_u(u) \]

Letting the composed error, \( \epsilon = \nu - u \), so that the joint density for \( \epsilon \) and \( u \) can be obtained as:

\[ f(\epsilon, u) = f_\nu(\epsilon + u)f_u(u) \]

Since the Jacobian of the transformation from \((\nu, u)\) to \((\epsilon, u)\) is equal to 1, then;

\[
\begin{align*}
    f(\epsilon, u) &= 2a\frac{u}{\sigma^2_u} e^{-\frac{u^2}{\sigma^2_u}} \left(1 - e^{-\frac{u^2}{\sigma^2_u}}\right)^{\alpha - 1} \frac{1}{\sqrt{2\pi\sigma_\nu}} e^{-\frac{(\epsilon+u)^2}{2\sigma^2_\nu}} \\
\end{align*}
\]

(3.6)

The marginal density function of \( \epsilon \) is then obtained by integrating out \( u \) from the joint density given by equation (6), which gives

\[
\begin{align*}
    f(\epsilon) &= \int_0^\infty f(\epsilon, u) \, du \\
    f(\epsilon) &= \int_0^\infty 2a\frac{u}{\sigma^2_u} e^{-\frac{u^2}{\sigma^2_u}} \left(1 - e^{-\frac{u^2}{\sigma^2_u}}\right)^{\alpha - 1} \frac{1}{\sqrt{2\pi\sigma_\nu}} e^{-\frac{(\epsilon+u)^2}{2\sigma^2_\nu}} \, du \\
\end{align*}
\]

This density is required in estimation of the parameters by maximum likelihood estimation. However, it is not available in closed form. By making the change-of-variable \( x = \frac{u}{\sigma_u} \) and the substitution \( \lambda = 1 + \frac{\sigma^2_u}{2\sigma^2_\nu} \) and \( e_{\sigma_\nu} = \frac{\sigma_u}{\sigma_\nu} \), the following is obtained

\[
\begin{align*}
    f(\epsilon) &= \frac{1}{\sqrt{2\pi\sigma_\nu}} e^{-\frac{\epsilon^2}{2\sigma^2_\nu}} \int_0^\infty 2\lambda x e^{-\lambda x^2} \left(1 - e^{-x^2}\right)^{\alpha - 1} e^{-q x} \, dx \\
\end{align*}
\]
Now since $0 < 1 - e^{-x^2} < 1$, for $x > 0$, therefore, by using the series representation (finite or infinite) of $(1 - e^{-x^2})^{\alpha-1}$, when the shape parameter $\alpha$ is not a natural number, the following is obtained.

$$(1 - e^{-x^2})^{\alpha-1} = \sum_{j=0}^{\infty} (-1)^j \binom{\alpha-1}{j} e^{-jx^2}$$

Where $\binom{\alpha-1}{j} = \frac{(\alpha-1)\cdots(\alpha-j)}{j!}$, the integral below is obtained

$$\int_0^\infty 2ax e^{-\lambda x^2} (1 - e^{-x^2})^{\alpha-1} e^{-qx} dx = 2\alpha \sum_{j=0}^{\infty} (-1)^j \binom{\alpha-1}{j} \int_0^\infty x e^{-x^2(\lambda+j)} e^{-qx} dx$$

(3.7)

For integer values of $\alpha$, equation (3.7) can be presented as a finite series representation. Using Gradshteyn and Ryzhik (2007) (pp. 365), the following is arrived at.

$$\int_0^\infty x e^{-x^2(\lambda+j)} e^{-qx} dx = \frac{1}{2(\lambda+j)} - \frac{q}{4(\lambda+j)} \frac{\sqrt{\pi}}{\sqrt{\lambda+j}} e^{\frac{q^2}{4(\lambda+j)}} \left[ 1 - \text{erf}\left( \frac{q}{2\sqrt{\lambda+j}} \right) \right]$$

Where $\text{erf}(x)$ is the error function defined as:

$$\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

Thus,

$$f(\varepsilon) = \frac{\alpha}{\sqrt{2\pi}\sigma_v} e^{-\frac{\varepsilon^2}{2\sigma_v^2}} \sum_{j=0}^{\infty} \frac{(-1)^j}{\lambda+j} \binom{\alpha-1}{j} \left[ 1 - e^{\frac{q^2}{4(\lambda+j)}} \frac{q}{2\sqrt{\lambda+j}} \left[ 1 - \text{erf}\left( \frac{q}{2\sqrt{\lambda+j}} \right) \right] \right]$$
The error function has the following property

\[ \text{erf}(-x) = -\text{erf}(x) \]

In addition, it has a relationship with the cumulative distribution of a standard normal \( \Phi \), given by

\[ \Phi(x) = \frac{1}{2} \left( 1 + \text{erf} \left( \frac{x}{\sqrt{2}} \right) \right) \]

Using these relations, the function below is obtained;

\[ 1 - \text{erf} \left( \frac{q}{2\sqrt{\lambda + j}} \right) = 1 + \text{erf} \left( \frac{-q}{2\sqrt{\lambda + j}} \right) = 2\Phi \left( \frac{-q}{2\sqrt{\lambda + j}} \right) \]

And therefore,

\[ f(\varepsilon) = \frac{\alpha}{\sqrt{2\pi}\sigma_v} e^{-\frac{\varepsilon^2}{2\sigma_v^2}} \sum_{j=0}^{\infty} \frac{(-1)^j}{\lambda + j} \left( \alpha - 1 \right) \left[ 1 - e^{q\sqrt{\pi}(\lambda+j)} \frac{q\sqrt{\pi}}{\sqrt{\lambda + j}} \Phi \left( \frac{-q}{2\sqrt{\lambda + j}} \right) \right] \]

Substituting \( q = \frac{\varepsilon\sigma_u}{\sigma_v^2} \), gives

\[ f(\varepsilon) = \frac{\alpha}{\sqrt{2\pi}\sigma_v} e^{-\frac{\varepsilon^2}{2\sigma_v^2}} \sum_{j=0}^{\infty} \frac{(-1)^j}{\lambda + j} \left( \alpha - 1 \right) \left[ 1 - \frac{\varepsilon^2\sigma_u^2(\lambda+j)}{\sigma_v^2} \frac{\varepsilon\sigma_u\sqrt{\pi}}{\sigma_v^2} \Phi \left( \frac{-\varepsilon\sigma_u}{\sigma_v^2\sqrt{2(\lambda+j)}} \right) \right] \]

It is important to note the following series expression

\[ \sum_{j=0}^{\infty} \frac{(-1)^j}{\lambda + j} \left( \alpha - 1 \right) = \frac{\Gamma(\lambda + 1) \Gamma(\alpha)}{\lambda \Gamma(\lambda + \alpha)} \]

Which gives the following expression:
\[ f(\varepsilon) = \frac{\alpha}{\sqrt{2\pi\sigma_v}} e^{-\frac{\varepsilon^2}{2\sigma_v^2}} \left[ \frac{\Gamma(\lambda + 1) \Gamma(\alpha)}{\lambda \Gamma(\alpha + \lambda)} \right] \]

\[ - \sum_{j=0}^{\infty} \frac{(-1)^j}{\lambda + j} \left( \alpha - 1 \right) \frac{\varepsilon^2 \sigma_u^2}{\lambda \sigma_v^2} \frac{\varepsilon \sigma_u \sqrt{\pi}}{\sigma_v^2 \sqrt{\lambda + j}} \Phi \left( \frac{-\varepsilon \sigma_u}{\sigma_v^2 \sqrt{2(\lambda + j)}} \right) \]

Then, if taking two terms in the partial sum, the following approximation for \( f(\varepsilon) \) is obtained below:

\[ f(\varepsilon) \approx \frac{\alpha}{\sqrt{2\pi\sigma_v}} e^{-\frac{\varepsilon^2}{2\sigma_v^2}} \left[ \frac{\Gamma(\lambda + 1) \Gamma(\alpha)}{\lambda \Gamma(\alpha + \lambda)} \right] \]

\[ - \frac{\varepsilon^2 \sigma_u^2}{\lambda \sigma_v^2} \frac{\varepsilon \sigma_u \sqrt{\pi}}{\sigma_v^2 \sqrt{\lambda + 1}} \Phi \left( \frac{-\varepsilon \sigma_u}{\sigma_v^2 \sqrt{2(\lambda + 1)}} \right) \]

When the shape parameter \( \alpha \) is a natural number, then the probability density function for the composed error given in equation (8) reduced to the finite sum

\[ f(\varepsilon) = \frac{\alpha}{\sqrt{2\pi\sigma_v}} e^{-\frac{\varepsilon^2}{2\sigma_v^2}} \sum_{j=0}^{\alpha-1} \frac{(-1)^j}{\lambda + j} \left( \alpha - 1 \right) \frac{\varepsilon^2 \sigma_u^2}{\lambda \sigma_v^2} \frac{\varepsilon \sigma_u \sqrt{\pi}}{\sigma_v^2 \sqrt{\lambda + j}} \Phi \left( \frac{-\varepsilon \sigma_u}{\sigma_v^2 \sqrt{2(\lambda + j)}} \right) \]

Equations (3.8) and (3.10) are new formulae for probability density functions for the composed error \( \varepsilon \). Since \( \alpha \) need not be an integer, there will be no closed form for \( f(\varepsilon) \). It is important to remark that the closed-form expression for \( f(\varepsilon) \) only exists for a single-parameter distribution for the inefficiency term \( u \) such as the half normal, exponential and truncated normal. In other cases such as a two-parameter gamma or Weibull distribution numerical or simulation based techniques are usually used to approximate the density function \( f(\varepsilon) \).
For $\alpha = 1$, the density function of composed error $\varepsilon$, $f(\varepsilon)$, is given by:

$$f(\varepsilon) = \frac{1}{\lambda\sqrt{2\pi}\sigma_v} e^{-\frac{\varepsilon^2}{2\sigma_v^2}} \left[ 1 - e^{\frac{\varepsilon^2\sigma_u^2}{\sigma_v^2}} \frac{\varepsilon\sigma_u\sqrt{\pi}}{\sigma_v^2\sqrt{\lambda}} \Phi\left( -\frac{\varepsilon\sigma_u}{\sigma_v\sqrt{2\lambda}} \right) \right]$$

Substituting for $\lambda = 1 + \frac{\sigma_u^2}{2\sigma_v^2}$ and setting $\sigma_u = \sigma_u\sqrt{2}$, gives

$$f(\varepsilon) = \frac{\sigma_v}{(\sigma_v^2 + \sigma_u^2)^{\frac{1}{2}} 2\pi} e^{-\frac{\varepsilon^2}{2\sigma_v^2}} \left[ 1 - e^{\frac{\varepsilon\sigma_u\sqrt{2\pi}}{\sigma_v\sqrt{\sigma_v^2 + \sigma_u^2}}} \frac{\varepsilon\sigma_u^2}{\sigma_v^2(\sigma_v^2 + \sigma_u^2)} \Phi\left( -\frac{\varepsilon\sigma_u}{\sigma_v\sqrt{2\lambda}} \right) \right] \quad (3.11)$$

The above expression is the probability density function for the composed error $\varepsilon$ when the technical inefficiency term $u$ is assumed to have a Rayleigh distribution. Thus if $\alpha = 1$ and $\sigma_u = \sigma_u\sqrt{2}$, the Burr X distribution reduces to a Rayleigh distribution. Oliviero (2014) and Hajargasht (2014) independently introduced a stochastic frontier model with the Rayleigh distribution with some promising results compared with the frequently used exponential and half-normal models. The model introduced in this research may be called a stochastic frontier model with a generalized Rayleigh distribution.

### 3.6 Log Likelihood for the Normal-Burr Type X Stochastic Frontier Model

There are several methods for estimating the parameters of a stochastic frontier model. The most widely used method of statistical estimation is that of maximum likelihood estimation which has good optimality properties.

The estimation begins by denoting $\varepsilon_i = y_i - \beta x_i = v_i - u_i$ for $i = 1, \ldots, n$; and $\varepsilon = (\varepsilon_1, \ldots, \varepsilon_n)$. The likelihood function of the sample as discussed is the product of the density functions of the individual observations because of the independence assumption of the distributions treated. Thus the likelihood function is given by

$$L(sample) = \prod_{i=1}^{n} f(\varepsilon_i) \quad (3.12)$$

The conventional approach is to take log of the likelihood function to get the log-likelihood equation

$$logL(sample) = l(\beta, \sigma_v, \sigma_u, \alpha | \varepsilon_1, \ldots, \varepsilon_n) = \sum_{i=1}^{n} \log f(\varepsilon_i)$$

Using equation (3.9), the log of the likelihood function is given by
\[
\sum_{i=1}^{n} \log \left[ \frac{\Gamma(\lambda+1)\Gamma(\alpha)}{A^\Gamma(\lambda+\alpha)} \cdot e^{\frac{-e\sigma_u^2}{\lambda \sigma_v^2 \sqrt{2\lambda}}} \Phi \left( \frac{-e\sigma_u}{\sigma_v \sqrt{2\lambda}} \right) + \frac{(\alpha-1)}{\lambda + 1} \cdot e^{\frac{-e\sigma_u^2}{\lambda \sigma_v^2 \sqrt{2\lambda+1}}} \Phi \left( \frac{-e\sigma_u}{\sigma_v \sqrt{2\lambda+2}} \right) \right] + \frac{n}{2\sigma_v^2} \sum_{i=1}^{n} e_i
\]

Then maximize the log-likelihood function using first order conditions to obtain unbiased parameter estimates for the stochastic frontier model. However, for the model (equation 3.9) described above, there is no direct closed-form solution for maximum likelihood. That is the likelihood functions cannot be evaluated analytically. Here, in order to calculate the maximum likelihood estimate of the parameters \( \beta, \sigma_v, \sigma_u \) and \( \alpha \), optimizing values are found using direct numerical method. Other methods such as maximum simulated likelihood (MSL) and Bayesian methods can also be used to estimate the parameters. Aigner, Lovell, and Schmidt (1977) were the first to use log-likelihood function for stochastic frontier analytic framework. The Maximum Simulated Likelihood (MSL) method and maximum likelihood are same. The only difference is that simulated probabilities are used instead of the precise probabilities in MLS. Gourieroux and Monfort (1993), Lee (1995), and Hajivassiliou and Ruud (1994) have documented the properties of MSL. The MSL is usually implemented using the so-called Halton draws instead of uniform draws (see Greene, 2003).

3.7 Efficiency Estimation

The main purpose of stochastic frontier analysis is the estimation of technical efficiency. The conditional distribution of \( u \) given \( \varepsilon \) is usually exploited to get estimates of efficiency. This was first established by Jondrow et al., (1982) Either the mean or the mode of this conditional distribution can be used. Following Jondrow et al. (1982) the conditional mean function, \( E(u|\varepsilon) \) is obtained.

Let \( \hat{\beta} \) to be the MLE of \( \beta \), and \( \hat{e}_i = y_i - X_i \hat{\beta} \). Then the usual estimate of \( u_i \), suggested by Jondrow et al. (1982), is \( E(u|\varepsilon) \), evaluated at \( \varepsilon = \hat{e}_i \). The technical efficiency \( TE_i \) can also be estimated by \( \hat{TE}_i = \exp(-u_i) \). However, a preferred estimate is \( \hat{TE}_i = E(\exp(-u_i) | \varepsilon) \) or \( \exp(-E(u|\varepsilon)) \), evaluated at \( \varepsilon = \hat{e}_i \). See Battese and Coelli (1988), who also show how to define \( u_i \) and \( \hat{TE}_i \) in the case of panel data. To obtain \( E(u|\varepsilon) \) it is proper to begin with

\[
f(u|\varepsilon) = \frac{f(u,\varepsilon)}{f(\varepsilon)} \tag{3.14}
\]
Substituting the results from equations (6) and (10) and cancelling out like terms in the fraction, the following expression is obtained

\[
f(u|\varepsilon) = \frac{\frac{2u}{\sigma_u^2} e^{-\frac{u^2}{\sigma_u^2}} \left(1 - e^{-\frac{u^2}{\sigma_u^2}}\right)^{\alpha-1}}{\sum_{j=0}^{\alpha-1} \frac{(-1)^j}{\lambda + j} \binom{\alpha-1}{j} \left[1 - e^{-\frac{\varepsilon^2\sigma_u^2}{\sigma_v^2(\lambda+j)}} \frac{\varepsilon\sigma_u\sqrt{\pi}}{\sigma_v^2\sqrt{\lambda+j}} \Phi\left(\frac{-\varepsilon\sigma_u}{\sigma_v^2\sqrt{2(\lambda+j)}}\right)\right]}
\]

Noting that

\[
E(u|\varepsilon) = \int_0^\infty u f(u|\varepsilon) \, du
\]

Then,

\[
E(u|\varepsilon) = \frac{1}{K(\varepsilon)} \int_0^\infty \frac{2u^2}{\sigma_u^2} e^{-\frac{u^2}{\sigma_u^2}} \left(1 - e^{-\frac{u^2}{\sigma_u^2}}\right)^{\alpha-1} e^{-\frac{(2u\varepsilon+u^2)}{2\sigma_v^2}} \, du
\]

Where

\[
K(\varepsilon) = \sum_{j=0}^{\alpha-1} \frac{(-1)^j}{\lambda + j} \binom{\alpha-1}{j} \left[1 - e^{-\frac{\varepsilon^2\sigma_u^2}{\sigma_v^2(\lambda+j)}} \frac{\varepsilon\sigma_u\sqrt{\pi}}{\sigma_v^2\sqrt{\lambda+j}} \Phi\left(\frac{-\varepsilon\sigma_u}{\sigma_v^2\sqrt{2(\lambda+j)}}\right)\right]
\]

Setting \( x = \frac{u}{\sigma_u}, \lambda = 1 + \frac{\sigma_u^2}{2\sigma_v^2} \) and \( q = \frac{\varepsilon\sigma_u}{\sigma_v^2} \) as per earlier substitution, the resultant expression is:

\[
E(u|\varepsilon) = \frac{2\sigma_u}{K(\varepsilon)} \int_0^\infty x^2 e^{-\lambda x^2} (1 - e^{-x^2})^{\alpha-1} e^{-qx} \, dx
\]

Since

\[
(1 - e^{-x^2})^{\alpha-1} = \sum_{j=0}^{\alpha-1} (-1)^j \binom{\alpha-1}{j} e^{-jx^2}
\]

When the shape parameter \( \alpha \) is a natural number, the following is obtained:

\[
\int_0^\infty x^2 e^{-\lambda x^2} (1 - e^{-x^2})^{\alpha-1} e^{-qx} \, dx = \sum_{j=0}^{\alpha-1} (-1)^j \binom{\alpha-1}{j} \int_0^\infty x^2 e^{-x^2(\lambda+j)} e^{-qx} \, dx
\]
The integral \( \int_0^\infty x^2 e^{-x^2(\lambda+j)} e^{-qx} \, dx \) can then be evaluated as (see Gradshteyn and Ryzhik, 2007 pp. 365),

\[
\int_0^\infty x^2 e^{-x^2(\lambda+j)} e^{-qx} \, dx = -\frac{q}{4(\lambda+j)^2} + \frac{\sqrt{\pi}}{4(\lambda+j)^2} \left( \frac{q^2}{2} + \lambda + j \right) e^{\frac{q^2}{4(\lambda+j)}} \left( 1 - \text{erf} \left( \frac{q}{2\sqrt{(\lambda+j)}} \right) \right)
\]

\[
\int_0^\infty x^2 e^{-x^2(\lambda+j)} e^{-qx} \, dx = -\frac{q}{4(\lambda+j)^2} + \frac{\sqrt{\pi}}{4(\lambda+j)^2} \left( \frac{q^2}{2} + \lambda + j \right) e^{\frac{q^2}{4(\lambda+j)}} \left( 1 - \text{erf} \left( \frac{q}{2\sqrt{(\lambda+j)}} \right) \right) - 2\sqrt{(\lambda+j)q} + \frac{\sqrt{\pi}(2(\lambda+j) + q^2)e^{\frac{q^2}{4(\lambda+j)}} \left( 1 - \text{erf} \left( \frac{q}{2\sqrt{(\lambda+j)}} \right) \right)}{8(\lambda+j)^{5/2}}
\]

Since \( q = \frac{\varepsilon u}{\sigma_v} \) and \( 1 - \text{erf} \left( \frac{q}{2\sqrt{(\lambda+j)}} \right) = 2\Phi \left( \frac{-q}{2\sqrt{(\lambda+j)}} \right) \), then;

\[
E(u|\varepsilon) = \sigma_u \sum_{j=0}^{\alpha-1} \frac{(-1)^j}{2(\lambda+j)^{5/2}} \binom{\alpha-1}{j} \left[ \sqrt{\pi}(2(\lambda+j) + \frac{\varepsilon^2 u^2}{\sigma_v^2}) e^{\frac{\varepsilon^2 u^2}{4\sigma_v^2(\lambda+j)}} \Phi \left( \frac{-\varepsilon u}{\sigma_v \sqrt{2(\lambda+j)}} \right) - \sqrt{(\lambda+j) \frac{\varepsilon u}{\sigma_v^2}} \right]
\]

\[
E(u|\varepsilon) = \sigma_u \sum_{j=0}^{\alpha-1} \frac{(-1)^j}{2(\lambda+j)^{5/2}} \binom{\alpha-1}{j} \left[ \sqrt{\pi}(2(\lambda+j) + \frac{\varepsilon^2 u^2}{\sigma_v^2}) e^{\frac{\varepsilon^2 u^2}{4\sigma_v^2(\lambda+j)}} \Phi \left( \frac{-\varepsilon u}{\sigma_v \sqrt{2(\lambda+j)}} \right) - \sqrt{(\lambda+j) \frac{\varepsilon u}{\sigma_v^2}} \right]
\]

For a sub-model, that is for \( \alpha = 1 \) or using the first term, \( E(u|\varepsilon) \) can be simplified as

\[
E(u|\varepsilon) = \frac{\sigma_u}{2\lambda^{3/2}} \left[ \sqrt{\pi}(2\lambda + \frac{\varepsilon^2 u^2}{\sigma_v^2}) e^{\frac{\varepsilon^2 u^2}{4\sigma_v^2 \lambda}} \Phi \left( \frac{-\varepsilon u}{\sigma_v \sqrt{2\lambda}} \right) - \sqrt{\lambda^{3/2} \frac{\varepsilon u}{\sigma_v^2}} \right] \quad (3.15)
\]

The estimate \( E(u|\varepsilon) \) is the point estimate of \( u \) and approximating the technical inefficiency of production. Once the point estimates of \( u \) are obtained, the technical efficiency \( TE_i \) can be estimated as the exponential of conditional expectation of \( u_i \) given \( \varepsilon_i \) (i.e. \( \exp\{-E(u|\varepsilon)\} \)) as
suggested by Jondrow, Lovell, Materov, and Schmidt (1982), evaluated at the fitted values of \( \varepsilon_i \) and the estimated values of the parameters.

Battese and Coelli (1988) alternative estimator for the technical efficiency \( \text{TE}_i \) can be estimated by \( E\{\exp(-u_i) | \varepsilon \} \)

\[
E\{\exp(-u_i) | \varepsilon \} = \int_0^\infty \exp(-u) f(u | \varepsilon) \, du
\]

\[
E\{\exp(-u_i) | \varepsilon \} = \frac{1}{K(\varepsilon)} \int_0^\infty \frac{2u}{\sigma_u^2} e^{-u} e^{-\frac{u^2}{\sigma_u^2}} \left(1 - e^{-\frac{u^2}{\sigma_u^2}}\right) e^{-\frac{(2u \varepsilon + u^2)}{2\sigma_v^2}} \, du
\]

Setting \( x = \frac{u}{\sigma_u}, \lambda = 1 + \frac{\sigma_u^2}{2\sigma_v^2} \) and \( g = \sigma_u + \frac{\varepsilon \sigma_u}{\sigma_v}, \) gives:

\[
E\{\exp(-u_i) | \varepsilon \} = \frac{2}{K(\varepsilon)} \int_0^\infty \frac{u}{\sigma_u^2} e^{-u} e^{-\frac{u^2}{\sigma_u^2}} \left(1 - e^{-\frac{u^2}{\sigma_u^2}}\right) e^{-\frac{(2u \varepsilon + u^2)}{2\sigma_v^2}} \, du
\]

Thus

\[
E\{\exp(-u_i) | \varepsilon \} = \frac{2}{K(\varepsilon)} \int_0^\infty x e^{-\lambda x^2} (1 - e^{-x^2})^{\alpha-1} e^{-g x} \, dx
\]

From equation (3.7),

\[
E\{\exp(-u_i) | \varepsilon \} = \frac{2}{K(\varepsilon)} \sum_{j=0}^{\alpha-1} (-1)^j \binom{\alpha-1}{j} \left[1 - e^{g \sqrt{\lambda + j}} \frac{g \sqrt{\lambda + j}}{\sqrt{\lambda + j}} \Phi \left(\frac{-g}{\sqrt{2(\lambda + j)}}\right)\right]
\]

(3.16)

Thus it is possible to estimate \( E\{\exp(-u_i) | \varepsilon \} \) by substituting in the maximum likelihood estimation of \( \lambda \) and \( g \).

In the section below, the different simulation data is generated and modelled with different SFA models with various statistical distributions. The stochastic frontier models used in the section include the Normal–Half-Normal, Normal-Exponential, Normal-Burr x and the Normal-Rayleigh models. Also in the next section, the models are tested against one another in order to conclude on the competitiveness of the proposed SFA Burr x model.

3.8 Monte Carlo Simulation

In order to assess the performance of the proposed normal-Burr X stochastic frontier model, a series of Monte Carlo simulations was conducted for the different cross-sectional stochastic frontier models. The estimation of individual inefficiencies by Burr type x is compared with
Raleigh, exponential and half-normal models. The Monte Carlo simulations are based on 1000 replications using a standard simulation setting:

$$y_i = \beta_0 + \beta x_i + (v_i - u_i)$$

With the random noise \((v_i)\) generated from standard normal distribution with zero mean and standard deviation \(\sigma_v\) and technical inefficiency \((u_i)\) generated from half-normal with mean zero and standard deviation \(\sigma_u = \sqrt{0.4 - \sigma_v^2}\). The input \(x\) was drawn from a uniform distribution on the interval \((0, 1)\). Sample sizes are \(n = \{20, 50, 100, 250, 500\}\). These sample sizes were chosen in order to analyse the behaviour of the estimations in small samples as well as in medium-sized and large samples. The parameters \(\beta_0\) and \(\beta\) are set to 1. The generation of the output values \(y\) proceeds in the following steps:

First obtain the deterministic output

$$y_i = \beta_0 + \beta x_i$$

This gives the true production relation in the absence of both inefficiency and random noise.

Generate random inefficiency terms and random noise for each firm according to the distributional assumptions.

Add the half-normal inefficiency terms \(u\) and the random noise \(v\) to the true production

Subsequently, the various stochastic frontier models (Burr x, Raleigh, exponential and half-normal models) were fitted to the simulated data.

For each parameter, the standard deviation (SD) and the mean observed in the 1000 replications are calculated. To assess the performance of the efficiency estimation, the mean square error (MSE) is calculated as seen below:

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (\hat{TE}_i - TE_i)^2 \quad (3.17)$$

Where \(TE_i\) is the true technical efficiency for firm \(i\) and \(\hat{TE}_i\) is the estimated technical efficiency. The MSE shows the difference between true and estimated efficiency scores for the \(n\) firms. In addition, the Spearman rank correlations between estimated efficiencies of various models are calculated and analysed.
3.9 Simulation Data, Results and Analyses
In this section, the simulation results are presented. First, the estimated mean values of sigma v and sigma u for various models are summarised in Appendix 3A. The standard deviations and squared mean errors are used to assess the performance of different SFA models. The results are presented in Tables 3.1 to 3.3. The density curve of the estimated efficiency term, u, is illustrated figure 3.2 for Normal- Burr x and Normal-Rayleigh.

Table 3.1: Standard Deviation of $\sigma_u$ for various SFA Models

<table>
<thead>
<tr>
<th>n/scale</th>
<th>SD of $\sigma_u$ for Normal-Half Normal SFA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>20</td>
<td>0.41</td>
</tr>
<tr>
<td>50</td>
<td>0.36</td>
</tr>
<tr>
<td>100</td>
<td>0.3</td>
</tr>
<tr>
<td>250</td>
<td>0.25</td>
</tr>
<tr>
<td>500</td>
<td>0.22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n/scale</th>
<th>SD of $\sigma_u$ for Normal-Exponential SFA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>20</td>
<td>0.23</td>
</tr>
<tr>
<td>50</td>
<td>0.17</td>
</tr>
<tr>
<td>100</td>
<td>0.13</td>
</tr>
<tr>
<td>250</td>
<td>0.11</td>
</tr>
<tr>
<td>500</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n/scale</th>
<th>SD of $\sigma_u$ for Normal-Rayleigh SFA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>20</td>
<td>0.42</td>
</tr>
<tr>
<td>50</td>
<td>0.37</td>
</tr>
<tr>
<td>100</td>
<td>0.32</td>
</tr>
<tr>
<td>250</td>
<td>0.28</td>
</tr>
<tr>
<td>500</td>
<td>0.24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n/scale</th>
<th>SD of $\sigma_u$ for Normal-Burr x SFA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>20</td>
<td>0.21</td>
</tr>
<tr>
<td>50</td>
<td>0.28</td>
</tr>
<tr>
<td>100</td>
<td>0.37</td>
</tr>
<tr>
<td>250</td>
<td>0.29</td>
</tr>
<tr>
<td>500</td>
<td>0.31</td>
</tr>
</tbody>
</table>
Table 3.2: Standard Deviation of $\sigma_v$ for various SFA Models

<table>
<thead>
<tr>
<th>n/scale</th>
<th>SD of $v$ for Normal-Half Normal SFA</th>
<th>SD of $v$ for Normal-Exponential SFA</th>
<th>SD of $v$ for Normal-Rayleigh SFA</th>
<th>SD of $v$ for Normal-Burr x SFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.2 0.3 0.4 0.5 0.6</td>
<td>0.2 0.3 0.4 0.5 0.6</td>
<td>0.2 0.3 0.4 0.5 0.6</td>
<td>0.2 0.3 0.4 0.5 0.6</td>
</tr>
<tr>
<td>50</td>
<td>0.14 0.13 0.13 0.12 0.1</td>
<td>0.09 0.09 0.09 0.08 0.06</td>
<td>0.14 0.14 0.14 0.14 0.09</td>
<td>0.14 0.14 0.14 0.14 0.15</td>
</tr>
<tr>
<td>100</td>
<td>0.09 0.08 0.09 0.08 0.06</td>
<td>0.08 0.08 0.08 0.08 0.06</td>
<td>0.08 0.08 0.08 0.08 0.06</td>
<td>0.08 0.08 0.08 0.08 0.06</td>
</tr>
<tr>
<td>250</td>
<td>0.06 0.06 0.06 0.06 0.03</td>
<td>0.04 0.04 0.04 0.04 0.03</td>
<td>0.04 0.04 0.04 0.04 0.03</td>
<td>0.04 0.04 0.04 0.04 0.03</td>
</tr>
<tr>
<td>500</td>
<td>0.05 0.05 0.05 0.04 0.02</td>
<td>0.03 0.03 0.03 0.03 0.02</td>
<td>0.03 0.03 0.03 0.03 0.02</td>
<td>0.03 0.03 0.03 0.03 0.02</td>
</tr>
<tr>
<td>n/scale</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.17 0.17 0.16 0.16 0.15</td>
<td>0.09 0.09 0.09 0.08 0.09</td>
<td>0.14 0.14 0.14 0.14 0.09</td>
<td>0.14 0.14 0.14 0.14 0.15</td>
</tr>
<tr>
<td>50</td>
<td>0.09 0.09 0.09 0.08 0.09</td>
<td>0.09 0.09 0.09 0.08 0.09</td>
<td>0.09 0.09 0.09 0.09 0.09</td>
<td>0.09 0.09 0.09 0.09 0.09</td>
</tr>
<tr>
<td>100</td>
<td>0.06 0.06 0.06 0.06 0.06</td>
<td>0.06 0.06 0.06 0.06 0.06</td>
<td>0.06 0.06 0.06 0.06 0.06</td>
<td>0.06 0.06 0.06 0.06 0.06</td>
</tr>
<tr>
<td>250</td>
<td>0.04 0.04 0.04 0.04 0.03</td>
<td>0.04 0.04 0.04 0.04 0.03</td>
<td>0.04 0.04 0.04 0.04 0.03</td>
<td>0.04 0.04 0.04 0.04 0.03</td>
</tr>
<tr>
<td>500</td>
<td>0.03 0.03 0.03 0.03 0.02</td>
<td>0.03 0.03 0.03 0.03 0.02</td>
<td>0.03 0.03 0.03 0.03 0.02</td>
<td>0.03 0.03 0.03 0.03 0.02</td>
</tr>
<tr>
<td>n/scale</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.27 0.26 0.24 0.22 0.13</td>
<td>0.21 0.21 0.19 0.18 0.11</td>
<td>0.14 0.14 0.14 0.14 0.09</td>
<td>0.14 0.14 0.14 0.14 0.15</td>
</tr>
<tr>
<td>50</td>
<td>0.14 0.14 0.14 0.14 0.09</td>
<td>0.14 0.14 0.14 0.14 0.09</td>
<td>0.08 0.08 0.08 0.08 0.06</td>
<td>0.08 0.08 0.08 0.08 0.06</td>
</tr>
<tr>
<td>100</td>
<td>0.14 0.14 0.14 0.14 0.09</td>
<td>0.14 0.14 0.14 0.14 0.09</td>
<td>0.08 0.08 0.08 0.08 0.06</td>
<td>0.08 0.08 0.08 0.08 0.06</td>
</tr>
<tr>
<td>250</td>
<td>0.06 0.06 0.06 0.06 0.06</td>
<td>0.06 0.06 0.06 0.06 0.06</td>
<td>0.04 0.04 0.04 0.04 0.03</td>
<td>0.04 0.04 0.04 0.04 0.03</td>
</tr>
<tr>
<td>500</td>
<td>0.06 0.06 0.06 0.06 0.06</td>
<td>0.06 0.06 0.06 0.06 0.06</td>
<td>0.04 0.04 0.04 0.04 0.03</td>
<td>0.04 0.04 0.04 0.04 0.03</td>
</tr>
</tbody>
</table>
### Table 3.3: Mean Squared Error of Efficiency Estimates for various SFA Models

<table>
<thead>
<tr>
<th>n/scale</th>
<th>MSE of efficiency estimates of Normal-Half Normal SFA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.2 0.3 0.4 0.5 0.6</td>
</tr>
<tr>
<td>50</td>
<td>0.07 0.07 0.07 0.07 0.04</td>
</tr>
<tr>
<td>100</td>
<td>0.06 0.06 0.06 0.06 0.02</td>
</tr>
<tr>
<td>250</td>
<td>0.04 0.05 0.05 0.05 0.01</td>
</tr>
<tr>
<td>500</td>
<td>0.03 0.04 0.05 0.03 0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n/scale</th>
<th>MSE of efficiency estimates of Normal-Exponential SFA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.2 0.3 0.4 0.5 0.6</td>
</tr>
<tr>
<td>50</td>
<td>0.04 0.05 0.07 0.08 0.05</td>
</tr>
<tr>
<td>100</td>
<td>0.03 0.04 0.06 0.06 0.04</td>
</tr>
<tr>
<td>250</td>
<td>0.02 0.03 0.05 0.04 0.02</td>
</tr>
<tr>
<td>500</td>
<td>0.02 0.03 0.03 0.04 0.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n/scale</th>
<th>MSE of efficiency estimates of Normal-Rayleigh SFA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.2 0.3 0.4 0.5 0.6</td>
</tr>
<tr>
<td>50</td>
<td>0.12 0.10 0.10 0.09 0.05</td>
</tr>
<tr>
<td>100</td>
<td>0.11 0.10 0.10 0.08 0.04</td>
</tr>
<tr>
<td>250</td>
<td>0.09 0.09 0.09 0.07 0.03</td>
</tr>
<tr>
<td>500</td>
<td>0.07 0.07 0.07 0.06 0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n/scale</th>
<th>MSE of efficiency estimates of Normal-Burr SFA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.2 0.3 0.4 0.5 0.6</td>
</tr>
<tr>
<td>50</td>
<td>0.04 0.07 0.04 0.07 0.04</td>
</tr>
<tr>
<td>100</td>
<td>0.06 0.06 0.07 0.03 0.04</td>
</tr>
<tr>
<td>250</td>
<td>0.05 0.06 0.06 0.08 0.04</td>
</tr>
<tr>
<td>500</td>
<td>0.04 0.06 0.08 0.05 0.05</td>
</tr>
</tbody>
</table>

*scale=\sigma_u, \text{sigmav}=\sqrt{0.4-\sigma_u^2}*

Tables 3.1-3.3 are some of the outputs of the simulation exercise. In appendices 3A, 3B and 3C, the mean estimates of \( \sigma_u \), \( \text{sigma v} \), \( \text{BO} \) and \( B1 \) are presented. For \( \text{BO} \) and \( B1 \), it is observed that all the models approximate 1 which was fixed in the simulation process. The Rayleigh model has relatively higher estimates of these parameters while the Burr x model has relatively lower values close to that of Normal-Half Normal.
Using the tables above, the SD and MSE are analysed in order to arrive at the performance of the different SFA models. Since the inefficiency term was simulated using half-normal distribution, it is not surprising the normal-half normal SFA model has the minimum SD and MSE for all cases considered as shown in Tables 3.1 to 3.3. Therefore the estimates of the normal-half normal SFA model are considered benchmark estimates while the other three are the ones subjected to the test.

According to Table 3.3, it is obvious to see that the Rayleigh model’s performance is out of place when compared with the rest of the models. Both Burr X and Exponential models are quite competitive on the MSE test and have very low MSEs that nearly approximates that of the Normal-Half Normal model. This means they perform nearly the same in terms of accuracy of the efficiency estimation. In terms of increasing sample sizes, there is no clear trend and so it cannot be concluded that the models perform better or worse on MSE values when samples sizes decrease or increase. However, with the Rayleigh model, the MSEs of the efficiency estimates seems to improve with increasing sample size and may even get better as samples sizes exceed 500. It is important to note that Burr X SFA’s performance on the standard deviation criterion is generally not the best especially, for sigma u, the performance of Burr X on the standard deviation is probably the worst.

Tables 3.1 and 3.2 show the standard deviations of sigma v and sigma u. For the SDs of sigma v, the exponential, half-normal and Rayleigh models generally have lower values. That of Burr are generally relatively higher. Using Half-normal as a benchmark, it can be concluded that both exponential and Rayleigh seems to fit the simulated data better than the Burr model. In terms of the SDs of sigma u, the trend is quite different as it is rather Burr X and the Rayleigh models that fit the values of the Half-normal model better than that of the exponential model which are generally low.

However, for the means square error measure, the Burr X seems to perform better in both lower samples and larger samples. The Rayleigh, exponential and Burr x are compared in terms of their densities of the inefficiency term, u, as seen below:
Figure 3.2: Density Plot for Normal-Half Normal Efficiency Estimates (Median Efficiency of 0.9)

Figure 3.3: Density Plot for Normal-Burr X Efficiency Estimates (Median Efficiency of 0.87)

Figure 3.4: Density Plot For Normal-Rayleigh Efficiency Estimates (median efficiency of 0.87)
The Rayleigh seems to relatively overestimate the efficiency term more than that of the Burr X. In the plots above, there is evidence of skewness which is very important in the SFA efficiency technique.

Figure 3.5: Kernel Density Plot of the Efficiency Estimates for Normal- Half Normal and Normal - Burr SFA Model

\[ \text{Mean efficiency for Normal-Burr X =0.7809778, Normal-Half Normal =0.8733968, Normal-Rayleigh=0.9999885. True mean efficiency=0.8800} \]
Figure 3.7: Correlation between Normal-Rayleigh Residual and the True Residual (v-u)

Figure 3.8: Correlation between Normal- Burr X Residuals and the True Residual (v-u)

Figure 3.9: Correlation between Normal- Exponential Residuals and the True Residual (v-u)
Table 3.4 Spearman Rank Correlations between Estimated Efficiencies of Various Models ($\sigma_u=0.2$, $\sigma_v=0.6$, n=100)

<table>
<thead>
<tr>
<th></th>
<th>Half-Normal</th>
<th>Exponential</th>
<th>Rayleigh</th>
<th>Burr –type x</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half-Normal</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exponential</td>
<td>0.9992559</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rayleigh</td>
<td>1</td>
<td>0.9992559</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Burr –type x</td>
<td>0.9962196</td>
<td>0.9940594</td>
<td>0.9962196</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3.4 shows the Spearman rank correlations between estimated efficiencies of various models ($\sigma_u=0.2$, $\sigma_v=0.6$, n=100). It is obvious to see that the rank correlation for the efficiency measurements is really high in all the distribution types. It does suggest that applying different methods to the same data does not affect efficiency rankings. This observation is consistent with most of the literature aimed at comparing the different SFA distributions, the ranking of the firms rarely change and this study confirms it too.

In summary, the Burr SFA is a competitive candidate for measuring technical efficiency. The experiments conducted used cross-sectional data and there is a possibility the behaviour of the model in question may even perform better in panel models. This could be an area of further research.

3.10 Summary
The objective of the chapter was to derive an SFA model based on Burr X distribution and to test it against other existing SFA models with different distributions. First, the Maximum likelihood approach was used to determine the parameters of the new SFA-Burr X model. Simulation experiments were carried out to assess the performance of the proposed Burr x in terms of mean values, SDs and MSEs and compared with that for half-normal, exponential and Rayleigh. The exponential and half-normal distributions have a mode at zero, suggesting that a high percentage of the firms under study are perfectly efficient. The Burr x like truncated normal and gamma distribution capture wide range of shapes and also can have non-zero mode.
A comparison was done and a conclusion was arrived at regarding the competitiveness of the SFA–Burr X model. There are opportunities to use other ways of testing for the robustness of the Burr X SFA model. A neutral distribution like a Laplace could have been used to also assess the performance of the half-normal SFA model which was not possible in this study as the data generated was biased towards the latter model. Another testing methodology would be to test the different models against their distribution types in order to judge which model performs well in almost all the distribution types. Also, the performance of Burr X SFA could be enhanced in the panel form and therefore another study could explore the construction and testing of the panel forms of the Burr X SFA against existing panel models.

In the following chapter, there is a practical application of the SFA panel models in testing the efficiency of the electricity distribution sector of West Africa. It would have been apt to try the newly constructed Burr X model in the applications to West Africa EDCs but unfortunately its panel counterpart has as yet to be developed.
Chapter 4

Stochastic Cost Frontier Analysis: Efficiency of West African Electricity Distribution Companies

4.1 Introduction

Power sector reforms in Africa have been on-going for the last two decades, although at various levels of implementation across the continent. Undeniably, challenges facing the African power sector and other sectors vary across the continent but with significant differences between sub-Saharan Africa and North Africa primarily due to disproportions in the levels of power sector development. The various sub-sectors of the electricity industry have evolved through the many reforms that have been deployed in the past. In spite of these reforms, the power sector of Sub-Saharan Africa is saddled with inadequate and unreliable power supply, frequent power outages and high technical and commercial losses. On the contrary, according to AfDB (2013) electricity prices in Africa are relatively high with an average of 0.17 USD/KWh compared to the East Asian and South Asian regions with an average of 0.07 USD/KWh and 0.04 USD/KWh respectively. The above presupposes that consumers are made to procure poor services at relatively higher prices while suppliers in the continue to post high technical and commercial losses midst of limited electricity supply.

Given the above and other issues discussed in detail in chapter two, it was therefore not out of place to see the involvement of the West African regional community in attempting to address this regional problem. Other multilateral funding agencies and donor agencies equally have been involved in assisting some West African countries to come out of this predicament. The Economic Community of West African States (ECOWAS) in addressing the energy issues of the Region established two regulatory institutions namely the West African Power Pool (WAPP) and ECOWAS Region Regulatory Authority (ERERA) in 2006 and 2008 respectively by the decision of heads of state and governments (ECOWAS, 2008) in order to address energy security issues. These institutions have been charged to establish a regulated regional market as well as increasing inter-country connections and power generation.

Regional markets require regulation and there are various types of this task depending on the objective intended to achieve. Nonetheless, agreeing with Farsi and Filippini (2008) and Jamasb and Pollitt (2001), benchmarking in incentive regulation is becoming increasingly accepted as a core component of all regulation types (rate of return or price cap) and it is
important in price setting or price control. In particular, efficiency targets are set for utility companies with the objective that their operations would be improved upon to reduce inefficiencies and make electricity more affordable. The motive is that they will perform to achieve such targets to justify price increases during the tariff review period. It incorporates the reward and punish scheme that encourages efficient operations in utilities.

Relative efficiency measurement is a principal component of most price control models in the electricity market and adequately measuring it provides accuracy in setting targets to regulate prices for the purposes of preventing utility companies from passing on unjustified cost to consumers. It follows therefore that in order to have an effective regulatory regime nationally or regionally, it is prudent for regulators to have an initial efficiency measuring exercise conducted on the existing utility companies in new markets with the motive that a benchmark of performance can be established.

In the same vein and considering the establishment of a regional market in West Africa, where most EDCs are perceived inefficient, conducting an empirical study with a technique that holistically measures efficiency would be apt for two reasons. First, it provides an opportunity to estimate the baseline relative efficiencies of the participating EDCs. Secondly, it could confirm or otherwise the many narratives including that of Eberhard and Shkaratan (2012) and Kumi (2017)) that regard most EDCs in West Africa as inefficient. The level of (in)efficiency of EDCs in the region is normally “estimated” using uni-directional indicators involving simple ratios such as labour productivity, customer density, output per staff, technical and non-technical losses, commercial losses and others. These indicators though relevant, do not measure the totality of technical efficiency, allocative efficiency or the combination of both referred to as economic efficiency. Therefore, the voluminous literature reviewed in chapter two offers an array of techniques that could be used to measure relative efficiency in a much holistic way.

The main aim of this work therefore is to model the relative efficiencies of the EDCs of West Africa using an approach that captures both technical and allocative efficiency. The stochastic frontier approach is largely used as one of the techniques for analysing efficiency is employed. In this work, the stochastic cost frontier model is applied to estimate the level of inefficiency or otherwise in a sample of 14 West African EDCs and 1 East African EDC (Comparator firm).
By this technique, a stochastic cost frontier is randomly constructed for each firm with which their observed costs can be compared.

The results of this research could be very important to the regional regulator (ERERA) as well as regulators of the individual host countries of the EDCs included in this research. Specifically, the estimated frontier cost model could be used to regulate prices for distribution networks that would access the Grid of the Power Pool. Jamasb and Pollitt (2001) indicate that the endogenous measurement of efficiency is much appreciated in markets that are very young and there is need to set up initial performance benchmarks. This suggestion could take a central-stage given that the regionalisation of the West African Electricity Market is young and thus requires an initial efficiency estimates.

The chapter is organised as follows: an overview of the stochastic cost frontier model is given followed by its econometric estimations and analyses of the various panel models. It is followed with an estimation and analysis of relative efficiency scores and subsequently concluding and offering some policy recommendations. An explanation or exposition to the stochastic cost frontier model and other sub-models is made available in the next section.

4.2. Efficiency Measurement Using the Stochastic Cost Frontier Model
A convincing and appropriate approach will be to briefly clarify the concept of efficiency and how the stochastic cost frontier could be used to measure it among other approaches already discussed in detail in chapter two. First, in the figure below, a distinction is made between the types of efficiency in a production function and how they are theoretically measured. Farrell (1957) clarifies the differences between allocative and technical efficiency (AE and TE).

Figure 4.1: Technical and Allocative Efficiency

![Source: Daude and Pascal (2016)]
With SS’ as an isoquant line, any firm (Q) that produces using a combination of x1 x2 to produce y and found on the isoquant is technically efficient. Firms (P) that lie above the isoquant are technically inefficient because they use more input than required. With an iso-cost or budget line (AA’), firm Q’ is allocatively efficient since its inputs prices and quantities touch the cost line. A combination of technical efficiency and allocative efficiency estimated in figure 4.1 gives the level of Economic Efficiency (EE).

In order to estimate these efficiencies various techniques have been developed all geared towards the construction of an optimum or appropriate frontier where both parametric and non-parametric options have been explored.

One of such parametric approaches is the stochastic frontier model originally developed by Aigner, Lovell and Schmidt (1977) is famous for estimating efficiency of production units through either maximisation of output, revenue, profit or the minimisation of cost. Depending on the objective of the model and the choice of a particular consumer behaviour many types of models can be estimated. There are also other extensions that are extensively reviewed in chapter two. The stochastic cost frontier was however excluded in the review in order to be elucidated and applied in this chapter.

Therefore, this chapter focuses on the stochastic cost frontier methodology which assumes a cost minimisation behaviour to produce a particular output level, given input prices and the prevailing production or transformation technology. Due to the variation in managerial, supervisory capacities of managements of firms, it is implausible that all firms may operate on the optimum frontier. Not operating on the frontier may infer that there exists technical and allocative inefficiency in the operations of the firm in question.

In this investigation, a stochastic frontier cost function using panel data is considered. It commences by using the basic SFA panel cost function which is illustrated below as:

\[ C_{it} = X\beta_{it} + U_i + V_{it} \]  (4.1)

\[ U \geq 0, i = 1,2,3, ..., N \text{ and } t = 1,2,3, ..., T \]

In this specification the error term is composed of two parts: the first, \( u_i \); is a one-sided non-negative disturbance reflecting the effect of costs; the second, \( v_{it} \), is a two-sided disturbance
capturing the effect of noise. The statistical noise is assumed to follow a normal distribution, and the inefficiency term $u_i$, is generally assumed to follow a half-normal, truncated, exponential, Rayleigh or gamma distributions.

According to Pitt and Lee (1981) panel data is preferred in efficiency analysis for at least four reasons. First, it is possible to observe structural changes in a firms production function over time. Panel data approaches offer the opportunity to estimate the efficiency of individual firms from a single cross-section. A third reason is that the use of pooled data permits the comparison of pooled approach to the traditional analysis of covariance approach. Fourth, it permits us to investigate whether the inefficiency of firms is time variant or time invariant, and if it is time variant, whether or not it varies randomly or not. Therefore, panel data models provide information about the behaviour of firms over time which cannot be revealed from cross-sectional data.

The above features of panel models have consequently caused the stochastic frontier model to evolve from one form to another in order to offer more opportunities to analyse efficiency. The stochastic panel model with time-invariant inefficiency can be estimated under either the fixed effects’ or random effects’ framework as suggested by Greene (2005). These form avenues to explore heterogeneity within and between firms or units. The type of panel model to select depends on the level of relationship that is assumed between the inefficiency and the covariates of the model. Under the fixed effects framework correlation is allowed between $X_{it}$ and $u_i$ whereas under the random effects framework, no correlation is present between $X_{it}$ and $u_i$. The idea of the standard fixed and random effect models as applied in SFA is to produce a simple transformation and interpret the transformed individual effects as time-invariant inefficiency as opposed to pure firm heterogeneity. As such with the SFA panel models, it is possible to separate inefficiency from individual heterogeneity as opposed to the standard panel models that account for effects.

Many other models that separate firm heterogeneity from inefficiency have been developed in the stochastic frontier approach to allow both effects to be identified and estimated with various types of assumptions for the type and interactions of heterogeneity. Some of these models will be subsequently explained in detail to enhance the methods chosen in this investigation.
A starting point with SFA panel will thus be the time-invariant model using a Cost frontier - Cobb-Douglas function specified as follows:

\[ C_{it} = \beta_0 + X_{it} \beta_i + V_{it} + U_i \tag{4.2} \]

\[ \text{Where } \beta_0 - U_i \equiv \alpha_i \]

\( \alpha_i \) and \( X_{it} \) by the way they behave and as to whether they are correlated or not defines whether it is a standard fixed effects’ or random effects’ model.

The notable drawback of the standard fixed effects’ and random effect’ models has been reemphasised in Greene (2005) motivates further extension of these panel models. Illustrated in two folds, the first is the inability to distinguish individual heterogeneity from inefficiency making all time invariant heterogeneity to be confused with inefficiency and the second, the implausibility of the level of inefficiency of a firm to stay constant as \( T \) becomes large.

The model is thus further modified as seen below to include a time-variant efficiency term.

\[ C_{it} = \beta_0 + X_{it} \beta_i + U_{it} + V_{it} \tag{4.3} \]

Compared to standard panel models and the time invariant model discussed in (4.2), there is a modification of the inefficiency term \( (U_i) \) to accommodate changes overtime and hence the term \( U_{it} \) in equation (4.3). If one treats \( \alpha_i \), \( i = 1, \ldots, N \), as a random variable that is correlated with \( X_{it} \) but does not capture inefficiency, then the above model becomes what has been termed the ‘true fixed effects’ panel stochastic frontier model (Greene 2005). Unlike the initially developed frontier fixed effect model by Schmidt and Sickles (1984), Green shows that the true fixed effects model captures unobserved heterogeneity as the fixed effects. A model is considered as the ‘true random effects’ stochastic frontier model when \( \alpha_i \) is treated as uncorrelated with \( X_{it} \) in addition to an introduced random constant assumed to be normally distributed and reconstitutes the constant term to be symmetrical with a finite variance.

In this chapter, the techniques employed include the time invariant Pitt and Lee (1981) model which is a random effects model with a time invariant inefficiency term \( (U_i) \) and the Pooled SFA model which considers an inefficient term that is time varying. The True Random Effects’ Model (TREM) and True Fixed Effects’ Model (TFEM) are also used as proposed in Greene (2004). These two models allows for a separate stochastic term that encapsulates the time-invariant unobserved heterogeneity. The main difference as stated earlier is that the TFEM
permits correlation with the regressors while in the TREM, $U_{it}$ is independent of $X_{it}$. As discussed earlier in chapters 2 and 3, the stochastic frontier model can assume different distributions. Thus the above models are estimated using various distribution assumptions of half-normal, truncated-normal and exponential distributions.

Regardless of the distribution chosen, for efficiency measurement and scores analyses, the composed error term needs to be decomposed and the efficiency score computed. Jondrow et al. (1982) showed that for the half-normal case, the expected value of $u_i$ conditional on the composed error term, $e_i$ is computed as:

$$E[u_i|e_i] = \frac{\sigma \lambda}{1 + \lambda^2} \left[ \phi \left( \frac{e_i \lambda}{\sigma} \right) - \frac{e_i \lambda}{\sigma} \right]$$

(4.4)

With $\phi(.)$ being the density of the standard normal distribution, $\Phi(.)$ the cumulative density function, $\lambda = \sigma_u / \sigma_v$, $e_i = y_i - \beta x_i = v_i - u_i$ and $\sigma = (\sigma_u^2 + \sigma_v^2)^{1/2}$

The technical efficiency estimates for each unit was computable once Jondrow et al. (1982) obtained the conditional estimates of $u_i$ found below as

$$TE_i = 1 - E[u_i|e_i]$$

(4.5)

Thus, in a stochastic cost frontier setting, efficiency is measured as the ratio of actual costs to the least-cost of production and can simply be shown as:

$$EFF = \frac{E(C|u_iX_i)}{E(C|u_i0X_i)}$$

(4.6)

Cost efficiency (EFF) predictions are therefore computed using the following expression:

$$EFF = \frac{E(X\beta_{it} + u_i)}{E(X\beta_{it})} \geq 1$$

(4.7)

There are other definitions suggested by other authors including Battese and Coelli (1988) Hjalmarsson, Kumbhakar and Heshmati (1996) and Bera and Sharma (1999) concerning point estimations of technical efficiency. However, the point estimator of Jondrow et al. (1982) also referred to as “JMLS point estimator”, is much popular and used in many SFA packages as a default estimator of efficiency.

In this section, the foundations of the Stochastic Cost Frontier Approach and its related models have been explained. This was a very important step towards achieving the objective of measuring the efficiency levels of the EDCs in West Africa which is the focus of the next section. The next section therefore presents the methodology and data used in estimating the cost efficiencies of the West African electricity distributions sector.
4.3. Methodology and Data
This section gives details of the methods and data used in the research. It begins with the specification of the stochastic cost frontier function for the electricity distribution. It shows the constituents of a representative cost function for the production units (EDCs) as well as factors that determine total cost in an electricity distribution system. It is followed by a description of the data as well as the data collection process.

In the efficiency estimation process, the cost frontier is applied to different panel models as well as different statistical distribution types. The Pooled, Pitt and Lee, TFEM and TREM are therefore assumed under different distribution types including Normal-Half Normal, Normal –Truncated and Normal –Exponential. The sub-models that are robust with significant variables are selected for further analyses and inference while models that do not fit the data are eliminated. Subsequently, empirical analysis is carried out and the cost efficiencies analysed. The Limited Dependent Variable Programme (LimDep) is the package used for the estimation of the above models. An understanding of the service provision as well as the cost variables of electricity distribution aids in the specifying a good model as well as making the making meaningful interpretations or inferences from the stochastic cost frontier model employed. The next section therefore explains the model specifications or the cost function.

4.3.1 Specifications of the Frontier Cost Functions for Electricity Distribution Utilities
The specification of the cost frontier model accounts for both endogenous and exogenous factors and can be seen below as:

$$TC = f(Y, P_l, P_c, CD, LF)$$

Where TC is total cost of electricity distribution and Y is the output represented by the total number of GWh delivered to consumers, while PC and PL represent the prices of capital and labour, respectively. CD is incorporated to introduce some observable heterogeneity and it is the customer density which is computed as the ratio of the number of customers to the length of the distribution lines measured in kilometres. LF is the load factor, which captures intensity of capacity utilisation of the electricity distribution system. These linkages have cost implications and therefore the LF is a very important variable in frontier analysis of electricity distribution companies and it is a derived variable from the peak demand of the system and the output delivered in a certain period (a year in this case). The variables CD and LF are therefore introduced in the model as output characteristics which create fair grounds for
comparison of firms. This is because most of the EDCs are normally limited by choice in determining which jurisdiction to operate as well as the initial consumer profiles which could significantly vary among the firms. For example, some EDCs have naturally low customer densities while other EDCs may have naturally high customer densities in some areas.

The variables or drivers of the total cost of electricity distribution were established through an understanding of the daily operations of electricity distribution companies. Building and maintaining the system of service lines, mains and transformers, metering or billing and collection of revenue form the core activities of electricity distribution companies. However, the costs associated with these activities can vary depending on total number of customers served, the concentration of consumers in the service area, the size of the distribution area, the total power sold, the length of distribution line, the security of supply and maximum demand. Other factors that could enhance the treatment of heterogeneity include, variables that can control for differences in quality of output, vegetation types, wind speed and size of area of operations but unfortunately due to the paucity of data, the specifications in this study could not include them. For example the quality related variables including hours of power cuts, frequency of low voltage, hours of low voltage, customer complaints etc. are very important in levelling the floor for companies that incur additional cost in achieving high quality standards of service. Unfortunately, the data on EDCs in West Africa for such controlling variables were mostly unobtainable. Even if they were available, they did not seem reliable enough and could have rather caused more modelling challenges. The lack of such variables are obvious limitations of this study and the cost function could have been enhanced were they made available to be included in the model specification.

The specification in a Cobb-Douglass functional form is simplified with the primary inputs of labour and capital. Equation (4.9) represents the cross-sectional2 version while the other models are the various panel extensions.

\[
\ln \frac{TC}{P_c} = \alpha_0 + \alpha_y \ln Y + \alpha_{P_1} \ln \frac{P_1}{P_c} + \alpha_{c_d} \ln CD + \alpha_{i_f} \ln LF + U_i + V_i
\]

\[
\ln \frac{TC}{P_c} = \alpha_0 + \alpha_y \ln Y + \alpha_{P_1} \ln \frac{P_1}{P_c} + \alpha_{c_d} \ln CD + \alpha_{i_f} \ln LF + U_i + V_i \tag{4.9}
\]

\footnote{This is discussed to offer a logical extension of the SFA model as it graduates from the cross sectional, Aigner et al. (1977) model.}
Equation (4.10) specifies the Pitt & Lee model which argued as the basic or first extension of the stochastic frontier in a panel data and it is a random effects model with time invariant inefficiency term.

Let \( \ln \frac{TC}{P_c} = \ln TC \quad \text{and} \quad \ln \frac{Pl}{P_c} = \ln Pl \)

\[
\ln TC_{it} = \alpha_0 + \alpha_y \ln Y_{it} + \alpha_{Pl} \ln Pl_{it} + \alpha_{Cd} \ln CD_{it} + \alpha_{LF} \ln LF_{it} + V_{it} + U_i \quad (4.10)
\]

\( U_i \) is time-invariant

The pooled model is specified in (4.11) and it differs from the Pitt and Lee only by a time invariant inefficiency term.

\[
\ln TC_{it} = \alpha_0 + \alpha_y \ln Y_{it} + \alpha_{Pl} \ln Pl_{it} + \alpha_{Cd} \ln CD_{it} + \alpha_{LF} \ln LF_{it} + V_{it} + U_{it} \quad (4.11)
\]

Below is the specification of the true fixed effects model:

\[
\ln TC_{it} = \alpha_{0i} + \alpha_y \ln Y_{it} + \alpha_{Pl} \ln Pl_{it} + \alpha_{Cd} \ln CD_{it} + \alpha_{LF} \ln LF_{it} + V_{it} + U_{it} \quad (4.12)
\]

\( \alpha_{0i} \) = time fixed constant and captures unobserved time invariant heterogeneity

\( U_{it} \) is time-varying, correlation between the regressors and the inefficiency term is allowed

The true random effects model is also specified below in (4.13)

\[
\ln TC_{it} = (\alpha_{0i} + w_i) + \alpha_y \ln Y_{it} + \alpha_{Pl} \ln Pl_{it} + \alpha_{Cd} \ln CD_{it} + \alpha_{LF} \ln LF_{it} + V_{it} + U_{it} \quad (4.13)
\]

\( (\alpha_{0i} + w_i) \) is a random constant with \( w_i \) distributed with mean 0 and finite variance. Here correlation between the regressors and the inefficiency term is disallowed.

A log-log functional form is employed and input prices further normalised by dividing them by the price of capital \((P_c)\). Filippini, Hrovatin and Zoric (2004) argue that such modifications impose a theoretical restriction that the cost function is linearly homogeneous in input prices.

The idea is adopted in this investigation forming the basis for the adjustment made to the input prices in equation (4.9).

### 4.3.2. Data and Data Collection Method

This research is based on an unbalanced-panel data set for 14 West African electricity distribution companies. The time frame of the data spanned from 2007 to 2016. Data was obtained using utilities’ annual reports collected from firms upon request as well as published reports on their web-sites. The annual reports included financial statements and technical
reports from the EDCs and the regulators. Both published and unpublished data from the EDCs and regulatory agencies were collected, cleaned and used for enriching the data pool. By using other sources other than those provided by the EDCs, it was possible to detect the veracity of data being used. It was impossible to collect data for earlier periods from the Nigerian EDCs because their operations after the privatisation of the erstwhile NEPA (National Electric Power Authority) began in 2012. Electricity Distribution Companies in Ghana, La Cote D’Ivoire and Togo had annual reports from 2007 to 2014. An EDC from East Africa- Kenya Power was also included in the analysis to serve as a comparator to the West African EDCs.

Some of the main unidirectional measures of “efficiency” are presented in Table 4.1 using 2012 figures. Substantial differences are noted in average costs, labour productivity and capital productivity. On the other hand, differences regarding the load factor, which measures the utilisation of the electricity distribution system (production or transformation system) over time, are significantly diverse, ranging from around 29% to 72%. Descriptive statistics of the variables included in the model are presented in Table 4.2.

Following, Filippini, Hrovatin and Zoric (2004), total distribution cost computed as total expenditures, excluding cost of purchased power from generators. By doing so the analysis is not flawed with the influence of external factors not under the control of the EDC. For example, in most of the electricity markets analysed, the EDC has limited choice on what generator to purchase from as there are usually one main producer or very few producers in the market. That apart, proximity is put into perspective when deciding on its suppliers and thus may not be reasonable to investigate the level of efficiency in negotiation and cost management at that level. Nonetheless, it should be considered as a vital input in markets which are competitive enough to offer the EDC to choose within a pool of suppliers at any point in time. In the context considered, the EDC has very little influence on deciding the company to purchase power and therefore including costs to reflect power purchased could flaw the level-ground created in the model used.

Average annual wages are estimated as the total labour expenditures divided by the number of employees. Finally, in our models, the price of capital is calculated as the ratio of total capital stock and the GWh distributed (Capital/GWh). This approach is different from those adopted in many studies where added capital or residual capital is used to estimate the cost /price of capital. The justification comes from the belief that the quantity and quality of
distributed power depends on the entirety of the company’s capital including old and new
distribution capital. This idea is adopted and perceived to be a better determinant of the cost
of capital factor than the flow concept used in many studies.

All cost variables are converted to Purchasing Power Parity (PPP) using 2011 US dollars to
allow for comparison considering that the sample of EDCs are in different countries with
different currencies and price levels.

The field work presented many data-collecting challenges but three main ones stand out and
are listed below as:

- There was no uniformity in reporting (both financial and technical reports). It
  therefore became a difficult task to understand the elements of the reports to make
  meaning of the cost components.

- The EDCs, despite having a high level of public ownership, were reluctant in providing
  even financial reports that should have been a public document.

- Different accounting principles were applied in different countries and this proved a
  challenge since components of the reports had to be disaggregated and recomposed
  to offer the right cost information needed. An example comes from the different
  treatment of labour cost or staff cost as well as the different ways depreciation was
  treated in the various financial reports. Jamasb and Pollitt (2001) suggest that the
  different cost treatments in various jurisdictions could pose distortions in most
  intercountry efficiency analysis.

As a result of these problems, cost elements in financial statements had to be thoroughly
regrouped and estimated to achieve accurate measure of cost variables which though
meticulous could have been more efficient and avoidable. Particularly for Nigeria, the caveat
by the regulator (Nigeria Electricity Commission) instructing all EDCs to publish their financials
eventually sped up the data collection process. Having said that, data from most of the EDCs
in the other countries were made available or could be found on their websites.

In the next section, the empirical results are presented and analysed. The section reports on
the estimation results from which the drivers of the cost of electricity distribution are
explained. Also, the efficiency levels are presented and discussed in the context of the
performance of West African EDCs against Kenya Power (East Africa) and Nigerian EDCs against other West African EDCs.

Table 4.1: Efficiency Attributes of 15 EDCs used in this Study (2014 data)

<table>
<thead>
<tr>
<th>Utilities</th>
<th>Host Country</th>
<th>Output (GWh)</th>
<th>Capital Cost/Output (GWh/USD (PPP of 2011))</th>
<th>Labour Cost/Worker</th>
<th>Load Factors (%)</th>
<th>Customer Density (Cus/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHEDC</td>
<td>Nigeria</td>
<td>1799</td>
<td>222689.36</td>
<td>29998.78</td>
<td>27.38</td>
<td>27.67</td>
</tr>
<tr>
<td>YEDC</td>
<td>Nigeria</td>
<td>730</td>
<td>33240.43</td>
<td>23909.47</td>
<td>34.01</td>
<td>6.81</td>
</tr>
<tr>
<td>AEDC</td>
<td>Nigeria</td>
<td>3458</td>
<td>293613.74</td>
<td>36855.46</td>
<td>47.91</td>
<td>72.40</td>
</tr>
<tr>
<td>BEDC</td>
<td>Nigeria</td>
<td>2589</td>
<td>130652.90</td>
<td>37482.63</td>
<td>29.44</td>
<td>49.77</td>
</tr>
<tr>
<td>Eko EDC</td>
<td>Nigeria</td>
<td>3164</td>
<td>213399.15</td>
<td>44469.58</td>
<td>32.99</td>
<td>102.76</td>
</tr>
<tr>
<td>Enugu EDC</td>
<td>Nigeria</td>
<td>3740</td>
<td>121716.40</td>
<td>27744.96</td>
<td>41.73</td>
<td>56.94</td>
</tr>
<tr>
<td>IEDC</td>
<td>Nigeria</td>
<td>3740</td>
<td>344509.57</td>
<td>36290.99</td>
<td>38.29</td>
<td>48.92</td>
</tr>
<tr>
<td>IKEDC</td>
<td>Nigeria</td>
<td>5500</td>
<td>193180.50</td>
<td>36057.24</td>
<td>48.67</td>
<td>28.63</td>
</tr>
<tr>
<td>JEDC</td>
<td>Nigeria</td>
<td>1582</td>
<td>252481.34</td>
<td>24143.34</td>
<td>32.25</td>
<td>22.22</td>
</tr>
<tr>
<td>KEDC</td>
<td>Nigeria</td>
<td>2933</td>
<td>262128.25</td>
<td>29575.15</td>
<td>58.74</td>
<td>76.69</td>
</tr>
<tr>
<td>Kaduna EDC</td>
<td>Nigeria</td>
<td>1936</td>
<td>237586.33</td>
<td>28198.88</td>
<td>52.54</td>
<td>43.16</td>
</tr>
<tr>
<td>ECG</td>
<td>Ghana</td>
<td>8370</td>
<td>881668.27</td>
<td>41940.90</td>
<td>64.98</td>
<td>34.56</td>
</tr>
<tr>
<td>CIE</td>
<td>La Cote D'Ivoire</td>
<td>7319</td>
<td>29810.58</td>
<td>34806.61</td>
<td>72.00</td>
<td>29.12</td>
</tr>
<tr>
<td>CEET</td>
<td>Togo</td>
<td>784</td>
<td>250995.10</td>
<td>36620.69</td>
<td>65.00</td>
<td>37.70</td>
</tr>
<tr>
<td>KPEDC</td>
<td>Kenya</td>
<td>8087</td>
<td>497115.24</td>
<td>22309.03</td>
<td>62.89</td>
<td>48.73</td>
</tr>
</tbody>
</table>

In Table 4.1, the attributes of the EDCs used in the study are presented. There is evidence of heterogeneity as some are relatively small, medium or large. It will be imperative to include controlling factors in order to level the grounds before any assessment is carried out. Table 4.1 makes a more vivid case as the mean, minimum and maximum of the variables are made available. Especially, with customer density, load factors and output, the EDCs can be said to be very different. YEDC which operates in the upper most north of Nigeria is particularly low
in customer density of about 7 customers per km network distance unlike Eko EDC which is in the southern part of Nigeria (in the capital Lagos) and operates in a more dense area.

4.4 Empirical Results and Analysis
In this section, the results of the estimation of the stochastic cost frontier model is discussed and the preferred model chosen for further analysis. The relative cost efficiencies are reported and discussed with the results presented in terms of efficiency scores of the Nigerian EDCs, other West African EDCs (EDCs from Ghana, Togo and La Cote D’Ivoire) and East African EDC (KPEDC).

4.4.1 Stochastic Cost Frontier Estimation Results
Before proceeding to present and discuss the estimation results, it is prudent to show the descriptive statistics of the variables used in the mode. Table 4.2 therefore indicates the logged variables that were used to model efficiencies of the firms under review.

<table>
<thead>
<tr>
<th>Variable (ln)</th>
<th>Description</th>
<th>Standard Deviation</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC/PC</td>
<td>Total Cost/Capital Price (PPP$)</td>
<td>0.6920</td>
<td>4.8450</td>
<td>3.0853</td>
<td>6.4583</td>
</tr>
<tr>
<td>Y</td>
<td>Distributed Electricity(GWh)</td>
<td>0.7982</td>
<td>7.9930</td>
<td>6.0753</td>
<td>9.0870</td>
</tr>
<tr>
<td>PL/PC</td>
<td>Labour Price/Capital Price(PPP$)</td>
<td>0.4661</td>
<td>4.6127</td>
<td>3.0777</td>
<td>5.6445</td>
</tr>
<tr>
<td>LF</td>
<td>Load factor</td>
<td>0.3346</td>
<td>3.8696</td>
<td>3.2222</td>
<td>4.2777</td>
</tr>
<tr>
<td>CD</td>
<td>Customer density</td>
<td>1.0505</td>
<td>3.3780</td>
<td>0.2999</td>
<td>4.6968</td>
</tr>
</tbody>
</table>

\[
\ln \frac{TC}{PC} = \ln TC \quad \text{and} \quad \ln \frac{PL}{PC} = \ln PL
\]

In the above table, it can be seen that the variables employed show some level of diversity. The customer density (CD) variable shows significant diversity with a mean of 3.3780, a maximum 4.6968 and a minimum as low as 0.2999. The suspicion of heterogeneity in between the firms for which the variable was included is becoming stronger and confirmed by a high standard deviation.
### Table 4.3: SFA Cost Models

<table>
<thead>
<tr>
<th>Independent Variables (ln)</th>
<th>Dependent Variable (lnTC)</th>
<th>Coefficients of Normal -Half Normal SFA Panel Models</th>
<th>Pooled Model</th>
<th>Pitt &amp; Lee Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td></td>
<td></td>
<td>0.67212</td>
<td>-3.73207**</td>
</tr>
<tr>
<td>Y</td>
<td></td>
<td></td>
<td>0.34302***</td>
<td>0.36084</td>
</tr>
<tr>
<td>PL</td>
<td></td>
<td></td>
<td>0.50578***</td>
<td>0.51326***</td>
</tr>
<tr>
<td>LF</td>
<td></td>
<td></td>
<td>-0.40447**</td>
<td>0.72599</td>
</tr>
<tr>
<td>CD</td>
<td></td>
<td></td>
<td>-0.02061</td>
<td>-0.09722</td>
</tr>
<tr>
<td>Lambda</td>
<td></td>
<td></td>
<td>3.03739***</td>
<td>2.75095</td>
</tr>
<tr>
<td>sigma</td>
<td></td>
<td></td>
<td>0.96158***</td>
<td>1.12986</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent Variables (ln)</th>
<th>Dependent Variable (lnTC)</th>
<th>Coefficients of SFA Normal-Exponential Panel Models</th>
<th>Pooled Model</th>
<th>P&amp;L Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td></td>
<td></td>
<td>1.19069</td>
<td>-3.16358**</td>
</tr>
<tr>
<td>Y</td>
<td></td>
<td></td>
<td>0.29917***</td>
<td>0.35938</td>
</tr>
<tr>
<td>PL</td>
<td></td>
<td></td>
<td>0.53605***</td>
<td>0.53090***</td>
</tr>
<tr>
<td>LF</td>
<td></td>
<td></td>
<td>-0.38129*</td>
<td>0.57666</td>
</tr>
<tr>
<td>CD</td>
<td></td>
<td></td>
<td>-0.05260*</td>
<td>-0.08235</td>
</tr>
<tr>
<td>Lambda</td>
<td></td>
<td></td>
<td>2.25446*</td>
<td>1.17994</td>
</tr>
<tr>
<td>Sigma</td>
<td></td>
<td></td>
<td>0.45526***</td>
<td>0.41981***</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent Variables (ln)</th>
<th>Dependent Variable (lnTC)</th>
<th>Coefficients of SFA Normal-Truncated Normal Panel Models</th>
<th>Pooled Model</th>
<th>P&amp;L Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td></td>
<td></td>
<td>0.55896</td>
<td>-5.52837</td>
</tr>
<tr>
<td>Y</td>
<td></td>
<td></td>
<td>0.34065***</td>
<td>0.56347*</td>
</tr>
<tr>
<td>PL</td>
<td></td>
<td></td>
<td>0.51095***</td>
<td>0.48323***</td>
</tr>
<tr>
<td>LF</td>
<td></td>
<td></td>
<td>-0.39004</td>
<td>0.75130</td>
</tr>
<tr>
<td>CD</td>
<td></td>
<td></td>
<td>-0.02240</td>
<td>-0.16951</td>
</tr>
<tr>
<td>Lambda</td>
<td></td>
<td></td>
<td>2.79863</td>
<td>1.80428</td>
</tr>
<tr>
<td>sigma</td>
<td></td>
<td></td>
<td>0.85208***</td>
<td>0.70905</td>
</tr>
</tbody>
</table>

Note: ***, ** and * denote 1%, 5% and 10% significant levels respectively.

Also, as discussed in Jondrow et.al. (1982), lambda for cost frontier, $\lambda=\frac{\sigma_u}{\sigma_v}$ and sigma for cost frontier, $\sigma=\sqrt{\sigma_v^2 + \sigma_u^2}$

The results of the estimation are set out in Table 4.3 above. The four stochastic cost frontier panel models discussed in the methodology were estimated using a half normal, exponential
and truncated normal distributions. Gamma was one of the chosen distribution but failed to yield meaningful results and as suggested earlier, stochastic frontier models based on gamma distribution are known to be problematic in its application in various data sets.

Also, out of the four panel models used, results produced by TFEM and TREM was inconsistent and not robust with insignificant Log likelihood ratios. Generally they overshot the efficiency levels in excess of 80% and sometimes 99% in the case of the TREM. That apart, the estimations of TFEM did not produce estimates that conform to the apriori signs (from theory and application) expected for most of the variables. Due to these shortcomings of the TFEM and TREM models, they have been eliminated and will not be included. The strict assumptions of these models may be violated as well as the panel problem of small size and could be a cause for the behaviour of the TFEM and TREM.

The Pitt and Lee model is essentially a random effects model constructed for the stochastic frontier technique with a time-invariant inefficiency term. Similar to a standard random effect, it is assumed that there is no correlation between the error term and the independent variables. The Pitt and Lee model produced consistent estimates but not robust enough compared to the pooled model.

The pooled model is a basic panel data model which does not make any assumptions of effects but constructed to accommodate the stochastic frontier technique. In terms of the estimation results, the pooled model fits the data better and shows more robust and significant results with relatively higher efficiency levels than that of the Pitt and Lee model. It appears that certain unobserved variables in the model possess some random effect which creates the high inefficiency estimates captured by the Pitt and Lee model.

In terms of the performance of the two chosen models on the assumed distribution types, the half-normal and the exponential seem to outperform the truncated-normal in terms of robustness and significant statistical estimates.

The sub-models (with the various assumed distributions) of the two preferred models (pooled and Pitt & Lee) generally produced estimates with their expected signs. However, not all of the sub-models yielded significant variables. The Normal-Half Normal Pooled model and the Normal–Exponential model were selected to be the most competitive sub models with the
former being more robust and a better fit. Using the log-likelihood ratio test, AIC (Akaike information criterion AIC) goodness of fit test and not ignoring discussion above, the Normal-Half Normal Pooled model exhibits a better fit and it is the preferred model for analysis. Appendices 4A1 and 4A2 show the regression and test outputs of the two models compared.

$$TC = 0.67212 + 0.34302Y + 0.50578P_l - 0.02061CD - 0.40447LF \quad (4.14)$$

Where

$$TC = \frac{T_C}{P_c} \quad \text{and} \quad P_l = \frac{P_l}{P_c}$$

Inference from the most preferred model in equation 4.10 can now be made to explain how the variables drive the cost of electricity distribution.

As evidenced in Filippini, Hrovatin and Zoric (2004) the positive coefficient of the labour and capital cost shares indicate that the cost function is monotonically increasing in input prices. The coefficient of output is also positive which suggest that total cost (not unit cost) increases with increasing output and this is expected regardless of the modification of the model in the linearization task as discussed earlier during the model specification. For the two factors controlling for heterogeneity (CD and LF), their negative coefficient suggest that as these variables increase, the total cost of electricity distribution decreases.

The model was estimated using logged dependent and independent variables and so the estimated coefficients can be interpreted as cost elasticities. Therefore, for the the pooled half-normal model, a 1% increase in output could increase total distribution costs by approximately 0.30% while a 1% increase in labour cost could drive a 0.51% increase in the total distribution cost. For the factors accounting for heterogeneity, a 1% increase customer density could reduce the total distribution cost by approximately 0.1%.while a 1% increase in the load factor could effect a 0.38% reduction in total distribution cost. The load factor has a

---

3 The null that OLS (u=0) as a preferred model is rejected given that the $\lambda < C$ (Kodde-Palm critical static). The pooled normal-half normal and the pooled normal-exponential models both were better models than the OLS alternatives.

4 Between the two models the pooled normal-half normal model had a lower AIC and hence could be suggested to fit the data better. It is therefore chosen as the preferred model from which further analysis can be executed.
relationship with the capacity of plants and the peak demand of a distribution system and for a capital intensive sector it is not unusual to see the high impact it has on the total cost of electricity distribution.

4.4.2 Cost Efficiency Estimates
In this section, the results of the relative cost efficiencies of the West African EDCs are analysed and discussed. The approach is to look at the individual performance of the EDCs, sub-group performance (Nigerian, Other EDCs and Kenya EDCs) as well as the global performance. Year on year trends are examined and discussed accordingly. Tables 4.4-4.7 and figures 4.2 -4.7 are presented to aid the analysis and discussions.

Table 4.4: Efficiency Estimates of the Stochastic Cost Frontier Panel Models

<table>
<thead>
<tr>
<th>Half Normal-Model</th>
<th>Mean Efficiency</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pooled Model</td>
<td>0.532983</td>
<td>0.208451</td>
<td>0.180192</td>
<td>0.874072</td>
</tr>
<tr>
<td>P&amp;L Model</td>
<td>0.503796</td>
<td>0.273277</td>
<td>0.170336</td>
<td>0.878942</td>
</tr>
<tr>
<td>Exponential-Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pooled Model</td>
<td>0.667324</td>
<td>0.162899</td>
<td>0.210497</td>
<td>0.864627</td>
</tr>
<tr>
<td>P&amp;L Model</td>
<td>0.418181</td>
<td>0.194281</td>
<td>0.153623</td>
<td>0.68549</td>
</tr>
<tr>
<td>Truncated-Normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pooled Model</td>
<td>0.506749</td>
<td>0.203718</td>
<td>0.197907</td>
<td>0.867606</td>
</tr>
<tr>
<td>P&amp;L Model</td>
<td>0.334982</td>
<td>0.239325</td>
<td>0.088716</td>
<td>0.782721</td>
</tr>
</tbody>
</table>

In Table 4.4, the means of the Pooled and Pitt & Lee models for the various statistical distribution assumptions are computed and presented as above. The efficiency estimates produced show significant variability with high standard deviation values. The pooled models generally show higher efficiency estimates than the Pitt & Lee models.

In Table 4.5, mean efficiency estimates for Nigerian EDCs, Other West African EDCs, East African EDC are shown across the various sub-models. Mean efficiency for Nigerian EDCs is the lowest when comparing all sub-models.
Table 4.5: Efficiency Scores for Different Segments of the Pool

<table>
<thead>
<tr>
<th></th>
<th>Normal-Half Normal</th>
<th>Normal -Exponential</th>
<th>Normal Truncated Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pooled</td>
<td>Pitt &amp; Lee</td>
<td>Pooled</td>
</tr>
<tr>
<td>Nigerian EDCs</td>
<td>49%</td>
<td>30%</td>
<td>62%</td>
</tr>
<tr>
<td>Other WA EDCs</td>
<td>63%</td>
<td>84%</td>
<td>75%</td>
</tr>
<tr>
<td>Kenya EDC. KPEDC</td>
<td>63%</td>
<td>81%</td>
<td>74%</td>
</tr>
<tr>
<td>Overall Mean Efficiency</td>
<td>53%</td>
<td>50%</td>
<td>67%</td>
</tr>
</tbody>
</table>

Figure 4.2: Mean Cost Efficiencies of EDCs
Figure 4.3: Cost Efficiency Scores for Nigerian EDCs

Figure 4.4: Annual Cost Efficiency of Benin Electricity Distribution Company (BEDC)

Figure 4.5: Annual Cost Efficiencies of Electricity Company of Ghana
The efficiency score estimates for three pooled SFA models are contained in Table 4.5. It shows a summary statistics of efficiency scores for the EDCs in our sample. The mean efficiency estimates for the EDCs for the Pooled and Pitt & Lee models are 53% and 50% respectively. The inefficiency or efficiency indicator (EFF) can be interpreted as the ratio of actual costs to the efficient level of costs and it is presented as in equations 4.6 and 4.7.

Estimates for the Nigerian EDCs recorded an average of 49% with BEDC measuring the highest at 78%. It is by far the most cost efficient EDC in West Africa and shows a consistent increase in cost efficiency. It is important to note that for BEDC to be the highest among its peers in West Africa requires further investigation. The results provide evidence that though Nigeria as a whole may be regarded as most inefficient in the public domain, not all of the EDCs can be labelled as such. Year on year efficiency scores for the individual firms can be seen in Appendix 4B.

For the other West African EDCs, ECG of Ghana recorded an average of 59% with a steady increase from 2010 to 2014 and a specular performance of 87% in 2014. There was a sharp decline from 2008 to 2010 and the reasons for such a performance could be explored. Both CIE and CEET of La Cote D’Ivoire and Togo respectively recorded an average of 70% and 62%. These companies performed relatively well but show a declining trend from 2010 onwards. The average efficiency estimates for more than half of the sampled companies had average efficiency levels of the less than 50% and this shows the extent of inefficiency in the electricity distribution sector of West Africa.

Also, it is noticed that at certain periods attributed to a particular EDC, performance was very low and out of place. It will therefore be prudent to investigate the characteristics of the periods or time in order to appreciate the outliers or any peculiarities at the time. It might well be that these companies operate in a region characterised by other constraints peculiar distribution entity which were not considered in the specifications of the model. The use of more heterogeneous control factors or variables was avoided because of the possibility of the presence of multi-collinearity. More so, due to paucity of reliable and relevant data, such variables were not readily available to impose additional firm specific characteristics. The same problem is encountered by Filippini, Hrovatin and Zoric (2004) in the Slovenian Electricity Distribution Sector. Growitsch, Jamasb and Wetzel (2010) proposed and applied
models with geographical and weather factors in estimating efficiencies of Norwegian
distribution utilities with some of the models affecting significantly firm performance.

Average cost efficiencies of the distribution companies are illustrated in figure 4.3 above. The
inclusion of Kenya Power (KPEDC) in the analyses allows a comparison of the West African
electricity distribution companies with an East African electricity distribution company.

**Figure 4.6: Efficiency Scores of Kenya Power**

The KPEDC records an average efficiency of 65% which is higher than the West African average
of 52%. KPEDC also performs better than the average of the EDCs in other West African
Countries even when the very inefficient Nigerian EDCs are excluded in the analyses.

It may be concluded from the mean cost efficiency estimates that within the time frame of
the analyses, the comparator from East Africa performs better that the West African countries
except to say that CIE from La Cote D’Ivoire is the only EDC in the group under review that
performed better than KPEDC (70% against 65%). However, it is important to note that
KPEDC’s performance in recent years has not been as good as its average and shows a decline
from 2013 (70%) to 2014 (63%) while some West African EDCs show improvements in those
years. ECG for instance increased its cost efficiency from 70% to 87% from 2013 to 2014 while
BEDC of Nigeria showed improvement from 67% to 77% in the same period. It is not
farfetched to conclude that KPEDC in the past has performed better than EDCs in the West
African Region but in recent years there seem to be a decline in its performance. This is
reflected in a year to year analysis within a recent time frame of 2012-2014 where KPEDC is
out performed by BEDC, ECG and CIE. The figure below is the average efficiency scores for the
various EDCs with the 2012-2014 period.
Figure 4.7: Average Cost Efficiencies for EDCs (2012-2014)

By the findings so far, it would thus be prudent for KPEDC to review what steps or strategies were executed or not executed in the last few years to account for such a decline in performance. On the other hand, it is equally important to understand the current strategies of the other three, particularly ECG and BEDC in order understand what caused the significant improvements in recent times.

Performance of EDCs in Nigeria after privatisation is another important analysis considered in this chapter. The results indicate that while some EDCs in Nigeria show an increase in cost efficiency from 2012 to 2016, most trend downwards which is normally not an expected outcome after the recent power sector reform in the country. Only three EDCs (PHEDC, BEDC and Enugu EDC) showed an increase in cost efficiency. These results though shocking may be explained by the high cost of uncompleted projects which could have affected the total cost but are not producing any outputs. A situation where an EDC has a substantial value of work in progress could significantly affect its capital productivity which could affect the cost efficiencies for that period under review. If that is the prevailing reason then judging EDCs in Nigeria a few years after privatisation may be unfair. However, they may be genuinely inefficient and such trends may well be representing the state of affairs. In that case the regulators may need to revise their monitoring strategy to incentivise innovation for the companies to offer quality and efficient services.

4.5 Summary
The deregulation of the West African electricity industry has changed the structure of the distribution sector. The establishment of WAPP and ERERA as institutions in the ECOWAS Commission was aimed at regulating the national and regional markets. In regulation or
specifically Benchmarking, the efficiency indicator is very important in initiating price or costing mechanisms. The electricity generating capacities of the countries under review are already inadequate and therefore the utility companies cannot afford to worsen the situation by running at very low efficiency levels. Inefficiencies of electricity utility companies have dire consequences on consumers and governments with regard to access, reliability and affordability of electric power. Regulating these companies may involve the use of incentive regulation and the benchmarking tools which give an indication of best practice in relation to the efficiency of an EDC’s technology and its cost of operation.

In this chapter, the stochastic cost frontier technique is applied to technologies in 14 Electricity Distribution Companies in West African Power Pool or ECOWAS region in order to estimate their cost efficiencies. Based on our findings, the presence of inefficiency at a mean level of 47% is confirmed. Comparing with East Africa, on the average even though EDC, CIE and BEDC seem to have outperformed KPEDC, the Kenyan EDC performed better than most of the other West African EDCs. It was poor in Nigeria as the cost efficiency levels showed a lower average of 49% with a declining trend in 8 out of 11 companies. To experience this immediately after privatisation could be further explored as it is widely accepted notion that privatisation enhances efficiency. It is worthy to note that among the many reasons could be the high cost of unyielding investments as well as the cost of restructuring after take-over. In some regards the cost efficiencies observed may well be due to pure inefficiency of management or some constraints not captured by the model.

The aim of this chapter was to determine the relative efficiencies of the EDCs in the ECOWAS region. The stochastic cost frontier model was applied using different statistical distributions to model different panel sub models. The pooled sub model was found to be the best-behaved with statistically significant coefficients and robust results. The West African EDCs recorded a mean efficiency of 53% showing a high inefficiency level of 47%. The narratives regarding the inefficient distribution sector have therefore been validated by the results of this chapter. It suggests that while few EDCs are improving on their efficiency levels, most are persistently inefficient and sometimes with a declining trend. This is worrisome and requires further investigation.

It is thus recommended that regulators, management of the EDCs investigate and if possible emulate and improve on the strategies adopted by ECG, CIE and BEDC. National and Regional
Regulators could rely on these estimations to regulate prices using price controls that incentivises efficiency as was practised in the UK RPI-X regime.\footnote{The UK regulatory framework until recently controls prices of network by incorporating retail price index and an x factor that includes specific targets to incentivise efficiency.}

At least, this study gives the state of affairs of EDCs in the sub-region which is a good place to start when thinking of regulating a regional market. Nonetheless, another important task is to understand the causes and solutions of inefficiency using approaches that can capture the rent seeking and opposing efforts of political and economic agents based on their level of influence and incentives.

The objects of many power sector reforms of West African countries never fail to prioritise efficiency of power distribution. Accordingly, significant efforts and investments have been put into the power sector to reduce both technical and commercial losses. However, the results from this chapter give empirical evidence of a substantial level of inefficiency in the sector which confirms the narratives in the public domain. With the foregoing, there is the need to investigate the problem from a political economy angle to comprehend and deal with the formal and informal rules in electricity distribution in West Africa. An understanding of how political and economic agents influence reforms in the distribution sector may uncover actions or inactions of some of the interested parties that eventually culminates into inefficiency. Thus, using a case of Ghana in the subsequent chapter, the Political Economy Analysis (PEA) framework is employed to understand the causes and solutions of the persistent inefficiency problem in the West African Region.
Chapter 5

Political Economy Analyses: Inefficiencies of Electricity Distribution Companies in West Africa

5.1 Introduction
The inefficient state of institutional and sectoral reforms of the electricity industry of West Africa calls for further investigation. First, to some extent, most of the countries have had reforms with the focus on increasing accessibility and affordability. The underlying impediment to achieving these two important features of a good electricity market is the high levels of inefficiency in the various segments of the market. The link is that if there is an inefficient distribution sector for example, there could be high levels of losses that will hinder investments to increase, extend and maintain network systems and eventually reduce accessibility. In the same vein, an inefficient system has the potential of suppliers pushing additional cost to consumers and thereby increasing the price of electricity and making it less affordable. Even though there has been some progress in efficiency, there is still more to be done on this front as the level of inefficiency is still very high especially at the distribution segment. Therefore, it may well be the case that the import of improving efficiency which features as a common denominator to most electricity sector reforms has not been realised yet.

Notwithstanding, while trying to understand the failure of such reforms, it is imperative to note that there is emerging evidence that reflect the notion that power sector reforms in Africa continue to be designed with the object of addressing technical, economic and in particular financial concerns. However, recent studies concerning interventions have realised the need for considering the differences in social and political factors across different jurisdictions and how they affect reforms in the power sector. As a result, Scott and Seth (2013) suggest that it is very usual to find most of the reform designs and evaluations focus on technical, economic and financial issues without exploring interactions of the social, political and institutional factors that can affect outcomes of reforms. These expected interactions depart from mere stakeholder meetings which some policy makers adopt as a formality to indicate inclusiveness during decision making to a level where such useful inclusiveness can yield solutions that are acceptable, internalised and actionable. There is little or no attention paid to the politics, culture and economics that characterise or define
the stakeholders or change agents of the reforms that could enhance ownership and promotion of the policy actions for the common good of the whole society.

In pooling energy resources together to ensure energy security, access and affordability - which are the main objectives of the West African Power Pool - the individual countries may navigate into a cul-de-sac, if issues regarding inefficiencies are not thoroughly investigated and dealt with. Efficiency studies conducted in chapter four have shown the existence of cost inefficiency in the Electricity Distribution Companies (EDCs) in West Africa. An average cost efficiency of 53% as presented in chapter four can only illustrate the gravity of the problem. Annual financial and technical reports of the EDCs considered in the study recorded technical and commercial losses in excess of 30% for even the relatively efficient companies. Regrettably, the consumers of these firms are saddled with power outages and bad quality of supply due to low generation capacities and fuel challenges regarding available generation plants. To this end, there is no better time to investigate and understand factors that drive inefficiency of the distribution sector as well as comprehend what catalyses its persistence after a long phase of unyielding reforms and policy actions. Fundamental to these intentions should be our understanding on the trends and dynamics of the interplay of politics and economics of relevant stakeholders or change agents which could provide meaning to the status quo. The drive to appreciate reform opposition and prevailing incentives which tend to nullify or reduce the impact of reform and investment efforts is the motivation behind this study and in particular the methodology chosen. Thinking politically to understand a problem can be useful in acting politically to solve sector problems. Infusing this in tools for development theory could enhance the building of “winning coalitions” that can enrich reforms as well as deactivate reform opposition as suggested by The Asia Foundation (2013).

In chapter two, a background of PEA tool is well detailed and explained with the motive of providing adequate background to achieving the objectives of this chapter. In that section a review on competing methodologies was carried out with a succinct elucidation of the benefit of the PEA tool. Political economy is the study of both politics and economics with more focus on the interaction that exists between these two elements. Specific to the electricity industry, the interest is to understand the way political power and resources are allocated to incentivise rent seeking of influential and powerful stakeholders. An additional concern relates to the commitment to revealing the implications of such dynamics on an electricity
distribution reform performance. By using the Political Economy Analysis framework, the focus is therefore to investigate why several reforms have ensued and yet the sector under review continues to be faced with inefficiency challenges. The type of Political Economy Analyses (PEA) applied in the chapter is the problem-driven approach and this calls for a thorough assessment that looks systematically at institutional structures and culture, the formal and informal rules of the game that characterise the institutions and even the problem DFID (2009). A key focus of the PEA framework is development entrepreneurship which employs an iterative process that progresses through three stages of technical and political economy analysis, development of strategies as well as technical and political action with the aim to understand why a particular reform has worked or failed.

The PEA begins with a survey that seeks to investigate stakeholders’ perception on the causes and solutions to the inefficiency problem in the distribution sector. An attempt is made to understand consumers’ behaviour or reaction to the effects of an inefficient distribution system. The research employs a quantitative method to understand the end-user and experts’ point of view and perception of the problem. In-depth interviews are conducted with key informants in order to clarify, verify and appreciate the results from the quantitative survey.

While the overall study targets the West African electricity distribution sector, the PEA focusses on Ghana as an important case study, while drawing on relevant narratives and commentaries from other West African Countries to give meaning to the regional context. The focus of the chapter therefore to investigate and analyse the possible causes and solutions of the persistent high inefficiency levels in West African EDCs.

The overarching aim of the Political Economy Analyses is therefore to understand the sources of inefficiency and accordingly propose an action framework or recommendations vital to the efficient distribution of electricity in Ghana and West Africa.

The objectives of the PEA therefore include:

- To understand consumer and stakeholder perceptions and reactions to inefficiency in the electricity distribution system
- To identify the interests of actors and institutions that contribute to inefficiency as well as finding the related sources.
To identify important concerns and related recommendations for policy and management to address.

Subsequent to this section the research explores the politico-socio-economic context of Ghana. This chapter proceeds thereafter with a snapshot of the electricity sector by exploring key issues pertaining to reforms, associated stakeholders and its linkages to efficiency. The third gives an overview on the methodology and data employed. The fourth section discusses the results and analyses of the diagnostic stage of the PEA while the final section discusses the prognosis as well as the intervention stages before arriving at a conclusion.

The PEA framework suggests an overview of the history, culture, politics and the general social setting of the people or change agents in the jurisdiction of investigations as a first and an important step. Therefore in the section following, the contextual characteristics of Ghana, its people, political structure and economic profile are presented.

5.2 A Brief Profile of Ghana

Ghana has a distinct profile in terms of its geographical location, natural resources and socio-cultural setting. The political and economic history of Ghana is unique and could play a vital role in understanding the current state of affairs of its institutions and reforms in general. In this section, the above features are reviewed and exposed to bring more understanding to the inefficiency problem of the power sector of Ghana.

5.2.1 The Place, People and Politics

Ghana which is a former British colony is centrally situated in West Africa with Togo, La Cote D'Ivoire and Burkina Faso as neighbours to the East, West and North respectively. The Atlantic Ocean links the south of Ghana. It covers an area of about 239,000 km2 and comprises three broad distinct ecological zones: a small coastal zone, a forest zone and a large savannah zone in the North (McKay et al., 2005). The Ghana Statistics Service estimates the country's population to be about 28.3 million in 2016. The population is distributed unevenly across 10 administrative regions which are further segmented into 216 districts. There is a clear regional development inequalities and almost all the political regimes endeavour to restore equality through various policies. Unfortunately, this dream has not being accomplished yet since dating back independence till present there continuous to be a significant differences in the economics and welfare of the Southern and Northern regions. Ghana is broadly divided into
North and South and the physical geography, the people and welfare contribute to this distinction with the former being worse off.

The Northern part of Ghana was formerly under colonial rule and titled the Northern Territory was occupied by the British in 1897 and formally annexed to the Gold Coast (now Ghana) in 1902. The North consists of 41% of the land area of Ghana, although it is home to only about 20% of its total population. After the struggle for self-government, the British eventually handed the sovereign rule to the people of Ghana who became independent in March 1957.

There is an inconsistent overlap between ethnicity and administrative regions in Ghana, both along the broader North-South divide and within individual regions. It is therefore not unusual to find the same ethnic group come from two different regions. According to Langer (2009), the country’s estimated ninety-two ethnic groups are often classified into four large groups that together comprise around 86% of the population. These include the Akan, Mole-Dagbani, Ewe and Ga-Adagbe where the Akans constitute the largest ethnic group (49%), and dominate in all the Southern regions, except in Greater Accra and Volta Regions.

The second largest group are the Mole-Dagbanis who constitute around 17% of the population and are largely found in the North. The Ewes are concentrated in the Volta Region close to Togo and are the third largest with a population of about 13%. The Ga-Adangbes representing 8% have the Greater Accra Region as their home. About 19 percent of the population is represented by a highly dispersed Guan people who live scattered in a great curve from Gonja in the Northern Region all the way south of Winneba in the Central Coastal Region. And the Lodagaa in the north-western part of the country. Ghana is known for attracting foreigners from neighbouring countries and many cases ethnic groups spill over these borders making it difficult to distinguish between citizens and non-citizen. That apart, other Africans have come from further afield. Due to the British Colonial days, inhabitants of fellow colonies like Gambia, Sierra Leon and Nigeria also migrated to Ghana and settled in pockets dispersed in the country. The largest of these are the Nigerians who dominate the group under review. After the Liberian War, some refugees that migrated to Ghana have stayed and settled and also forming a small minority around the Greater Accra Region and the Central Region.

For the purposes of the objectives of this research, the sophisticated ethnic mix is very important in understanding the politics of electricity access and the management of utilities
in Ghana as well as its implications for energy inequalities. The exploitation done by political and cultural entrepreneurs as a result of the divisions and sub-classification will be dealt with in a later chapter. However, it could be less challenging to appreciate after considerable analysis to agree with Asante and Gyima5h-Boadi (2004) on how allocation of public expenditure could be linked to cultural and political divide elements. Political agents find it a normal practice to favour those groups and cultures that they are aligned with even in sharing the national cake.

**Figure 5.1: Map of Ghana and its Neighbouring Countries**

Important timelines in the politics and history of Ghana dates back in the 15th century where the Portuguese settlers arrived and commenced trading in gold, ivory and timber can be followed in boxes 5.1 and 5.2.
Box 5.1: Economic History of Ghana

1482 Portuguese settlers arrive and begin trading in gold, ivory and timber.
1500s Slave trade: Slavery overtakes gold as the main export in the region.
1600s Dutch, English, Danish, and Swedish settlers arrive; slave trade becomes highly organised.
1642 The Portuguese relinquish their territory to the Dutch and leave the Gold Coast.
1807 British dominance: British ban on slave trade from the Gold Coast becomes effective.
1874 The Gold Coast is officially proclaimed a British crown colony.
1957 Independence: Ghana becomes first black African colony to declare independence.
1964 Military rule: Succession of destabilising coups, Ghana is predominantly a one-party state.
1992 New constitution, multi-party system is restored.

Source: BBC News (2018)

Box 5.2: Political History of Ghana

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Basic Law</th>
<th>Legislative Body</th>
<th>Executive Body</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) 1957</td>
<td>Independence (Constitution</td>
<td>Independence Constitution</td>
<td>Parliament</td>
<td>Queen + Prime Minister + Cabinet</td>
</tr>
<tr>
<td></td>
<td>Peoples Party Government)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) 1960</td>
<td>Constituent Assembly (CPP</td>
<td>Independence Constitution</td>
<td>Constituent</td>
<td>Queen + Prime Minister + Cabinet</td>
</tr>
<tr>
<td></td>
<td>Government)</td>
<td></td>
<td>Assembly</td>
<td></td>
</tr>
<tr>
<td>(3) 1960</td>
<td>1st Republic (CPP Government)</td>
<td>1st Republican Constitution</td>
<td>Parliament</td>
<td>President + Cabinet</td>
</tr>
<tr>
<td>(4) 1966</td>
<td>1st Coup d’Etat (NLC Government)</td>
<td>National Liberation Council</td>
<td>National</td>
<td>President + Prime Minister + Cabinet</td>
</tr>
<tr>
<td>(5) 1969</td>
<td>2nd Republic (Progress Party</td>
<td>National Redemption Council</td>
<td>National</td>
<td>President + Prime Minister + Cabinet</td>
</tr>
<tr>
<td></td>
<td>Government)</td>
<td>Establishment Proclamation</td>
<td>Redemption Council (NRC)</td>
<td></td>
</tr>
<tr>
<td>(6) 1972</td>
<td>2nd Coup d’Etat (NRC Government)</td>
<td>Supreme Military Council (SMC)</td>
<td>Supreme</td>
<td>President + Cabinet</td>
</tr>
<tr>
<td></td>
<td>(Establishment Proclamation)</td>
<td>Establishment Proclamation</td>
<td>Military Council (SMC)</td>
<td></td>
</tr>
<tr>
<td>(7) 1975</td>
<td>Revised Composition renaming</td>
<td>-Ditto-</td>
<td>-Ditto-</td>
<td>-Ditto-</td>
</tr>
<tr>
<td></td>
<td>the NRC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(8) 1978</td>
<td>“Palace Coup”</td>
<td>-Ditto-</td>
<td>-Ditto-</td>
<td>-Ditto-</td>
</tr>
<tr>
<td>(9) 1979</td>
<td>Military “Uprising” (3rd Coup</td>
<td>Armed Forces Revolutionary</td>
<td>Armed Forces</td>
<td>Armed Forces Revolutionary Council (AFRC)</td>
</tr>
<tr>
<td></td>
<td>d’Etat (African Government)</td>
<td>Revolutionary Council</td>
<td>Revolutionary</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Establishment Proclamation)</td>
<td>Establishment Proclamation</td>
<td>Council (AFRC)</td>
<td></td>
</tr>
<tr>
<td>(10) 1979</td>
<td>3rd Republic (Peoples Party</td>
<td>3rd Republican Constitution</td>
<td>Parliament</td>
<td>President + Cabinet</td>
</tr>
<tr>
<td></td>
<td>Government)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(11) 1981</td>
<td>“Revolution” (4th Coup d’Etat</td>
<td>Provisional National Defence</td>
<td>Provisional</td>
<td>Provisional National</td>
</tr>
<tr>
<td></td>
<td>(PNDC Government)</td>
<td>Council (Establishment</td>
<td>National Defence</td>
<td>Defence Council (PNDC)</td>
</tr>
<tr>
<td></td>
<td>(PNDC Government)</td>
<td>Proclamation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(13) 1997</td>
<td>4th Republic (NDC Government)</td>
<td>4th Republican Constitution</td>
<td>2nd Parliament of</td>
<td>President + Cabinet</td>
</tr>
<tr>
<td>(15) 2005</td>
<td>4th Republic (NPP Government)</td>
<td>4th Republican Constitution</td>
<td>4th Parliament of</td>
<td>President + Cabinet</td>
</tr>
<tr>
<td></td>
<td>(7th January)</td>
<td></td>
<td>the 4th Republic</td>
<td></td>
</tr>
</tbody>
</table>
The political history of Ghana post-independence is composed of both military and democratic regimes. Until after the 4th republic in 2001, governance was interspersed with many military coups causing moments of fear and panic that curtailed the rights of citizens even though the leaders of these governments aimed to disallow economic injustices and marginalisation in many regards at the commencements of their regimes. They came with the intention to sanitise the economy but it might be a moot issue to suggest any achievement during this period of coup d’états. Nordlinger (1977) supports the above by suggesting that the military regimes in many countries have been associated with the same ills and failures, incompetence and corruption which they charged their predecessors of’.

The last military rule that lasted for nearly 12 years eventually came to an end before the start of the fourth republic. It is worthy to note that such violent takeover of power has a potential to affect the psyche of the people of Ghana especially in the frequency at which they came. A certain generation still in the system must have lived in some fear and uncertainty and are likely to extend these attributes to their progeny or next generations. The effect of coups on a group of people can contribute to some characteristics of a people. Nevertheless, there has been a smooth transition of power from government to government from 2001 to date. All matters regarding elections have been dealt with in peace through petitions to the courts or otherwise. In the fourth republic, there has been many human rights acts that continue to enhance or improve democracy in the system. However, there are still signs of fear and panic regarding being discriminated against when some citizens air their views. People are normally tagged to a particular political party as long as they do not agree with certain policies or acts of a political party. This has degenerated into very essential elements of an economy including recruitments and award of contracts giving little regards to expertise and rather selecting based on political affiliations.

In Ghana, the National Democratic Congress (NDC) that emerged from the erstwhile Provisional National Defence Council (PNDC), a military government and the National Patriotic Party are the two main political parties that have been taking turns since the 4th republic. The NDC is supposed to have a leftist ideology and consider themselves as social democrats as they show a bit of the rightist attributes like divestiture of state assets. On the other hand, the NPP are rather more of a rightist but also show some main feature of the socialism such as the National Health Insurance Scheme, School Feeding Programme and Free
Education. Along the lines of electoral strongholds, the Akans have a strong affinity for the NPP whiles the Northerners and the Ewes are generally attracted to the NDC. It is not extremely polarised along the tribal lines in recent years as both parties have won some seats in areas known to be for their opponent.

5.2.2 Economic Context of Ghana: Welfare and Macroeconomics of Ghana

Present-day Ghana was involved in international trade because of its high gold-reserves, an asset that bestowed on it the name Gold Coast. European, North African and Saharan traders did not only exchange gold but also kola nuts and slaves. It was the Asante State that controlled prices through production and marketing. In the fifteenth century, and in 1482, the Portuguese were the first among the Europeans to come to Ghana to establish a trading post where gold, ivory and pepper from coastal merchants were purchased. In the era of improved navigation, the Dutch and the English traders also joined the search of direct trade at the West African coast where they eventually arrived on the shores of Ghana. The British eventually took control and engaged in domestic production of gold, palm oil and timber. With the inflow of luxurious or new products or consumables from Britain and other European traders, some African products (textiles especially) were displaced. In 1878 cocoa trees were introduced from the America’s and cocoa eventually became a competing international commodity to gold. Ghana in 1920 recorded nearly half of the global production of cocoa. Gold, cocoa and timber have for many years been the main export commodities of Ghana until recently when oil was found in commercial quantities. The structure of the economy has been export led with high import levels that have consequences on the strength of the Ghana Cedi.

Ghana Statistical Service (2016) states in the labour force report of 2015 that not much has changed over decades regarding the structure of economy and its related employment structure. Agriculture, forestry and fishing remains the industry the employs most Ghanaians and engages about 3.3 million people in Ghana. This is followed by Wholesale and retail trade and the repair of motor vehicles and motor cycles (1.9 million). Manufacturing is the third major industry of employment, engaging about 1.2 million of the currently employed. In 2015, it is reported that more than half of the population (67.9%) above 15 years are employed. Unemployment in the region of 30% is still very high.
By the Ghana statistical services data in 2006, two revelations show that Ghana has made considerable progress in poverty reduction but there is still a high level of poverty in the rural areas particular as we move northwards of the country. In the rural areas there are more severely poor people than non-severely poor people. At the national level, poverty level stands at 28.5% and quite low in the urban areas at 10%. The inequality level estimated with a Gini coefficient of 43% is therefore expected. Inequality is confirmed by the Cooke and Mckay (2016) to rise in Ghana since 1992 but at a slow pace. They also suggest that highest levels of inequality are rather pervasive within particular regions.

**Figure 5.2: Aggregate and Sectoral GDP of Ghana**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Population estimate (million)</td>
<td>24.56</td>
<td>25.24</td>
<td>25.82</td>
<td>26.43</td>
<td>27.04</td>
<td>27.67</td>
<td>28.31</td>
<td>28.96</td>
</tr>
<tr>
<td>Average exchange rate ($/C)</td>
<td>1.43</td>
<td>1.51</td>
<td>1.81</td>
<td>1.92</td>
<td>2.94</td>
<td>3.78</td>
<td>3.92</td>
<td>4.36</td>
</tr>
<tr>
<td>GDP current (million C)</td>
<td>46,042</td>
<td>59,816</td>
<td>75,315</td>
<td>93,416</td>
<td>113,343</td>
<td>136,957</td>
<td>167,353</td>
<td>205,914</td>
</tr>
<tr>
<td><strong>Non-Oil GDP current (millon C)</strong></td>
<td>45,865</td>
<td>56,070</td>
<td>69,666</td>
<td>85,377</td>
<td>105,550</td>
<td>131,647</td>
<td>164,099</td>
<td>195,200</td>
</tr>
<tr>
<td>GDP current (millon US$)</td>
<td>31,186</td>
<td>39,217</td>
<td>41,656</td>
<td>48,934</td>
<td>58,811</td>
<td>64,264</td>
<td>78,905</td>
<td>87,685</td>
</tr>
<tr>
<td>Per capita GDP (C)</td>
<td>1,867</td>
<td>2,370</td>
<td>2,916</td>
<td>3,535</td>
<td>4,182</td>
<td>4,950</td>
<td>5,911</td>
<td>7,110</td>
</tr>
<tr>
<td>Per capita GDP (US$)</td>
<td>1,305</td>
<td>1,566</td>
<td>1,613</td>
<td>1,841</td>
<td>2,421</td>
<td>2,990</td>
<td>3,621</td>
<td>4,163</td>
</tr>
<tr>
<td>GDP at constant 2006 prices (millon C)</td>
<td>24,101</td>
<td>27,486</td>
<td>30,040</td>
<td>32,237</td>
<td>33,522</td>
<td>34,808</td>
<td>36,104</td>
<td>39,175</td>
</tr>
<tr>
<td><strong>Non-Oil GDP at constant 2006 prices (millon C)</strong></td>
<td>24,035</td>
<td>26,114</td>
<td>28,372</td>
<td>30,268</td>
<td>31,465</td>
<td>32,731</td>
<td>34,379</td>
<td>36,063</td>
</tr>
<tr>
<td>GDP at constant 2006 prices (millon US$)</td>
<td>16,848</td>
<td>18,158</td>
<td>16,615</td>
<td>16,790</td>
<td>11,420</td>
<td>9,217</td>
<td>9,209</td>
<td>8,993</td>
</tr>
</tbody>
</table>

**Growth Rates %**

- GDP at current market prices: 25.8 29.9 25.9 24.0 21.3 20.8 22.2 23.0
- GDP at constant 2006 prices: 7.9 14.0 9.3 7.3 4.0 3.8 3.7 8.5
- Non-Oil GDP at constant 2006 prices: 7.6 8.6 8.6 8.7 4.0 4.0 5.0 4.9
- Change in GDP deflator: 16.6 13.9 15.2 15.6 16.7 16.4 17.8 13.4

**Source:** Ghana Statistical Service (2017)

**Figure 5.3 National Poverty Rates (1992 to 2013)**

Source: Cooke and Mckay (2016)
Increasing labour productivity is definitely a requirement for improving economic production and thereby it is a key requirement for a country’s development. To improve on labour productivity, it is important to continuously improve on the health and education of the country’s human capital. In Ghana and most African countries, it is believed that the high unemployment rate could be linked to the low level of education which prevents the access to gainful employment. According to the Ghana Statistical Service (2013) 28.5% of the working age population in 2010 had no formal education. About 48% of the working class have basic education while only 3% have university education with 21% having a secondary education or better. The country’s educational profile as well as the quality of the quality of labour force produced can seriously affect economic production especially when the standard does not meet industrial expectations. The narratives seem to suggest that there is a gap between the expectation of industry and the quality of students produced by the educational system. Current and previous governments have worked on the progressive free compulsory basic and secondary education agenda to increase the level of literates by supporting and financing the education of all Ghanaians in public schools. This intervention is geared towards producing skilled labour for the Ghanaian industry to increase productivity and production. This task accounts heavily for the budget deficit of the Ghanaian economy and its sustainability depends on how the government can continuously fund it without affecting its obligations in other sectors such as health, agriculture, energy etc. With high increases in population (refer to figure 5.8) government’s expenditure on education and health is expected to rise and the necessity of sustainable funding sources is therefore indispensable.

**Figure 5.4: GDP Growth Rates of Ghana**

5.3.2 A Recap of the Ghanaian Electricity Sector
In part one of chapter two, a detailed analysis of the electricity sector of Ghana as a whole was considered. In this chapter and under this section, the focus is on the distribution sector with the aim to dovetail into the essentials that concern the running of an efficient distribution network. The goal is to understand the distribution subsector for onward utilisation in achieving the objectives set out in the introduction of the chapter.

Ghana’s agenda to achieve universal access to electricity by the 2020 was initiated in the late 1980s. In 1989 the National Electrification Scheme was established to serve as the principal agent or instrument to front the extension of electricity to all parts of the country in a space of 30 years. The most recent access review suggests a national access rate of 82.5% in 2016 from as low as about 20% in 1990. With an annual growth rate of 2.6%, the performance of the scheme can be viewed as satisfactory especially when compared to its peers in West Africa, however, it appears Ghana may not be able to achieve universal access to electricity by 2020. As confirmed by Kumi (2017), there must be a special drive to attain full access by 2020 and that comes with a herculean task of huge investments in all segments of the industry. Additional generation, reinforcement and grid extension must be carried out in the next three years for the 2020 target to be achieved.
In the National Electrification Master Plan, a special scheme called the SHEP (Self Help Electrification) Scheme contributed immensely to the increase in accessibility. In this scheme, communities were willing to support in terms of logistics and labour as part of their equity in extending electricity lines to them before the planned time as suggested by Kemausuor and Ackom (2017) Government was therefore supported particularly in terms of electricity pole and meter procurement as the communities financed that from their internal resources. Apart from the supply of poles, the communities were committed to connecting 30% of households with installed meters to the grid.

Electricity consumption continues to increase and the evidence of suppressed demand in the figure below suggests same. In periods, where the consumption detracts should not be misrepresented as a reduction in demand but rather a reduction in supply capacity. Though there is adequate installed capacity, the available capacity is always less than the actual demand. There is a deficit in the supply and actual demand. The required margins are depleted exposing the system to high risk. In 2016 the consumption levels stood at 17700 GWh after the system suffered a shock in 2015 as a result of unavailable capacity due to unplanned repair schedules, fuel related issues and other factors. The implications are much serious for the economy especially as over 55% of total consumption is the suppressed demand for the Industrial and commercial segments. To appreciate the extent to which the supply-demand gap poses significant risk, the energy requirements of the country is expected
to increase given the many policies of industrialisation yet to be realised by every regime of government. However, with an ambitious vision of one factory in every district, it is time to address issues relating to reliability, security and affordable power. Without a supporting power sector, the country will be heading for many redundant assets and waste of the limited resources. Like in other jurisdictions, captive power and community energy for industrial zones may have to be encouraged using if possible renewable sources.

Table 5.1: Electricity Consumption by Customer Classes

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>1,966</td>
<td>2,168</td>
<td>2,275</td>
<td>2,483</td>
<td>2,527</td>
<td>2,819</td>
<td>3,060</td>
<td>2,772</td>
<td>2,436</td>
<td>3,932</td>
</tr>
<tr>
<td>Non-residential</td>
<td>802</td>
<td>876</td>
<td>924</td>
<td>966</td>
<td>1,199</td>
<td>1,549</td>
<td>1,532</td>
<td>1,529</td>
<td>1,530</td>
<td>1,066</td>
</tr>
<tr>
<td>Special Load Tariff²</td>
<td>2,687</td>
<td>2,963</td>
<td>2,951</td>
<td>3,174</td>
<td>3,901</td>
<td>4,153</td>
<td>4,435</td>
<td>4,680</td>
<td>4,179</td>
<td>4,528</td>
</tr>
<tr>
<td>Street lighting</td>
<td>101</td>
<td>132</td>
<td>144</td>
<td>254</td>
<td>296</td>
<td>369</td>
<td>445</td>
<td>540</td>
<td>536</td>
<td>603</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5,586</td>
<td>6,139</td>
<td>6,294</td>
<td>6,877</td>
<td>7,922</td>
<td>8,890</td>
<td>9,472</td>
<td>9,521</td>
<td>8,681</td>
<td>10,129</td>
</tr>
</tbody>
</table>

Source: Energy Statistics from Energy Commission of Ghana 2017

Figure 5.7: Electricity Demand by Sectors and Losses

Source: Energy Commission (2016)
From figure 5.7, it is agreeable that the distribution system is overwhelmed with a considerable level of losses in transmission and distribution. From the figure above, total losses would be about 20%. This is really huge and are considered unaccounted power which continue to put the distribution companies in financial distress. High related tariffs make consumers unyielding to further increases as utilities propose cost-reflective tariffs. From figure 5.8 above, end user tariffs are running into 25 cents per kWh and the implications of that includes social exclusion and poor competitiveness of the Ghanaian producer to its international competitors. If the system is allowed to run in the manner in which it is managed, the sustainability of it will eventually become an impossibility. There is therefore a sense of urgency in reducing inefficiency in the system. The narratives seem to support what is on ground as the network companies continue to suffer from revenue theft, power theft, mismanagement and lack of investment. The supply infrastructure needs reinforcement and capital injection to conform to modern practices that have led to reduced inefficiency.

Chapter two explored the structure of the Ghanaian Electricity sector and showed the various stakeholders and their respective roles. Figure 5.9 below does same to recapitulate the players in the sector.
The power industry is segmented into generation, transmission and distribution. The generation segment is dominated by Volta River Authority, Bui Power Authority and various Independent Power Producers. A combination of hydro and thermal plants constitute the energy mix. Renewables is almost missing in this mix even though the country can boast of a 5mw solar plant and potential solar and wind projects on the drawing board. Generation is the most competitive of the segments and power from private participation accounts for over 25%. Transmission is executed by Ghana Grid Company (Gridco) which is responsible for transporting power from the generators to distribution points. The distribution segment are therefore also responsible for retailing and there is not competition at that point of the value chain. Two main distribution companies exist and they are ECG and NEDCo. The former covers the southern sector while the latter is in charge of distribution in the norther sector of Ghana. Enclave power is a small network that is specialised for a few energy intensive industrial customers.

There are national commitments supervised by the national regulatory bodies which are Energy Commission and Public Utilities Regulatory Commission. Regional (ECOWAS) regulators include WAPP, ECREEE and ERERA. Power sector reforms count from the moment of its proposal to establishment of a regulatory framework where EC and PURC were born.
Unbundling of Volta River Authority followed then the establishment of the unregulated market for IPPs. Later on performance contracts for ECG and VRA including NEDCo were designed to be implemented. The creation of five demarcated regions of electricity distribution with only thee one in the Tema Enclave established and operational. Finally the rules and the technical issues spelt out in a regulatory framework or codes for grid operations were established to make the market work. There has been a call for reforms ever since with increasing inefficiency of the two main distribution companies. The usual rescue plan of privatisation of publicly owned utilities was proposed and ECG especially is going through the process to hand management to a private company. Manilla from Philippines has won the bid and is expected to operate the main distribution company of Ghana for a period of 25 years. The state of affairs calls for retrospection dwelling on an effort to unpack the narratives regarding politics of the power sector. The idea is to link the narratives to implications on realistic pricing, independent regulation, strategic investment decisions, and corruption in the sector.

5.4 The Narratives and Politics of Electricity Distribution
Distribution of electricity seem to be the crux of the matter when quality of service is concerned. This is because they are the closest to majority of final consumers (except bulk buyers like the mines and VALCO). There are significant losses in the technical and commercial operations of the distribution companies. The Energy Commission reports an average technical loss of in the range 24%-30% for both NEDCo and ECG. This loss is significant explaining mainly why a country with a generation capacity of 2936MW cannot manage an average dependable peak in the range of 1980 MW-2300MW. Thus the solution does not lie only in increasing the generation of capacities but also managing the technical and economic inefficiencies of these distribution companies. As suggested by the Executive Director of KITE (Kumasi Institute of Technology) in 2016, the low cost recovery and unpaid electricity bills leading to low investments in replacing deteriorated distribution assets accounts for the high levels of technical losses in the distribution sector. He suggests that the opening up of the market to competition in 2007 has not seen enough private participation or investment because over the years tariffs have not been great to attract the private sector. Also the other limitations refers to the exchange rate instability or depreciation of the cedi which reduces margins of profits.
The fact that electricity pricing does not match the cost of producing, transmitting and distributing of power as well as the subsidy policy of the government have significantly disadvantaged the entire power industry and thus require urgent deeper attention. The IMF in 2016 reported that the power firms in Ghana were in a GHS 19 Billion maze of debt. The borrowings of four state owned Enterprises (SOEs) including VRA, ECG, GRIDCo and the Tema Oil Refinery (TOR) owed such an amount to banks and their suppliers. They cautioned that a systemic crisis was imminent if the government did not take immediate measures to remedy the situation. The Energy Sector Levies Act (ESLA)6 came into force to accumulate funds to pay off the restructured loans of these SOEs in order to offer liquidity into the banking industry as well as reduce the financial obligations of the energy companies. The strides in improvement in technical and financial efficiencies have not been particularly satisfactory given that losses still are in the range 23%-30% of distributed power and an increasing trend in operating profit margin of 32.1% in 2009 to loss margin of 94.5% in 2012 (Energy Commission of Ghana, 2014). These indicators should be doing well in the era of increased turnover (increased customer size and per capita consumption) and revised prices but it is not the case with Electricity Company of Ghana. Quality of service to final consumer continues to deteriorate but the blame certainly cannot entirely be that of the distribution companies since there are also issues with generation and transmission. In plain language, the distribution companies can only distribute what is generated and any problems that curtail the availability of power for distribution has the potential to contribute to some of the problems faced in this segment of the market.

The above discussions and suggestions are common knowledge in the domains of power supply in Ghana, nevertheless, for many years, plans, policies, strategies etc. have not been able to adequately solve issues regarding security, reliability and affordability. This very dilemma propels the discussion around the politics of the power industry in Ghana. The many narratives seem to suggest that collective action of interest groups, political objects, and the economic and social attitude of the people overstep the common interest of all and eventually inhibit functional decision making. Discussions surrounding, Grid Extension, Tariffs, Power theft, uncollected revenue, lack of a common energy policies across different regimes, and

6These levies (GH¢ 0.41 per litre on petrol and diesel) serve as collateral and funding for energy debt restructuring with banks
others will reflect how inefficiency is perceived to be an outcome of the interest of political and economic agents.

As suggested in other jurisdictions especially in the Indian case by Kannan a barnend Pillai (2001), in Ghana and most West African countries, political parties promise electricity extension to rural areas even before they look at the economics of it. They do so to win the peoples votes and may or may not even ensure such promises are fulfilled. In cases where they are honoured, transmission and distribution companies that are wholly or partly owned by the government are coerced to providing such services without any frantic cost benefit analyses. Sometimes, certain projects are rushed and higher costs incurred because elections are close by and the government in power dreads to lose power. In such cases, investment decisions are not necessarily the best. The misgivings of the cost efficiency of such projects seems to be justifiable apparent in the circumstance. An extension of this behaviour is observed by Scott and Seth (2013) who suggest that during these periods, projects including grid extensions create avenues for rent seeking and to justify “judicious” use of funds, politicians are more attracted to tangible infrastructure than improving reliability of service, regulation and efficiency.

Electricity tariffs are normally decided by the relevant regulatory authority. There are normally price control models designed by experts but it is true that the real cost of electricity is not reflected. Political parties are known to have declared prices before consulting the supposedly independent regulator. In cases, where they do, it is perceived to be manipulated by the incumbent government for their political interest. The norm seems to be that the opposition parties tends to be quite critical of the regulators and seem to fight for the general consumer and the private enterprise engaged in the power sector.

According to ESMAP (2005) in their report on Ghana, the price of electricity is a dangerous “political tool” such that any government anticipates dire electoral consequences especially when tariffs are increased during periods close to elections. It is noted that residential consumers have little influence on tariff setting during periods within elections but become very powerful negotiators during election years. This and the related economic hardship on the citizens are some of the reasons why electricity price increases tends to be contested vehemently governments even if it is intended to make utilities more financially and technically sustainable. Examples in Ghana are numerous with the most recent one being the
price increases during 2016 by the Electricity Company of Ghana. Prices were increased to over 50% by the then NDC government that needed to repay outstanding debt to the IPPs in face of power shortages. With such a courage, the protest by unionist, Association of Ghana Industries, opposition parties and the citizenry as whole caused the government to remove taxes and reduce the price of electricity towards the commencement of the 2016 elections. The opposition party then promised a massive reduction of prices should they be voted in power.

In order to deliver their manifesto promises or otherwise, then opposition power reduced electricity prices not long after they were voted into power in 2017. However, the contrast is that, the government will be penalised as well when the system suffers power outages because of the unsustainable operations of the utilities. There is not much of a choice than to continuously declare subsidies and respites that leave the distribution companies in huge debt. Organised Unions are aggressive when it comes to power price increases and will do within their rights and power to threaten and eventually stop government from supporting such increment.

It is true also, that because of government’s ability to control the utilities, some consumers also suspect issues around wrong metering as a strategic way of secretly increasing prices even though the utilities continue to defend it as genuine malfunctioning of pricing software.

Power theft is thought of as a social problem that is exacerbated by the economic woes of the lower income bracket. Nonetheless, even consumers in higher income brackets have been charged for power theft. A longstanding solution around power theft regarding smart metering, prepaid meters and whistle blowing have not achieved much. Investigations conducted by Anas (2012) among many narratives suggest that there is some level of internal opposition impeding the fight against power theft and non-payment for electricity usage by even high load consumers. They found that there is some collusion between the contracted meter readers, ECG staff and disconnected consumers. In the investigations, moneys were paid to staff to either stop or postpone meter disconnection.

With prepaid consumers, the same staff are alleged to be bribed so as to stop reporting by-passing or meter tempering cases. The public perception is that there are many under-dealings where ECG staff are involved with the burning of warehouses stocked with meters cited as one of the controversial cases. Over 25000 prepaid metres worth $2 Million were
burnt in the fire that broke out at the Kumasi warehouse. More so, the reluctant efforts of distribution utilities to find other ways of ensuring 100% prepaid meters for consumers especially in areas or localities known for power theft. Unrecovered revenue losses prevails at a rate that is alarming and yet not much has been done to intensify collection and prosecution. There is enough evidence in the narrative that some agents may be collectively truncating the process for their personal gain. Last but not the least, the politics regarding abandoning projects of past governments extend to all sectors including energy, housing, health, education, transportation, infrastructure development and many more. Many authors have suggested the lack of consistency in the policies on energy from one regime to the other. In the narratives, it seems to suggest that policies are changed partly for the purpose of assuming ownership or entitlement but not for the motive of enhancing its intended aims for the general welfare of the people. A case in point is the pending investigation into the purchase of electricity budes at a critical time of energy shortages where the then party in opposition suspected over-invoicing and later renegotiated terms that are considered worse of the previous Power Purchase Agreement (PPA) with AMERI\textsuperscript{7}. The influence of other witty influential people in the communities could be another factor that may influence the rules of the games.

Renewable energy at the moment is a minute part of the total generation. There has been a policy direction to increase renewable energy in the energy mix to account for 20% in the 2030. In order to meet these targets, a renewable energy master plan has been developed. The Energy Commission working with different governmental and non-governmental agencies promotes alternative energy by granting licenses for their respective operations. Similar to securing licenses for generating conventional energy, many influential and elite have secured these limited licenses and hold it high in esteem without commencing projects. This is done at the expense of industrious entrepreneurs who have the desire and skills to operate. Regarding contracts of renewable energy generation with the utilities, feed in tariffs are negotiated by all parties. Interest groups may push for more compensation in which the increased cost of production is absorbed by the consumers. Others have explained the bureaucracy in the application of licenses to offer services to the electricity distribution

\textsuperscript{7} Africa Middle East Resources Investment Limited is a privately owned group that has an Energy subsidiary with an object of providing innovative and clean energy solutions.
sector. There are many such narratives such as those discussed above that could add to the inefficiency problem of the Electricity Supply Industry of Ghana. The Political Economy Analysis therefore intends to investigate empirically to substantiate or debunk these assertions, allegations or perception in the public domain as well as profess possible pathways for managerial and policy actions

5.5 Methodology and Data
As indicated in the introductory chapter, using Electricity Company of Ghana (ECG) as a case study, a political economy analysis framework is adopted to understand the interplay of politics and economics that contribute to the inefficiency of the distribution system. It is important to recap the analytical framework of the PEA framework (explained in section 2.3) in order to enhance the comprehension of the methodology chosen. At this point, the problem of inefficiency of the distribution sector has been identified from previous chapters and therefore the diagnostic stage comes next where features of political economy are identified. The prognosis stage has the ability to uncover potential for change and the most realistic avenues or pathways for change. The intervention stage which is the final stage of the framework details the specific actors that could reshape the incentives in a manner that enhances the required change.

To accomplish the three last stages of the framework, the PEA employs both quantitative and qualitative approaches to capture the perception and opinions of stakeholders on the issue at stake. The interest in understanding the perception of the consumers on inefficiency is key to validating their responses beforehand. The way consumers respond to an inefficient distribution system is also important in the discussion of the causes and solutions of the inefficiency problem. Investigating consumers’ reactions to an inefficient system could therefore augment the understanding of the existing system. The methodology and data used are based on the three objectives highlighted in the introduction section of the chapter. First, a survey is used to explore the perception of consumers and their reaction to an inefficient distribution system. Secondly, the core of the PEA framework is used to find possible political economy avenues that contributes to the problem. Finally, it is the objective of this investigation to find plausible recommendations to policy makers and management of EDCs to consider in tackling the problem.
In the first phase, consumers of electricity including industrial, commercial and residential users of electricity were the participants in the survey conducted using a questionnaire that is tested and verified using a structural equation model. The second phase of data collection was accomplished by using in-depth face-to-face interviews, video interviews and transcribed interviews in newspaper articles conducted by third parties. Therefore a mixed approach was utilised to augment the PEA analysis and such an approach is in line with the suggestions made by Barnet (2016) in relation to supporting PEA with ‘factual evidence’ especially in measuring the perception of stakeholders on reform changes. Incorporating such an element is useful to determine whether the actors’ perceptions of the impacts of change are valid before considering such information into building coalitions for change.

The output of the questionnaire designed for the study is used to solicit opinions on both consumer perception and consumer reactions towards an inefficient distribution system. This chapter focuses on key issues identified in the survey and further interrogates these using interviews of selected stakeholders which then becomes useful data for the diagnostic stage of the political economy analyses task.

In view that the questionnaire designed has not been tested before, there is a need to validate it before the data collection stage. This task is the first to be carried out before the quantitative analysis can be conducted. This is followed by the qualitative analysis after which recommended change factors or actions are identified and discussed for the necessary stakeholders or interest groups to consider for action.

A Structural Equation Model (discussed in the next section) is used to validate the survey instrument as well as confirm the perception of the respondents on the efficiency of the electricity distribution sector before subjecting any information collected to analysis. A brief overview of the theoretical framework of SEM is given in the succeeding section in order to bring adequate understanding to the validation technique.

5.5.1 Structural Equation Modelling Framework

Structural Equation Model (SEM) is suggested by Kaplan (2001) as one of the most popular statistical methodologies used in quantitative analyses by social scientists. As an extension of factor analysis, SEM is constructed to mainly test fundamental theory using empirical data. For example, in the questionnaire used in the PEA analyses, it is suggested that variables that determine the benefit of an efficient system and the variables that determine the attribute
of an inefficient electricity distribution system could determine how consumers or stakeholder perceive efficiency of electricity distribution by a particular utility. In SEM, the focus normally is on latent constructs which are abstract psychological or mental variables like “perception”, “intelligence” or “attitude” regarding a certain service or product. However, to do so, the manifest variables that measure these constructs though not the main interest are the measurable determinants or factors called items.

In general, the SEM is a system of linear equations with several unobservable variables (constructs) and observed variables. A structural part links the constructs to each other and a measurement part that connects the construct to observed measurements. This framework is normally displayed in a visual form called a path diagram. The SEM is estimated from a measurable data set and inferences drawn with other tests performed to validate the substantive theory (Sinharay, 2010). To this end, SEM allows multiple measures to be associated with a single latent construct. A structural equation model implies a structure of the covariance matrix of the measures. Once the model's parameters have been estimated, the resulting model-implied covariance matrix can then be compared to an empirical or data-based covariance matrix. If the two matrices are consistent with one another, then the structural equation model can be considered a plausible explanation for relations between the measures.

Using SEM in this investigation, the interest is in the validation of the questionnaires as a research tool for measuring accurately the views of the participants in the sample used. In this case, it is important to measure the perception of the respondents on an inefficient distribution utility before carrying out our political economy analysis which is the aim for using SEM. Also with this exercise, it can be established whether the respondents did have an appreciation of the concept of efficiency in electricity distribution before taking part in the survey and also to find how consistent they were with their responses. Therefore, using the SEM in our PEA analysis, consistency and confidence in the survey responses are explored before subjecting them to any rigorous analysis. Our two factors of inefficiency attributes and benefits of efficiency are assumed to relate to the latent construct of inefficiency perception. The two factors are also determined by measurable variables called items. In figure 5.10 below the components of the SEM used for determining the perception of stakeholders on power distribution is illustrated.
The items of the factors are measured using responses from Likert-scaled questions or variables that determine the factors A and B. (refer to Appendix 5A: Questions 5 and 12)

Usually with SEM an exploratory analysis is first executed which randomly conducts a factor analysis on the constructs. The output of the exploratory analysis indicates how all the constructs may be relating to the latent construct without classifying the intended factors. It normally confirms the possible factor classes that load on to the latent construct. A confirmatory factor analysis then follows using the items that satisfactorily load on to the constructs. For validation purposes, various tests are normally conducted on the SEM and include convergent validity, discriminant validity and the fitness tests which are briefly explained below.

Convergent validity is conducted and this is manifested when each item correlates strongly with its intended construct. Thus the items that are indicative of the construct should share a high proportion of variance in common. Convergent validity evaluated by measuring statistics such as the individual item reliability, construct reliability (CR) and average variance extract (AVE). The items should all be correlated with each other to varying degrees and this means that the average inter-item correlation should be in the moderate range. (0.2 to 0.80 is assumed to be moderate range to item-total correlations). Fornell and Larcker (1981)
proposed a three-condition criterion that must hold to be convergent valid. First, all item factor loadings should be significant and exceed 0.5. Also, construct reliabilities should not be less than 0.7. Lastly the AVE by each construct should exceed the variance due to measurement error for the construct (i.e. AVE should exceed 0.5).

If AVE is less than 0.5 then the variance due to measurement error is larger than the variance explained by the construct. A scenario of this kind tells us the validity of the items as well as the construct is questionable (Fornell and Larcker (1981)). A rule of thumb with AVE in excess of 0.5 is proposed for convergent validity according to Hair et al. (2010).

Discriminant validity measures the extent to which a construct is truly distinct from other constructs (Bagozzi, Yi, and Philips, 1991). This implies that a construct should explain better the variance of its own items than the variance of other assessment objectives. Fornell and Larcker (1981) suggest that discriminant validity is established if a construct accounts for more variance in its associated item variables than it shares with other constructs in the same model. The discriminant validity is therefore evaluated by comparing the AVEs with the squared correlations for each of the constructs. The AVE of the construct should thus be higher than the squared correlations between the construct and all the other constructs.

Model fitness of SEM is another way of validating our model. The model fit measures the extent to which the covariance predicted by the model corresponds to the observed covariance in the data. A common approach used for model performance is the model convergence which suggests whether the model converged within the limited iterations or not (within 500 iteration in our study). The model goodness of fit approach which is evaluated using the root mean squared error of approximation (RMSEA), the comparative fit index (CFI) and the Tucker-Lewis Index (TLI).

With adequate elucidation of the methods and approaches employed, the next section describes the type of data, their sources and collection procedure used.

**5.5.2 Sampling and Data Collection Methods**
For the quantitative survey, the study administered questionnaires to all stakeholder types in the electricity industry. The response rate was 57% for 100 questionnaires distributed. The questionnaires were disseminated to residential consumers, commercial consumers, industrial consumers and experts/consumers using various approaches. Survey Monkey was used for the design and electronic dissemination of survey questionnaires. A portion of the
questionnaires were delivered manually by post. Since the primary focus of the quantitative analyses was to give direction or guidelines to the details of the in-depth interviews in the qualitative analysis, the sample size of 57 used was fit for purpose. The area covered by the survey falls in the jurisdiction of Electricity Company of Ghana (ECG) with its operations in the Southern Sector of Ghana and covering cities including Accra, Kumasi, Cape Coast, Koforidua and Takoradi. Most of the experts and staff were located in the Accra and Kumasi where the Utility has its Strategic Business Units and a Head Office. The questionnaires found in Appendix 5B covered the following areas as:

- Consumer and expert knowledge of the industry or market or reforms
- Consumer behaviour or reaction in an inefficient distribution system
- Consumer and expert perception on management of EDC
- Consumer and expert views on electricity regulation
- Consumers and experts views on political interference of the electricity distribution system
- Consumers and experts opinion on the proposed privatisation or concession arrangement of the EDC.

The survey data from survey monkey was imported into SPSS and that of the manually filled questionnaires inputted into same software.

Analysis was then done subsequent to merging the responses from the two data collection platforms. Responses were plotted in graphs and discussed accordingly. Trends and clear consumer behaviour patterns were discovered and discussed in the context of understanding why these trends and patterns exist. The opinions of the stakeholders in the questionnaire were identified analysed and incorporated in the qualitative analysis section.

In the qualitative survey, 20 stakeholders (detailed in Appendix 5) consisting of experts, regulators, civil society groups, consumers, management and staff of ECG were interviewed on a face-face basis. Over 40 commentaries from articles in newspapers, video interviews of key stakeholders who were not captured in the face to face session form part of the data pool. Secondary sources of data including commentaries and interviews from regulatory bodies, Management ECG, Operational Staff of ECG, experts, multilateral and donor agencies like the
World Bank, USAID and AfDB enriched the data pool. These information were coded in Nvivo programme and analysed using a thematic approach. From theory and literature, certain themes were developed before coding and that was a good place to commence the thematic approach adopted. These themes or categories were refined and enriched as coding progressed, following an inductive category development process. To clarify, themes were split, combined, deleted, and added as coding progresses.

The stakeholder matrix below gives details of the different types of change agents that were included and interacted with in the study.

**Figure 5.11: Electricity Distribution Sector Stakeholder-List and Data Collection Methods.**

- **Green coded:** Questionnaire
- **Blue coded:** Face-to-face interview
- **Purple coded:** Secondary data sources (News articles, online video and audio recordings)

* Two colour codes on one stakeholder indicate two data collection methods were used.

The figure above shows the stakeholders in the power distribution sector. There are different levels of interactions within this network of stakeholders with different interests and incentives, already explained in the section that gives the background to the electricity supply
sector of Ghana. There are obvious dependencies based on their roles and that culminate in a deeper understanding of the inefficiency problem outlined in the results section following.

5.6 Results, Analyses and Diagnosis
In this section, the focus is to discuss the results in two folds. The outputs of the surveys and interviews are discussed. In the first part, the results of the quantitative part is presented and analysed. It is then followed with the qualitative analyses where thematic themes developed from NVivo are thoroughly discussed.

The quantitative part commences with a validation exercise using the SEM as discussed earlier in the chapter in order to validate the type of research instruments used. Two elements introduced in our questionnaire accounts for the effect of political power and influence of powerful people on how inefficiency is perceived in the electricity distribution system of Ghana. The relationships of these factors as well as the high tariff effect factors are regressed on the inefficiency perception of the survey respondents in this same section. By doing so, insights on how the perception of inefficiency is affected by their view on the existence of Political Factors and dominance/influential agent factors could be discussed. The same is done on how high tariffs affect the perception of inefficiency in the electricity distribution system.

After the quantitative analyses, an investigation is carried out on the qualitative data from the in-depth interviews where a deeper appreciation of the challenges as well as possible mitigation strategies or actions are analysed. This section therefore seeks to understand the opinions and reactions of consumers and stakeholders in an inefficient distribution system. This task is executed while being guided on what the problems are and how the problems may be eliminated or managed from the responses as well as the other sources of data used.

5.6.1 Quantitative Results and Analyses
In this part of the study, quantitative results are presented and analysed accordingly. It commences with the validation of the research instrument (questionnaire) and then followed by the analyses of the responses from the questionnaire in order to capture emerging issues, trends and potentials of the various aspects of the inefficiency problem being investigated.

5.6.1.1 Validation of Survey Questionnaire and Responses
Using the items listed in Table 5.2, an exploratory test was conducted with the output shown in figure 5.12. The essence of an explorative test is to allow the data to determine possible constructs from a range of items under review. Three constructs, F1*, F2*, and F3* are generated with considerable factor loadings or correlations. Although most of the items have relatively high factor loadings, a few items have factor loadings below a recommended threshold of 0.4. See appendix 5A for factor loadings and statistics results of exploratory tests.

Table 5.2: Items and Constructs Used in the Exploratory and Confirmatory Analyses

<table>
<thead>
<tr>
<th>Attributes of an inefficient Distribution Sector</th>
<th>Constructs</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Voltage is a major cause of inefficiency</td>
<td>AIDS1</td>
</tr>
<tr>
<td>Inadequate supply of power is a major cause of inefficiency</td>
<td>AIDS2</td>
</tr>
<tr>
<td>Irregular Meter reading is a major cause of inefficiency</td>
<td>AIDS3</td>
</tr>
<tr>
<td>Heavy electricity bills is a major cause of inefficiency</td>
<td>AIDS4</td>
</tr>
<tr>
<td>Unfenced transformers is a major cause of inefficiency</td>
<td>AIDS5</td>
</tr>
<tr>
<td>Defective connections is a major cause of inefficiency</td>
<td>AIDS6</td>
</tr>
<tr>
<td>Unusual power cut is a major cause of inefficiency</td>
<td>AIDS7</td>
</tr>
<tr>
<td>Improper working of transformers is a major cause of inefficiency</td>
<td>AIDS8</td>
</tr>
<tr>
<td>Loose connection in the main wire is a major cause of inefficiency</td>
<td>AIDS9</td>
</tr>
<tr>
<td>Poor customer service by staff is a major cause of inefficiency</td>
<td>AIDS10</td>
</tr>
<tr>
<td>Illegal connections by bad customers is a major cause of inefficiency</td>
<td>AIDS11</td>
</tr>
<tr>
<td>Non-payment of electricity bills is a major cause of inefficiency</td>
<td>AIDS12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Benefit of an Efficient Distribution Sector</th>
<th>Constructs</th>
</tr>
</thead>
<tbody>
<tr>
<td>One of the benefits of an efficient distribution sector is lower cost of power to consumers</td>
<td>AEDS1</td>
</tr>
<tr>
<td>One of the benefits of an efficient distribution sector is reliable energy source to the industrial and commercial sectors</td>
<td>AEDS2</td>
</tr>
<tr>
<td>One of the benefits of an efficient distribution sector is more financial stability of Private Power Producers or Power Producers in general</td>
<td>AEDS3</td>
</tr>
<tr>
<td>One of the benefits of an efficient distribution sector is more financial stability of Electricity Distribution Companies</td>
<td>AEDS4</td>
</tr>
<tr>
<td>One of the benefits of an efficient distribution sector is less corruption</td>
<td>AEDS5</td>
</tr>
<tr>
<td>One of the benefits of an efficient distribution sector is less power theft</td>
<td>AEDS6</td>
</tr>
</tbody>
</table>
Figure 5.12: Exploratory Analysis Output

Figure 5.13: Confirmatory Factor Analysis Output
Subsequent to the exploratory analysis, a confirmatory factor analysis using factors meeting the 0.4 loading threshold is conducted. The output of the test can be seen figure 5.13 and a complementary path diagram seen below in figure 5.14

**Figure 5.14: A Path Diagram Illustrating the Factor Correlations of the Standardised Model**

![Path Diagram]

**Table 5.3: Goodness of Fit of Model**

<table>
<thead>
<tr>
<th>Model fit Indices</th>
<th>X2/df</th>
<th>CF</th>
<th>NFI</th>
<th>SRMSR</th>
<th>RMSEA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended Threshold</td>
<td>≤3</td>
<td>≥0.9</td>
<td>≥0.9</td>
<td>≤0.08</td>
<td>≤0.05</td>
</tr>
<tr>
<td>Observed</td>
<td>1.32</td>
<td>0.90</td>
<td>0.91</td>
<td>0.074</td>
<td>0.076</td>
</tr>
<tr>
<td>Comment</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

The model fit measures the extent to which the covariance predicted by the model corresponds to the observed covariance in the measurement data. The most commonly used SEM model performance indicators are the root mean squared error of approximation (RMSEA), the comparative fit index (CFI; Bentler, 1990) and the standardised root mean squared residual (SRMSR). Hu and Bentler (1998) have suggested a set of model-fit cut-offs for these indices (SRMSR≤.08, RMSEA≤.05, and CFI/TLI ≥.95).

---

RMSEA (root mean squared error of approximation) assesses the goodness of the approximation of the model rather than its correctness; NFI (normed fit index) compares the chi square of the empirical model with the chi square statistics of the null model; and CFI (comparative fit index) takes the same approach as the NFI but is adjusted by the degrees of freedom.
According to the results in Table 5.3, the SEM shows a good fit for the efficiency attribute and efficiency benefit as two latent constructs. All of the goodness-of-fit indicators (Table 5.3 –CFI = .90 and NFI=.91 – satisfy the threshold of .90, the standard deemed important for model fit. However, the root mean square of approximation (RMSEA) = 0.08, approaching the required threshold model of 0.5 but not satisfactory. Hu and Bentler (1999) recommended that assessments of SEM model fit should be based on a joint evaluation of several fit indices. In this case apart from the RMSEA indicator, all the other thresholds are satisfied and fitness for the SEM is satisfactory.

Table 5.4: Convergent Validity Test Results

<table>
<thead>
<tr>
<th></th>
<th>Efficiency Attributes</th>
<th>Efficiency Benefits</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha C</td>
<td>0.8441189</td>
<td>0.4061459</td>
<td>0.6913126</td>
</tr>
<tr>
<td>Composite Reliability</td>
<td>0.8521425</td>
<td>0.4235272</td>
<td>0.6913126</td>
</tr>
<tr>
<td>AVE</td>
<td>0.3478154</td>
<td>0.1274986</td>
<td>0.1779216</td>
</tr>
</tbody>
</table>

Table 5.5: Fornell-Larcker Criterion for Discriminant Validity for Efficiency Attributes and Efficiency Benefit

<table>
<thead>
<tr>
<th></th>
<th>Efficiency attributes (EA)</th>
<th>Efficiency benefits (EB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency attributes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\sqrt{\text{AVE(EA)}}$</td>
<td></td>
</tr>
<tr>
<td>Efficiency attributes</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>Efficiency benefits</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>COR(EA,EB)</td>
<td>$\sqrt{\text{AVE(EB)}}$</td>
</tr>
</tbody>
</table>
|                      | 0.349                       | 0.36                     

Table 5.5 shows the results of the Fornell-Larcker criterion of assessment with the square root of the construct’s average variance extracted (AVE) on the diagonal and the correlations between the constructs in the off-diagonal position. The discriminant validity of the construct is examined by comparing squared root of AVE of the efficiency attributes with the correlation between efficiency attributes and efficiency benefit and verse versa. To establish discriminant validity, the square root of each construct’s AVE must be larger than its correlation with other construct(s). In the Table 5.5 above the two constructs EA and EB, which are conceptually different, are sufficiently empirically different, since the square root of the AVE of EA (0.59) is

9 Fornell and Larcker (1981) criteria, specified as:
- Convergent validity: $\text{CR} \geq 0.7$ and $\text{AVE} > 0.5$
- Discriminant validity: $\sqrt{\text{AVE}} > \text{highest correlation between constructs}$
larger than its correlations with EB. In the same vein, the AVE of EB (0.36) is greater than its correlation with EA which is 0.349.

With convergent validity test, factor loadings, AVE and composite reliability are examined. As can be seen from the results of the confirmatory factor analysis in figure 5.16, Table 5.4 and Table 5.5, all the items load significantly on their purported factors, they load positively and sufficiently high (i.e. above 0.4) on their factors except item AEDS4 which has a factoring of 0.28. The efficiency attribute construct has a good level of composite reliability (more than 0.7) and AVE value of 0.35. This suggests the efficiency attribute construct satisfies the convergent validity criteria. However for the efficiency benefit, the composite reliability was 0.42 with an AVE of 0.13. The results could be improved on with an increased sample size and may not be that the factors of Efficiency Benefits do not show much convergence. However, the entire test proved that the questionnaire used in the consumer survey is valid with constructs or factors that predict the latent variable (perception) on the efficiency of the electricity distribution sector of Ghana.

5.6.1.2 Summary of SEM or Validation Test.

Two different constructs were applied and tested to estimate the perception of the stakeholders on the efficiency of electricity distribution in Ghana. Attributes and benefits of an efficient electricity distribution sector were the two main constructs used to determine the respondents’ perception of electricity distribution efficiency. The results of the test shows that the composite reliability of these constructs are acceptable. The impetus was to be certain that the two constructs theoretically designed can adequately determine or drive the respondents’ perception of the efficiency of power distribution. In short, given that most of the tests conducted are satisfactory, the main of the exercise is achieved and it suggests that the respondents’ survey responses can be relied upon for further analysis in the next section.

5.6.1.3 Consumer Perception and Responses to an Inefficient Electricity Distribution Sector

Subsequent to the validation of the research instrument, the survey responses are then analysed and discussed in this section. These findings are examined in the context of the main themes on which the questionnaire is designed and listed below as:

- Consumer and expert knowledge of the industry or market or reforms
- Consumer behaviour or reaction in an inefficient distribution system
• Consumer and expert perception on management of EDC
• Consumer and expert views on electricity regulation
• Consumers and experts views on political interference of the electricity distribution system
• Consumers and experts opinion on the proposed privatisation or concession arrangement of the EDC.

**Figure 5.15: Consumers Informed of Major Reforms in the Electricity Industry**

Over 90% were confident to say they are aware of the major changes of the industry. They have been saddled with enormous issues in this industry to have not known them. There is a teeming public that is unyielding to the inefficiencies of the electricity sector.

**Figure 5.16: Reforms and Improved Efficiency**
As will prove to be the case by our questionnaire validating results, over 90% do understand the benefits of reforms on the efficiency of distribution companies. Our validation results show that the survey respondents were consistent and appreciated the questions asked. Less than 9% did not acknowledge the effect of reforms on electricity distribution.

Figure 5.17: Customers' Perception on the Level of Efficiency and Reforms

Only 9% accept that the pace of reforms on efficiency is fast. Over 58% believe that it is rather of a low pace while a considerable size of 27% think the results shown out of the reforms embarked on are normal or just expected.

Figure 5.18: What Consumers Do When They Have Problems with the EDC
Nearly 73% report the incident should they have problems with the EDC. A significant number of customers (27%) do not bother reporting at all. They explain by saying it is not cost effective to do so and they will rather engage electricians in their localities to repair the problems. One of the consumers say:

“I will not waste my time to go and queue only for the line to be jumped by VIPs. I will rather pay someone to do it”.

The analyses of this may well mean that the staff could be stretched further should this 27% of customers decide to contact the EDC when they are faced with distribution problems (refer to 5.20). Out of those who report or have reported problems, about 65% admit that the problems get solved but not on time. Nearly 24% concede that the EDC does not solve their problems and this could mean the distribution company never attempts solving the problem at all or is unable to resolve the problems after attempting to do so. 12% of the survey responses suggested being attended to and service delivered on time. Therefore, only about 12% out of the 73% who report cases to the EDC are satisfied with their service delivery. (See figure 5.19 for details)

Figure 5.19: Consumers Who Have Reported Problems to the EDC

Consumers’ responses to hikes in electricity prices.

It is anticipated that customers will respond to price through changing their consumption behaviour or patterns either in the short term or long term. In the same vein, electricity consumers are expected to react to high electricity prices. Our survey reveals that as a result
of the status quo (unreliable power and high cost of power and other factors) a section (22%) of Ghanaian consumers are becoming prosumers i.e. they fully or partially produce and consume their own electricity. That apart, nearly 50% of the respondents indicated that they reduced their energy consumption in response to high tariffs. Over 18% have found investments into more efficient gadgets useful in dealing with high energy prices. By these findings, an agenda to introduce alternative power sources from renewables could thrive. In the same vein, there is a potential to promote efficiency at the demand side. There could be an important stage in the history of the country that was once bedevilled with power crisis but also on the whole has challenged the country and its electricity consumers to think of ways to survive this. Two strands of lessons: first is the change to produce and consume their own energy and second is the attitudinal change towards energy saving.

**Figure 5.20: Consumers’ Reactions to High Tariffs**

<table>
<thead>
<tr>
<th>High tariff response</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changed appliances</td>
<td>18%</td>
</tr>
<tr>
<td>Changed jobs/job type</td>
<td>4%</td>
</tr>
<tr>
<td>Nothing</td>
<td>22%</td>
</tr>
<tr>
<td>Prosumers</td>
<td>50%</td>
</tr>
<tr>
<td>Increased consumption</td>
<td>0%</td>
</tr>
<tr>
<td>Reduced consumption</td>
<td>0%</td>
</tr>
</tbody>
</table>

**Possible Sources of inefficiency of the EDC**

**Figure 5.21: Survey Opinion on the Main Sources of Inefficiency**

<table>
<thead>
<tr>
<th>Perceived possible sources of inefficiency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrupt managerial staff</td>
<td>40%</td>
</tr>
<tr>
<td>Corrupt operational staff</td>
<td>35%</td>
</tr>
<tr>
<td>Financial inefficiency</td>
<td>30%</td>
</tr>
<tr>
<td>Technical constraint</td>
<td>25%</td>
</tr>
<tr>
<td>insufficient transformers</td>
<td>20%</td>
</tr>
<tr>
<td>Insufficient skilled labour</td>
<td>15%</td>
</tr>
</tbody>
</table>
Corrupt managerial practices is perceived by 42% of the survey participants to be a major cause of the EDCs inefficiency. Financial Inefficiency is observed by 37% of the survey respondent to be a major cause of the EDC’s inefficiency.

66% accord political interference in the electricity distribution sector as one of the major causes of the inefficiency of the distribution system. About 57% of the survey respondent perceive that some influential people benefit from the inefficient system.

**Promoters of Efficiency –the right channel**

*Figure 5.22: Most Important Institution That Can Influence EDCs to Be More Efficient*

The Press, Civil Society and Regulators are the three most important organisations that can support EDCs to be more efficient in their business. 42% trust the energy sector regulators to do a good job to enhance the efficiency of the sector. About 22% of the survey believe that the Press could support in promoting efficiency and bringing to the fore issues of inefficiency in the public domain. This is not surprising as of recent times the press, civil societies groups have shown immense interest in reviewing PPAs signed by the distribution company. The results of their actions manifest in initiating discussions around the issue in question and some sort of settlement being accepted or otherwise in the end.

**Privatisation as an option**

Over 90% of the respondent agree that there should be some level of privatisation. Three groups are observed:

- One that uses the term without defining the boundaries.
• One that accepts some arrangements but still supports that ownership be unchanged
• One that further subscribes to an approach that privatisation could be executed with specific guidelines.

Nonetheless, only about 8% still wants the company to be under the stewardship of the existing management. Their justification is that the engineers are equally qualified and so are good managers. The point which is missing and one that can affect the rationality behind their choices is rather debilitating in the sense that, engineers are different from managers. That is not to say engineers cannot be good managers and certainly does not mean that good engineers turn to be good managers. The story unfolds that about 95% of the number of managing directors since inception have been engineers.

The section following will investigate further some of the chosen themes from the survey. This implies that the results above are thoroughly investigated using face to face interviews, commentaries from the press and videos from experts. The triangulation approach is adopted during the interviews to ensure counter-views are captured and equally analysed to bring findings that are more representative of the matters on ground.

5.6.2 Qualitative Diagnostic Results and Analyses (3d thematic analyses)
In this section, the qualitative data obtained from both primary and secondary sources are analysed using a thematic approach aided by the NVivo software. The qualitative data come from interviews with industry professionals, energy experts from academia and civil society groups, development partners’ consultants, management and operational staff of ECG, regulators and the energy ministry. Other secondary sources from video interviews, documentaries, newspaper articles are also included in the data pool for onward qualitative analysis. The survey results were transcribed and a three-D thematic approach employed to understand the causes and some proffered solutions from the different stakeholders in the electricity industry. NVivo is used to capture our interviews as well as the existing commentaries and literature on the subject matter. With about 20 interviews and over 100 commentaries from videos and newspaper articles, the PEA arrived at 6 themes in which the causes of inefficiency in the electricity distribution sector of Ghana are enveloped. In this

---

10 A software that aids in organising, storing and retrieving data in a more efficient way. In both qualitative and mixed method analysis, the NVivo software provides a platform that can categorise qualitative data into themes.
section, an analysis of the conversations around these themes are executed with the motive of bringing out the focal points of the inefficiency problem that could warrant an understanding of the status quo. In figure 5.23, foundations of the problems adding on to inefficiency are bundled up into the themes below.

Figure 5.23: An NVivo Output of a Thematic Analysis of the Sources of Inefficiency in ECG
5.6.2.1 Cultural and Attitudinal Issues

Pascoe and Welsh (2011) suggest that the level of whistleblowing cases increases the detection and conviction rates for corporate crime. They propose legislative provisions and corporate codes of conduct or ethics as the two methods utilized for the purpose of encouraging corporate sector whistleblowing.

The 2006 whistle-blower’s act in Ghana is meant to enable citizens to disclose information about the corrupt or unlawful activities of other people. It offers them protection from victimization linked to such disclosures. However, over a decade of its being enacted, Ghanaians seem reluctant to use this platform to report corruption or illegalities. According to an anti-corruption officer Adam Bani and many other stakeholders being interviewed, the law was passed after Ghana was upset by a series of financial scandals but ten years later, most Ghanaians spoken to appeared unwilling to acquire the whistleblowing habit.

Our attitudes are affected or influenced by the things we are exposed to and what could be collectively called culture. A section of the stakeholders hold the view that Ghanaians are rather less confident to report their neighbours for wrong doing. Others including a manager of ECG said that nature of the Ghanaian is much explained in the details of the guiding principles in our culture. He said:

“But sometimes if you are down there you will not understand it... It is also a societal problem.... I can say 80% is due to our culture. I dare say Ghanaians are trained to be cowards and timid...What do they tell us in our culture? That an elder can never be wrong!”

Ghana, has shown some progress in dealing with corruption to some extent but being ranked 56th out of 168 countries as surveyed by Transparency International in 2016 (from the index of business perceptions of corruption) indicates the high level of efforts expected to make significant changes to the status-quo. Undoubtedly deepening of the incentives to blow the whistle as well as a collective action to be championed by many non-governmental organisation are some of the resolutions to address the short-falls in the act and its needed activation.

Favouritism affects the level of efficiency in the ways of quality of labour, quality of invested capital and finally quality of service delivery. The Ghanaian culture and some West African culture are extensive to the core even though westernisation is gradually eroding the social
and cultural settings that were accorded Africans and Ghanaians. Notwithstanding, With reference to the quantitative data, there are about 70% of the respondents who agree that the staff of ECG are well qualified and can technically discharge their duties. The question of professionalism which is lacking as underscored by the survey data must be coming from the way in which recruitment is made and what happens after recruitment. According to another senior manager of ECG, many people have had to consider relatives over others when it comes to employment and that this practice is not peculiar to the ECG alone or the energy industry—it is a systemic problem which comes from many years of the culture of “helping our own”. In a system where relatives and friends are recruited, it will be difficult to crack the whip when compliance to work ethics are abdicated. It is not surprising therefore that the prevalence of power theft and “illegal connections” has not been addressed as a result of inadequate deterrence even with existing laws and law enforcement agencies. This is explained by the lack of application of laws and their related punitive measures.

During the interviews, it was observed that some people high in authority and people who are influential can abuse and exploit the system. An Engineer at ECG (one who dislikes the state of ECG management) says

“Very prominent chiefs in this country are using electricity free of charge because their subjects will not even let you send them a bill. There are many chiefs and even Kings who comment on inefficiencies of our work yet may have never asked to know how much electricity they consume let alone to pay for it. This is wrong! Not one palace not two, here in Kumasi. You can check for yourself. How then do you go to the man who finds it difficult to buy food and expect him to pay?”

Another customer expressed his opinion on how favouritism undermines even the quality of services to their customers by referring to the customer service desks of ECG in some branches where some customer types have priority just because they are branded very important people (VIP) and are permitted to jump queues for services.

Another feature that characterises the people of Ghana as suggested in many of conversations around factors that drive corruption is the external financial pressure on the working class. The nature of the extended family network which is very different from most western culture creates a certain expectation of support from families and friends from
working class. Workers have more than just their immediate family to cater for and so are hard-pressed by the situation to give in to corrupt practices.

The above socio-cultural attributes are very important concerns that management will have to appreciate before driving any organisational change. These attributes may be considerable in defining the type of labour force or customers the organisation is operating with. By this, the intention is not to describe the situation as unvarying but it is also important to note the level of efforts required to drive a cultural change. Nonetheless, some companies now and in the past have had to scrap and replace their organisational culture before they could perform competitively and efficiently. According to Yoram and Main (1999), this kind of alteration occurred in the history of IBM, Xerox and Perot Systems. This requires planning over years for the kind of culture fit for the kind of business they do. There is an important aspect of linking the needed culture to the values of the company. In the case of ECG, there is an irony of what their values and organisational culture propose and this view is shared strongly from the survey feed-back.

As asserted by Dartey-Baah and Amoako (2011) some managers in African organisations, particularly in Ghana, perhaps because of societal norms and expectations, place emphases on bureaucratic practices with total reliance on rules and regulations that employees obey without questioning or proffering constructive criticisms. Ghanaian civil and public sectors are characterised by such a culture. As a results employees turn to work as robots and merely follow rules and regulations without taking initiatives of their own. According to Kippis (1976), such mechanistic approach separates workers from both their jobs and the organisations. At this point workers only enjoy achieving personal needs instead of those of the whole organisation while managers, engaged in these bureaucratic practices, are often more interested in exercising absolute power over their employees.

Jaeger and Kanungo (1990) suggest that, it is important for Ghanaian managers to note that employees can be motivated to work without being perceived as driven mainly by the economic benefits that are to be gained because of the work they do. However, this requires an appreciation of their needs and strategies that will boost the full commitment of workers in pursuing organisational objectives.
“Go to some branches like Kasoa where you will see that some customers are more human that others and have the right to jump the line for fast services while we those considered less important stay in the lines for ages before we get attended to”

A consumer in the Kumasi Metropolis showed her grief concerning the abuse of ECG’s monopoly and how poor their quality of service is. She said:

“When we have problems we go there and they say; you go we will come and check... But you will be there for ages and they won’t come. Look, to be honest, if electricity was like a phone sim card... I will have thrown that into the ocean by now”

5.6.2.2 Financial Mismanagement

“We need to pay our bills ... if we do not pay our bills, how can ECG pay its generators and the generators pay its suppliers and the suppliers pay the banks. Our electricity industry is waiting to collapse before or after the collapse of our banks. Where do we go from there? No production and so we are in for economic crisis if we do nothing about that. Financial management and efficiency are major challenges. “By Kwaku Awotwi (Former CEO of Volta River Authority)

Funding is an indispensable requirement for most part of the operations of EDCs. As a result, any inefficiencies whether technical or commercial is reflected in financial inefficiency. However, in this context we try to separate financial implications as a consequence of other operations from the real financial inefficiency arising from an improper funding and investment. By this we are able to distinguish between financial consequences due to corrupt practices from financial consequences due to a misapplication of a financial strategy, poor negotiation of core contracts and/or causing financial loss to the company.

The issues surrounding high cost of electricity and its selling prices have contributed to some of the illegalities and non-payment of bills. A perfect example will be the heavy levies or bills imposed on consumers as a result of bad contract negotiations that has little value for money. The high cost in the value chain before the distribution point becomes a pass-through if the negotiating or consortium is unable to reach a reasonable off-taker price of generated power. The high prices of electricity against low income levels could influence some consumers to resort to illicit behaviour (power theft) conferred earlier.
With reference to some commentaries in the newspapers, most of the PPAs signed by the ECG need to be reviewed as other stakeholders including some staff of the energy commission believe that the state was short-changed in most of the agreements. They highlight the role ECG plays in the negotiation and have varied perception on the complexity of the role and the related competence in this area. Top managers have expressed their opinion on the need to involve all generators and other energy experts when reviewing off-taker agreements. This suggests that the company needs to match up the role with the required competence or may have to outsource some consultants in the future. Defence from the ECG and the erstwhile Ministry of Power indicate that the urgency of the increasing generation during the long period of power outages (Dumsor) makes the negotiation at the time justifiable. Renegotiation of the PPAs has been proposed by some experts. ACEP (African Centre for Energy Policy), one of the stakeholders and civil societies opined that there could be some gains if these PPAs are reviewed in order to reduce the cost of production and distribution of power.

The financial efficiency ratios of ECG indicate instability in the management of its debt. From the financial analyses below, there is a consistent decline in ECG’s ability to settle liabilities in both the short and medium term. Penalties and charges from not honouring its contractual obligations can only increase their debt profile. ECG is highly geared and Mr Kwaku Awotwi highlighted the rippling effect of the financial mismanagement of ECG.

**Figure 5.24: ECG Financial Performance from 2008 to 2013Q2**

<table>
<thead>
<tr>
<th>Operating Ratio</th>
<th>Potential Target</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013Q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Ratio %</td>
<td>&lt;80</td>
<td>81</td>
<td>82</td>
<td>87</td>
<td>90</td>
<td>91</td>
<td>94</td>
</tr>
<tr>
<td>Rate of Return (pre-tax) on Net Fixed Assets %</td>
<td>&gt;5</td>
<td>2.2</td>
<td>1.6</td>
<td>2.8</td>
<td>-1.6</td>
<td>-2.5</td>
<td>-1.5</td>
</tr>
<tr>
<td>Return on Equity %</td>
<td>&gt;8</td>
<td>-5.3</td>
<td>-1.8</td>
<td>0.4</td>
<td>-0.9</td>
<td>-4.7</td>
<td>-2.1</td>
</tr>
<tr>
<td>Interest Coverage</td>
<td>&gt;1.5</td>
<td>1.9</td>
<td>1.5</td>
<td>8.2</td>
<td>-2.0</td>
<td>-5.9</td>
<td>-4.6</td>
</tr>
<tr>
<td>Profit Margin %</td>
<td>&gt;5</td>
<td>-8.6</td>
<td>-3.4</td>
<td>0.6</td>
<td>-1.9</td>
<td>-9.5</td>
<td>-7.1</td>
</tr>
<tr>
<td>Current ratio</td>
<td>&gt;1.5</td>
<td>1.8</td>
<td>1.7</td>
<td>1.2</td>
<td>0.9</td>
<td>0.8</td>
<td>1.1</td>
</tr>
<tr>
<td>Quick ratio</td>
<td>&gt;1.1</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
<td>0.9</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Debt to total assets %</td>
<td>40-60</td>
<td>20.2</td>
<td>26.4</td>
<td>28.8</td>
<td>20.9</td>
<td>23.1</td>
<td>24.8</td>
</tr>
<tr>
<td>Debt to equity %</td>
<td>0.7-1.5</td>
<td>8.3</td>
<td>16.4</td>
<td>9.0</td>
<td>7.5</td>
<td>9.9</td>
<td>11.0</td>
</tr>
<tr>
<td>Long term debt to total capitalisation %</td>
<td>40-60%</td>
<td>6.9</td>
<td>12.8</td>
<td>6.7</td>
<td>5.4</td>
<td>7.0</td>
<td>7.6</td>
</tr>
<tr>
<td>Average days in accounts receivables</td>
<td>&lt;60</td>
<td>155</td>
<td>187</td>
<td>210</td>
<td>151</td>
<td>147</td>
<td>184</td>
</tr>
<tr>
<td>Average days in accounts payables</td>
<td>&lt;60</td>
<td>177</td>
<td>229</td>
<td>245</td>
<td>226</td>
<td>235</td>
<td>212</td>
</tr>
</tbody>
</table>

Source: International Financial Corporation (2014)

The figure above validates the weakening financial position of the company and the USAID is justified for referring to it as such in their due diligence report published in 2014. It states
“ECG’s financial position is extremely weak. ECG is currently loss making, reporting negative net pre- and post-tax profit for the last two years (2011 and 2012) and the first half of 2013. For the previous three years ECG reported positive pre-tax net profit, however, if account is taken for its practice to include deferred taxation in the Income Statement it has reported negative net (post-tax) profit over practically all of the period considered from 2008.”

5.6.2.3 Technical Inadequacies

This aspect of inefficiency could be a major contributor of high cost inefficiency given the related technical and allocative implications on input quality, technology quality as well managerial or supervisory quality. In our survey, the technical expertise of the employees of ECG was not in doubt even though they speak highly of only the engineering workforce without considering other technical participants relevant to ECG’s operations. Both regulators and consumers take pride in the expertise of their Engineers even counting them as the best in Africa. With this preamble, one may begin to wonder and may conclude that given all materials ECG should face little technical inefficiency. That may be a bit misleading as it is revealing that systems to check and monitor the contracts of these supposedly quality engineers are impaired by some external political and non-political factors. Below is Dr Asirifi’s comment on the awarding of contracts in ECG and many public owned institutions.

“It is the politicians who are supposed to change the status quo... But because they are benefitting from it ...where is their will power to do that... Why should engineering council up to date after fifteen years of defending the bill in parliament, why is it not fully operational? Because it is the politicians controlling the engineering practice in Ghana. All government contracts are handled by the politicians. So let me ask you a question... In Ghana, have you ever heard that a work has been scheduled down and the engineer who supervised the work has ever been mentioned?”

A source of technical inefficiency from the interviews is the unmet expectations of contractors by management and vice versa. The management of ECG having taken a strategic decision to outsource some aspect of their operations expect a certain level of delivery from these contractors. Our investigations show that management is not satisfied with their level of delivery and have over the period found ways of assisting them to improve. However, they believe it is a systemic problem that requires a national intervention in our education system.
The sub-contractors on the other hand have directed their inability to meet the standards to management’s inability to offer them adequate materials to do the job. One of the contractors (member of ECG contractors association) who wants to remain anonymous said:

“You ask for a 50 meter length of a specific wire and other materials but they do valuation and arrive at 40 meters of wire, and you know you cannot do the work well with that which is provided….. You still have to manage to do a job that is not up to the standard required. We need to be in jobs and provide for our families so we just do with what we have.”

5.6.2.4 Regulatory and Supervisory Inadequacies

Transmission, distribution and generation (wholesale) are all licensed activities in Ghana. A public utility can apply for a licence to distribute and sell electricity subject to the EC’s conditions. The rates and charges for its services must also be approved by the PURC, as a condition to the grant of the licence. When granting the licence, the EC must consider the demand and supply of electricity in the designated area, the capability to interconnect distribution facilities or installations with transmission systems in the designated area and the ability to fulfil the duty to provide electricity in the designated area. The licensee must make diagrams and maps of its electricity facilities authorized by the EC available for public inspection at its offices.

With the exception of the transmission licence, of which only one may be granted, the EC may grant more than one of all the other categories of licence. To date, the EC has granted only three distribution licences to ECG, NEDCo and the Enclave Power Company. Each of these distribution companies has a separate area of operation in which they effectively operate as monopolies, although as indicated, there is no legal bar to the grant of one or more licences for electricity distribution in all or parts of their areas of operation.

During our deliberations with the Energy Commission, they indicated that they were open to the idea of granting up to three more distribution licences, creating up to six distribution utilities in all. However, the regulators and some of the stakeholders doubt the financial viability in terms of economy of scales when 6 utility companies are carved out of the nation. Processing applications for new service, minimum requirement in terms of reliability of electricity supply and requirements for metering installations are some of the parameters involved in the regulation of task under L.I. 1935 4 as issued in 2008.
Payments, dispute resolution, notification of rights of customers and provision of information also fall under the ambit of the EC. These above aspects of regulation are in tandem with international standards and are supposed to provide a robust framework for regulating activities of the distribution sector.

The review of the distribution codes and performance standards indicate that the current regulations are in line with other international standards and provide solid technical framework for the development of the distribution sector’s activities.

In general, these regulations follow international best practices. However, it is quite clear that not all provisions stated in them are actually being applied. For example, based on the analysis undertaken, the penalties applicable in case the duration and frequency of interruptions to customers exceed the thresholds set in the Electricity Supply and Distribution (standards of Performance) Regulations are not being applied. However, there are impediments that impair the discharge of such regulatory duties.

According to the head of Technical Regulation at the Energy Commission, the challenges are compounded because the ECG has both distribution and retailing licenses which currently overwhelms the company. On one hand, the economies of scale and the structure of the distribution sector hinder introduction of competition in this very sector. On the other hand, the other available option which is to horizontally unbundle the sector where regions could be created and each region open for competitive tendering by capable investors seem to be challenged economically. This is explained in the bias of customer density and the lack of economies of scale at this level which is a disincentive to most investors. As stated by one of the senior managers of ECG:

“They all want the juicy part of the business and that cannot be... who should go for the non-lucrative regions?”

One way to reduce the burden of ECG is to further unbundle the electricity sector by introducing a competitive retailing end. The issue of commercial losses could be reduced as competition will encourage companies to embark on productive revenue collection and good customer services especially at the commercial and residential segments of the market. A senior officer in charge of technical regulation is quoted as saying:
“...the fact that the company is not financially liquid means that financial risk is high but if you can commercialise the tail end (retail end) of the value chain the liquidity issue could be solved. So it is either the whole company is privatised or the retail end should be commercialised and privatised.”

Our deliberation hinged also on the independence of the electricity regulators and how they could discharge their duties without fear and panic. It was revealed that the independence of the regulators are curtailed in many ways. First, government is the sole owner and any sanctions meted out to these companies do not materialise. Also, being that the ruling government chooses the executive secretary or commissioner of the electricity regulatory bodies, they are compromised in their line of duties. As a very senior regulator puts it

“Most of the rots turn not to be inbuilt but externally sourced. You are forced to work and to do what you are told to do what the powers want not what is right in your judgement”.

5.6.2.5 Political Interference

“We have used politics to retrogress instead of progress...Look! If you are politically appointed as the managing director... when another party comes into power, whether you are performing well or not... you will be removed... this is not good for the company. The company should appoint its own directors.”

The above relates a major part of corporate governance and the polarisation of the top management positions are bound to cause problems if the company stands the chance of being led by a new Managing Director every four Years. This opinion is generally shared by some of the staff of ECG, some Civil Society Groups and some consumers.

The one decision or change at the top trickles down to various aspects of the operations from changing contractors to changing roles and tasks of the work force.

A Senior Manager of ECG at the Ashanti Region Head Office could not have expressed that more vividly as he lamented:

“Then we come to the political atmosphere... the managing director is appointed by the government to pursue government interest. And because of that...it trickles down... the managers also cherry pick their people not on merit... but people who will help him or her build his kingdom.”
The issue of favouritism remains in the network where competence is sacrificed and consequently the company becomes more inefficient and impairing quality of service delivery. The quality of human capital goes beyond the technical skills of the employees and that is why recruiters investigate how prospective employees can manage other aspects of the job. Driving change in organisations is possible but depends on what workforce we are dealing with. When politicians and external forces interfere with recruitment processes, the possibility of getting inadequate service delivery from the employed is almost predictable. They are likely to distort the desired direction of the company and even the organisational culture.

Government interference in the business of ECG according to some of the survey responses is a major cause of ECG’s financial inefficiency as well as some aspect of technical inefficiency. As the Deputy General Secretary of the Public Utilities Workers Union Mr. Michael Nyantakyi posits

“"The real problem of the power distributor is political interference. It does this in two main ways – taking power for the Ministries and public offices without paying and also resisting ECG's calls for tariff review. These two main factors have left ECG on its knees with huge debts”.

Our analyses made on ECG reveals that government’s debt to ECG constitutes over 60% (US$500 million) of the company’s total debt. PUWU, ACEP and many policy advisors have insisted that the financial weakness of the company could be improved on if government is reliable in redeeming its debt to ECG. Governments by this action is affecting the revenue streams of the company making it illiquid and unable to meet its operational costs as well as its obligations with its creditors which comes with high penal charges.

Another issue is with the payment for the actual cost of electricity which is a debatable one which stakeholders may have to come to a settlement with sooner or later. There is question of which should come first? Should consumers accept high prices of electricity to receive a better quality of service or the company should find its own investments to improve on quality and then charge consumers a cost-recovery based tariff thereafter? The social contract between the consumers and the ruling government limits the latter’s political will to pursue the first option while the current economic conditions continue to make it even more difficult to negotiate the first option. Therefore, government will seek ad hoc measures such as
opposing tariff increases and subsidising electricity tariffs just before national elections even though a raise in tariffs might have been agreed earlier. That apart, approval for tariff increment is acknowledged to be problematic. Generally in developing countries, there is a low political will to let consumers pay for the cost-recovery tariff. The values and externalities of electricity supply to citizens account for its high demand. As a result, it can give electricity considerable political salience, reflected in electoral promises and actions by politicians to certain groups with the anticipation that the groups will be coerced to support them. (Scott and Seth, 2013) Aside the fact that price of electricity in Ghana and the West African region (average of 17cents against an average of between 4cents and 6cents in East Asia) is already relatively high and could impose more economic hardships on consumers, the ruling governments are unwilling to permit tariff increases during their regimes and even so around election periods.

5.6.2.6 Managerial Inadequacies

Discussions around corporate governance of most public owned institutions have come to the fore. Particularly in the case of quality of service delivery, that is a finality of the efforts of the actors in the institutions. There is a great disparity between the governance efforts of private companies and that of publicly owned companies. As in the case of ECG, most publicly owned institutions are tagged weak in governance. Governance refers to the art of steering societies and organisations. According to the Ottawa Institute on Governance, it is the process by which stakeholders articulate their interests with their inputs absorbed, decisions taken and implemented while these decision makers are accountable for the consequences of their actions. Thus good governance in electricity utilities could be described as the range of political, organisational and administrative processes through which communities (stake holders) articulate their interests and input, make decisions that are implemented with decision makers held accountable in the distribution and management of electricity resources in order to deliver the best quality of services.

It is evidenced in many cases how failure to adhere to good corporate governance could lead to dire consequences which may stifle the growth and sustainability of these organisations. A specific relationship can be seen in how cost of distribution is likely to increase when institutions do not adhere to safety requirements as well as not conforming to the required standard of quality of services provided.
By the survey results, it is becoming established that ECG’s inefficiencies could be coming from management’s failure to address good governance issues in the aspects below:

- Institutional and regulatory structures
- Tender/bid processes and evaluation criteria
- Power purchase agreements and associated tariff structures
- Financing Strategies and its implications

5.6.2.6 Power Theft

There are many factors that encourage people to steal electricity. Socio-economic factors influence people to a great extent in stealing electricity. An interesting but also common view by many people is that, it is dishonest to steal something from their neighbour but not from the state or public owned utility company. Williams and Ghanadan (2006) argue that the above consumer reaction is due to the lack of social legitimacy of reforms which encourages stealing of electricity. By the survey, it admitted that high electricity prices, growing unemployment, poor economy and corrupt employees of utility companies work against policies to curb power theft. Irregular readings of meters by staff may well contribute to over invoicing or under invoicing. However, there are situations where staff have connived with consumers to bill them with a lower meter reading. In Ghana, during electoral campaigns some politicians give out metres as tokens or “bribes”. According to one of the senior managers of ECG, these are done without the knowledge of the company and so these meters are not identifiable on the database. However, they are connected to the grid anyway and the consumer normally will consume electricity for free until it is brought to the notice of the distribution company. Politicians may influence illegal consumption by supporting the views that electricity is a public good and should not be that expensive. During opposition or in power they promise them lower tariffs but are unable to do so as they suffer protest from the management of the company and other stakeholders.

Prepaid meters are considered the solution for power theft but it is only conclusive if the meters can determine or detect their bypass as well as any illegalities to steal power. They may be right in averting the irregular and wrong reading by employees but may not be able to detect if a consumer is tempering with the device or not. The ECG for example has had to recheck places with prepaid meters over and over again since they suspect illegal connections
in these places. It emerged that a number of consumers were investigated and charged with illegalities even in areas where the middle-class is predominant. Power theft may seem simple to tackle but could require a more sophisticated and robust approach with punitive measures for even the least of all crimes related to power theft.

5.6.2.7 Summary of Qualitative Analyses

The focus of the qualitative analyses was to understand the sources of political economy in the power sector of Ghana and its related repercussion on the distribution of electricity. From the thematic analyses, key themes emerged covering technical, sociocultural, political and financial factors that contribute to the political economy openings in the distribution industry. It is clear within the analysis, that there are incentives for rent seeking which overcomes the moral fibre of the Ghanaian society. To the extent that, some institutions meant to shape good behaviour are also involved in illegitimate practices to advance their personal interests can only tell the gravity of the problem. However, it is possible to reshape the stakeholder interest and potential rent seeking behaviour by considering strategic intervention and policies. In the section following, the possible pathways are discussed to offer relevant stakeholders, management of EDCs and policy makers recommended actions to enhance efficiency in the distribution sector.

5.7. Possible Intervention and Policy Issues

The study gathered options and solutions to some of the causes of inefficiency in the distribution system. The PEA relied on both the causes and solutions suggested by the stakeholders to understand the status quo except to say that the triangulation technique was applied during the interactions with some experts and stakeholders to see their opinion on these proffered solutions. Additionally, it is realised that some of the problems were within the control of the management of the EDC and others were not. An internal and external classification of the interventions was therefore the approach employed to bring clarity to this section of the analysis.

5.7.1 Internal Interventions

This section is intended to discuss the factors or causes that can be resolved within the walls of ECG. This requires more efforts from the management of the company and operational staff. Firstly, it is assumed that the actions and inactions of these stakeholders resulted in those problems which the next section attempts to make available. The perception of the
consumers regarding the corporate entity is not commendable given the statistics and the deliberations in the previous sections. The interventions following therefore requires a committed internal cleansing and reshaping of the expectations and thinking of the corporate entity as a whole.

5.7.1.1 Restructuring of Corporate Governance Terms

The governance structure of the company after the entire survey seems to be lacking robustness. The company culture must be streamlined by the governance structure for desired outcomes. Since the corporate culture has an external influence and maybe quite difficult to build, it is not unsurmountable. At least there is evidence of corporates that have very good governance structure that has impacted on their organisational culture. Professionalism and ethics are at its best in some of the Ghanaian owned business that choose from the human resource markets as the ECG. An engineer who remains anonymous in this case, said to his one of his colleagues during a site visit:

“You know you and I are thieves, you taught me how to steal and you were also taught to steal by someone”

This may have been said in a playful way and that may mean there is no truth to it but the blatant acceptance of such a sensitive perception in the public domain resounded the allegations of corruption peddled against ECG workers. There are factions with “Godfathers” in which the existing monitoring system for punishing unethical and unprofessional behaviour of staff is compromised. It is therefore important promote a system that works and discourage nepotism in such an important industry.

According to Wembley and Werner (2008), there seems to be is a gap between the existence of explicit ethical values and principles, often expressed in the form of a code, and the organisational attitudes and behaviour. They suggests that ineffective ethics programmes and deficiencies in corporate culture could be the underlying reasons for the presupposition. This means that ECG should not just design codes and conducts and expect good governance to prevail. The ethical values requires a well-designed ethics policies, sustained ethical leadership and incorporation of ethics in organisational processes and strategy as part of organisational culture at all levels of the company.

5.7.1.2 Streamlining Required Skill Sets for Subcontractors
The subcontractors are contracted to represent ECG on the field and as such must show the ideals that is expected of them. Any subcontractor who falls short of such quality in the discharge of their duties should be investigated and the right penalty meted sourcing of these subcontractors should be devoid of nepotism so that the system can get the best from the pool of electrical technicians in the market. On the external arrangements, the ECG and most of the power industry players should help sponsor students from Technical Institutes and Technical Universities to learn the trade from decent subcontractors so that they will be enriching their recruitment pool. The association of subcontractors of ECG have major concerns that need to be addressed by the management of ECG. A consensus must be reached and service level agreements in the contracts adhered to. It is expected that if the governance structure of ECG is improved, the conduct of subcontractors, perceived by some stakeholders to be substandard, could improve significantly.

5.7.1.3 Incentivising the Base of the Organisation

A reduction in the conspicuous and disproportionate employee remuneration across the organisational structure should be taking seriously. Some of the management have not been impressed by the existing structure and continue to make comparison with the structure in most developed economies. Some believe the misconducts of some of the operational staff is due to the discriminatory salary and remuneration structure.

One of the managers of ECG who not impressed with the skewness of working incentives towards top management shows that in the quote below:

“Justify why I require three toilet rolls and the man down there should be okay with just one. Simply, it is a bias against the people at the base.”

The technicians believe that there should be enough risk allowances paid to compensate for the kind of job they do. They conceive their task as very dangerous and have complained that working conditions should improve. For example they is a common opinion within the field workers that health and safety needs to be improved upon.
5.7.1.4 Independent and Private Recruitment System

Employment and recruitment to be outsourced to independent and private companies to avoid or reduce government or political interference. As was revealed in our surveys, nepotism exists in the Company because of the existing unofficial recruitment system. Most people employed are based on their relations with either management or political and external influential personalities. It would be easy to conclude that the best staff may not be recruited for the post in question. Also, even the number of required staff may be exceeded since once a recruitment request comes from a higher authority, management are coerced to employ at times when they do not need to. An independent recruitment system could curtail some of the shortcomings of the existing system of recruitment.

5.7.1.5 Boosting of Bidding and Contract Processes

The ECG operates within their own procurement arrangements but also subject to the Procurement Laws of Ghana. In the survey, matters relating to quality of procured services were brought to the fore. Managers and Consumers observed the deterioration of the quality of procured items like meters, feeders, transformers and even wires over a short period of time. They juxtapose that with the same in the past and conclude that the ECG is short-changed in its procurement. That contractors are allowed to complete works that are not up to standard and leave with impunity when, to start with, there are guarantees entered into at the beginning of the contracts. From Bid Guarantees, Performance Bonds, Advanced Payment Guarantees and Bank Guarantees in general are required to secure these contracts from the tendering stage to closure of procurement. Thus to enforce quality is to activate or call on the guarantees when it is established that job execution has not met the agreed scope of works and quality. Since it is clear that the institutions of the procurement process is not in contention then, the issue of enforcement needs to be addressed and departments and persons that do not discharge their duties creditably should be investigated and sanctioned accordingly. Competitive bidding may not be that competitive as some stakeholders and some staff have disclosed that there is interference at some stages of the procurement process. They have made claims of some tenderers being given insider information on what amount to bid in order to win the tender regardless of their level of expertise. There are also issues of over invoicing where contract sums are abnormally high to justify the scope and quality of work. In the middle of the discussion is also matters relating to the competence of
the human resources to handle such contracts. Power Purchase Agreements by the EDC has come with the argument that the company does not get the best deal in favour of its consumers. ACEP, one of the civil society groups has protested some contractual arrangements in PPA’s and sense that ECG has been short-changed. An example is the African Middle East Energy (AMERI) PPA signed with the Ghana Government and ECG which is currently under investigation for certain charges purported and spanning from causing financial loss to the state, fraud to value for money. The emerging issues surrounding the AMERI deal are rather dramatic where NPP (Incumbent) intends to show that the previous government (NDC) supervised over-invoicing for their self-interest. In 2018, in attempt to justify this, the Energy Ministry presented a proposed amendment that intended to cut ties with AMERI and initiate a new one with another entity. It was reviewed by parliament and rather found to be more expensive than the original deal which subsequently led to the dismissal of the Minister. The procurement of assets and materials seem to be very political and perceived to open avenues for rent-seeking. The motivation may be the huge contract sums and the difficulties in comparing and justifying prices since items procured are mostly bespoke.

5.7.1.6 Improving Customer Service

Our observations at some of the customer services centre confirmed the comments of some of the stakeholders who agree that the delay in attending to customer needs is one of the major factors leading to illegal connection and power theft. The turnaround time from the time a job is logged in and when it is completed is unacceptable to majority of the consumers. There are suggestions that a queuing system be provided by each centre to prevent others from receiving preferential services. In relation to a queueing system, it must be admitted that the Company has recently installed such systems in a few of its prime offices including Adum, Kumasi Airport, Accra Central and Circle branches. Man hours are lost when commercial traders go to ECG offices for issues relating to billing discrepancies, request of meters and malfunction of meters. It is believed that this circumstance promotes bribery and corruption since some decide to pay staff to get quick services. The ECG could improve on their queuing systems, tracking of jobs and validating completion of jobs. SLA (service level agreements) and KPIs (Key Performance Indicators) needs to be redesigned and made enforceable by reviewing sanctions and queries that have the potential to improve on the
attitudes of staff. These should be part of the high-tech innovative approaches that could be adapted for problem solving. The commercial inefficiency of the company has been confirmed by many stakeholders to be very high. As, the former minister of Power said:

“Commercial efficiency can significantly be improved. ECG’s commercial management systems are outdated and this has a big effect on the quality of customer service offered” Improving management systems of the EDC has a potential to improve the quality of customer service and also reduce the level of commercial inefficiency.

5.7.1.7 Internal Arrangements to Incentivise Whistle-Blowing

The citizens must be encouraged to report the illegal activities of other citizens without fear or favour. They ought to report illegal connections, corrupt staff and customers, meter tempering, staff that condone illegal activities etc. There are stages in the process of whistle blowing; arrest, interrogation, verdict and reform. ECG has the responsibility to corporate with both internal and external agencies that are involved in the full process. However, the least the whistle blower could get is security. Staff and customers both agree that this particular ingredient is lacking in the whistle blowing process. Since whistle blowers are exposed eventually, they risk the attacks of perpetrators especially when they are not reformed in the process. To incentivise whistle-blowing there should also be some token or incentive offered to the blowers in order that they are motivated to report another illicit activity. Thus ECG should find a robust reporting system that would keep whistle-blowers anonymous and any staff proven guilty of sharing such confidential information should be punished accordingly.

5.7.1.8 Investigating the Resilience of the System to Harsh Environmental Factors

The vigour of distribution equipment to thunder and lightning, heavy storms and vegetation was discussed by technical experts during the survey. A consensus is formed on the need to investigate the resilience of these equipment manufactured by foreign companies. It is believed that the voltages of lightning and thunder in the tropics against the strong winds during the rainy season causes more harm to the distribution system. Wires get torn and transformers have their down times and all of these increase cost of operation. Notwithstanding, others are of the opinion that the poor quality of the procurement output is the factor accounting for the lack of resilience of the system.
Technically, as Ward (2013) and Knight (2001) explain how harsh weather conditions can upset some components of power systems. They add that these factors have a significant impact on the reliability and operation of electrical constituents and eventually on the resilience of the entire system. High temperatures and heat waves, high winds, lightning strikes on conductors may cause an array of disruption by way of energy losses, sagging lines, disconnections, short circuit faults and voltage surge which can cause damage to equipment such as transformer wings.

It is therefore not out of place to recommend a proper research to assess impact of weather on ECG’s distribution system. An adaptability studies should be conducted and finally resilience-enhancing measures should be put in place. As recommended by Panteli and Mancarella (2015), it is essential to compare the cost of enhancing resilience (including capital, operating and maintenance costs) with the reduction in the risk achieved by these measures before implementation.

Having discussed the possible internal interventions within the EDC, issues outside the control of the management could also be looked at and this becomes the focus of the next section.

### 5.7.2 External Interventions

In this section, the external factors that affect ECG’s operations are re-considered and possible interventions discussed. The external factors includes all other that are outside the control of the management of ECG.

#### 5.7.2.1 Separation of ECG’s Business from Government of Ghana’s Business

Under the current operations, since government is the sole owner of ECG, it finds it difficult to insulate its operations from that of ECG. Investment decisions by ECG are distorted with Government’s intended projects which may have social advantages but may be economically and financially inimical to ECG. It is believed that most distribution companies have the tendency to deal with such interruption from government. However, the extent to which government interfere with the investment decisions may create inefficiencies in the company. Extension of the Grid to other areas requires investment analysis but Governments after governments have influenced the Company to carry out extension projects while ECGs balance sheet could not absorb such project expenditures. The discourse on this issue was addressed partially as governments created funding for the physical construction of the
project but did not consider the much more expensive operational and maintenance aspects for such projects. The SHEP project is one example that best describes the situation when a Special Purpose Vehicle (SPV) was created but did not cater for operations and maintenance expenditures.

5.7.2.2 Independence and Competence of Regulators

There many reasons that account for the lack of independence of the regulators of the market. The core of this is still government’s interference in the appointment of the heads of these institutions. The regulators knowledge of government interference with ECGs business makes it difficult for the regulators to apply penalties for the intended purposes. In this way, incentives for efficiency improvements may exist but could remain impracticable. As it is suggested by many assessment of the power industry, there is the need to build capacity for regulation. There is a need for example to get more engineers into regulation for a better appreciation of their roles and expected tasks. In conclusion, the independence and competence of the regulatory institutions should be enhanced to monitor the activities and targets of ECG with no influence from the government.

5.7.2.3 Enhancing Efficiency of Generators and Transmission Companies

ECG is down the value chain and the quality of operations of other players in the market up the chain could impact on the quality of service of ECG. For instance, there is the tendency of inefficiencies of generators and transmitters to shoot up prices of electricity. High electricity prices can influence illegal connections, low sales of power and non-payment of bills which could increase inefficiency at the distribution end. Types of fuel that are used by power plants are decisions made by the generator and so if they choose to go for expensive fuels (clean or unclean), resulting high prices could trigger other drivers on inefficiency at the distribution end. The other players up in the value chain should be monitored and encouraged to be less wasteful to reduce the cost of production of electricity.

5.7.2.4 Financial Engineering of ECG’s Debt

Further deregulation of the retail aspect of the value chain could bring in some level of competition. ECG has both distribution and retail licenses and it is possible for other private companies to compete with it at the retail end. Issues relating to illegalities of residential and
commercial customers could be reduced as competition will enhance management and technological innovations to reduce inefficiency in the system.

5.7.2.5 Financial Engineering of ECG’s Debt

The involvement of government and ECG’s mismanagement have led to the financial weakness of ECG. Government of Ghana owes ECG a significant amount and there are uncollected debt some customers. However, these payments when redeemed may not be able to turn things around as ECG owes its VRA and most of the Independent Power Producers. In order to sustain the company, there is a need to have external funding or investment to be able to make ECG viable again. At the heart of the discussion is a decision to fully or partly privatise or concession the operations of ECG. On the other hand, others are convinced that if government insulates itself from the operations of ECG and allow the company to run as a proper corporate institution.

5.8 Summary

This chapter presents analysis on electricity distribution in Ghana using the Electricity Company of Ghana as a case study. A political economy analysis is employed to the “inefficiency problem” in the electricity distribution sector. Largely, the study endorses the significance of assessing stakeholder interests, winners and losers, incentives and losses when dealing with a sectoral problem. In addition, it provides evidence of the prevalence of exploitation in the electricity industry. It exposes some of the informal rules that cause one to gain and many others to lose. The research provides stakeholders, other interested parties and investors, empirical evidence that support the rationales behind the following status quo:

- Relatively high and persistent inefficiency in the face of inadequate power supply and high electricity prices.
- Stakeholders calling for total or partial privatisation of the ECG.
- Poor financial performance of ECG and its related inefficiency problems despite continuous support from government of Ghana.
- Significant investments and reforms in the sector but on the contrary inefficiency problem persists.
ECG’s financial weakness and how that links to the kind of relationship that it has with Government’s obligation and political will.

First of all, the investigation finds evidence that the stakeholders interviewed in the matter have a perception or a view on the efficiency of the electricity distribution sector of Ghana. It further explored the perception of stakeholders on reforms, their reaction to high tariff and unreliable power supply where consumers by the situation may have become more energy efficient, changed life styles and even a significant percentage have become complete or partial “prosumers” This gives an indication of the sense of enterprise that can drive adoption of new technologies which are more energy efficient in Ghana.

The PEA found that the interplay of political and economic factors influences the level of inefficiency in the electricity distribution sector of Ghana. The emergence of political incentives—in the shape of employment or electoral support—for extending unsolicited managerial assistance and interfering with the management of the EDC. Incentives for staff to remain corrupt could be well routed in the governance structure and the organisational culture adulterated by internal and external factors. Regulators are unable to monitor and discipline the distribution sector because of government’s interference and inadequate skilled labour. There was also evidence that technological and social-economic solutions could help address the challenges of illegal connection, meter by-passing and other inefficient practices of the electricity industry.

Subsequent to comprehending the causes of the problem, the research further engaged in dialogues, conversations and discussions to develop technically feasible and politically acceptable measures that seek to improve on the efficiency of the electricity distribution sector. The next chapter attempts to synthesise the research finding of the various themes against the set objectives originally discussed in the introductory chapter of this thesis.
Chapter 6

Synthesis of Thesis

6.1 Introduction

This thesis looked at three different themes in the efficiency space. In the first part, a comprehensive review was conducted on the concept of efficiency and productivity in production theory. It explained the concept and explored varied measuring techniques used in industry. This was looked at in the context of cost minimisation or output maximisation and therefore using the various functions developed in production theory, this thesis physical, revenue and profit were also reviewed. Frontier techniques were investigated and the two main approaches (parametric and non-parametric) discussed accordingly. Sub-models used in these techniques were comprehensively analysed in the review chapter. The stochastic frontier technique which is one of the parametric approaches for measuring technical, allocative and economic efficiency. The SFA model, first introduced by Aigner, Lovell and Schmidt (1977) essentially introduces an inefficiency term in the composed error term aside the random noise term which is the main distinction between it and the DEA non-parametric model. The SFA technique has since been extended from its cross-section models to very varied panel models and all are explained in chapter two. As highlighted in chapter two, the statistical distribution used for the inefficiency term in the SFA models include half-normal, truncated normal, exponential, gamma and Rayleigh. Though the first three are the most popularly used, it is evidenced by literature that the choice of the best distribution type remains debatable. While a conclusion has been drawn by many other authors that, apart from the particular efficiency estimates that may vary from one distribution to the other, the ranking of the firms or the analysed firms did not change. Other authors are of the opinion that the distribution type could affect the scores and may have the potential to change the ranking of the firms when the right distribution that fits the data is applied. With this gap there was a need to investigate and experiment with a much accommodating Burr type X whose features have been well explained in chapters two and three. In order to contribute to this debate, the research as part of its first theme looked at the performance of the SFA models based on Burr X by comparing its performance with SFA models based on the popular distributions mentioned earlier.
Chapter two also reviewed the electricity distribution sector of West Africa with its finding leading to the conception of the second theme which is a practical application of the Stochastic Frontier models discussed in chapters two and three. In the review, it was clear that the West African EDCs have been tagged inefficient. The state of affairs in terms of the quality of supply, blackouts, load shedding, high technical and commercial losses in the reviewed reports and other narratives pointed to the inefficient situation. Many of these indicators are unidirectional and are unable to capture the entire inefficiency in the distribution sector and therefore the need to measure the real inefficiency was imminent.

The foundations of the second theme of the thesis is thus hinged on the above discussed gap and upon review, the stochastic frontier approach was chosen to investigate the level of inefficiency. Various sub-models of stochastic frontier models were experimented on 14 West African EDCs and 1 East African EDC in chapter four. The analysis pointed to a high inefficiency level of the West African electricity distribution sector. The mean efficiency level was just over 50% which called for an investigation especially noting that the sector had undergone many reforms and significant investments. Theme three was then introduced to investigate the issue from a political economy perspective to clearly understand the formal and informal rules of the sector that may be contributing to the high inefficiency levels.

Using the Political Economy Analysis framework and the Electricity Company of Ghana as a case study, quantitative and qualitative methods for data collection and analysis were applied in chapter five. The structural equation model is applied on the quantitative data to verify the questionnaire in order that the data collected can be relied upon for a meaningful analysis. Narratives from articles as well as qualitative data from in depth interviews with key stakeholders of the power industry of Ghana are analysed accordingly with very interesting findings. The chapter provides the possible causes and solutions to the persistent inefficiency problem with some policy recommendations.

The next section of this chapter focuses on the key findings and theoretical implications of the design and testing of the SFA model based on Burr type x. Sections 6.2 and 6.3 will also discuss the key findings and policy implications on themes 2 and 3 in relation to the efficiency of the West African electricity distribution sector.
6.2 Findings and Implications of Investigations on the SFA Model Based on Burr X

The main objective of the first theme was to investigate the competitiveness of the proposed Stochastic frontier Burr type x model in relation to other models. This work is the first regarding the treatment of SFA with Burr distribution and adds to the discussion on which is the preferred choice of distribution underlying the inefficiency term. The adopted methodology was to construct the joint distribution of normal and Burr x distributions, estimate the parameters using Maximum likelihood estimation and then incorporate the resultant distribution into the stochastic frontier model. In order to test its competitiveness, the normal-half normal stochastic frontier model was first applied on generated input and output data. The other three SFA models including exponential, Rayleigh and Burr x also utilised the same simulated data. SDs and MSEs were computed for the two variances of u and v as well as the efficiency estimates.

There are three main findings from this theme of research. First, by this investigation, the Burr-type x stochastic frontier model has been constructed and its potentials explored using a cross-sectional data. It is among the few two parameter models to be constructed aside the popular gamma that have be critiqued for having identification problems.

In the investigations, it was found that, generally all the models under review closely predicted the parameters estimated using simulated data. There were differences in the absolute efficiency measurements but with a high spearman rank correlation which indicated the ranking of the units analysed did not significantly change when different models were used. There were very little differences in the ranking of the firms using different models. The spearman correlation was very high meaning that the ranking of the firms barely changed. This arguments supports the opinion of a group of authors who suggest that changing the distribution underlying the inefficiency term least affect the ranking of the firms. Using a Monte Carlo analysis, the rank correlation of the stochastic frontier estimates when Ruggiero (1999) compared half normal to exponential showed very little differences between the true distribution and the misspecified distributions. In practice with data, some authors like Greene (1990) and Kumbhakar and Lovell (2000) tested the possibility of change of rankings. Greene (1990) using US electricity utility providers tested the half-normal, truncated normal, exponential, and gamma distributions and found average efficiency to be of no significant difference. Kumbharkar and Lovell (2000) found also very high rank correlation with the same
data with values between 0.75 and 0.98. Our investigations seem to support the notion that, the frontier of the stochastic frontier could change when different models are used but in items if the relative distances from it, the firms under analysis do not change their rankings. Finally, to comment on the performance of Burr type x for cross-sectional data, it is observed that the misspecified models competed satisfactorily. There was no significant differences between the estimation of the control model (Half Normal) and the misspecified models. It will be over ambitious to indicate that the Burr a better model and it will be far from true to conclude that it did not compete well with exponential and Rayleigh. However, the potential of Burr x will need to be further explored in other tests with different sample sizes and with panel data to see the advantages that these conditions offer to Burr X.

6.3 Findings and Implications of Investigating the Cost Efficiencies West African EDCs
Fourteen West African EDCs from Nigeria, Togo, Ghana and La Cote d’Ivoire were involved in the investigations. The main aim of the theme was to empirically test the efficiency level of the electricity distribution sector of West Africa. As a result, the research relied on the stochastic cost frontier model to empirically estimate drivers of total cost of operations and the efficiency levels. Aside cost variables such as labour and capital costs, the models included load factors and customer density to control for certain constraints beyond the control of the management of the firms. Given that these EDCs sometimes operate in somewhat inherent and persistent conditions, it was a reasonable adjustment especially with the recently privatised Nigerian EDC. Using Kenya Power as a comparator from East Africa the study was able to make comparisons with sub-groups in the sample. Nigerian EDCs, other West African EDCs and East African EDC were the subgroups within the sampled EDCs. The key findings of the research are as follows:

The Pooled model and the Pitt & Lee models were the two among other stochastic frontier panel models used in the investigation that produced robust results with the former being the more robust. With the sample data used the True Fixed Effects Model (TFEM) and True Random Effects Model (TREM) produced unreasonable and less robust results and so were not considered for analysis. However the most preferred sub-model was the Pooled Normal-Half Normal one which was used in the analysis of the total cost drivers and the level of inefficiencies of the EDCs in West Africa.
Generally as discussed earlier, the efficiency levels for the entire West African electricity distribution sector as per the results from the cost efficiency estimates is highly inefficiency with an average efficiency level of 48% (Pooled Normal-Half Normal Estimates). These results is in consonance with the narratives that surround the perceived underperformance of the sector. That, the stakeholders’ perceived inefficiency of the West African EDC is empirically tested and confirmed as such.

The level of inefficiency was very high in the Nigerian EDCs and there was no clear trend to show an improvement even after privatisation of the Electricity Supply Industry. The Nigerian EDCs performed worst in the sub-group analysis with a below average inefficiency performance of 51%. It is important to state, however, that some of the EDCs in Nigeria outperformed some of the other West African EDCs and BEDC in one of the years recorded as high as 78%. The notion that Nigeria has an inefficient distribution system may be a generalisation as the investigation conducted suggest that not all of the EDCs are inefficient. In addition, the low average cost efficiencies of the West African and particularly the Nigerian EDCs suggest that there are opportunities to improve which comes with high expectations for investment by the private sector.

6.4 Findings and Implications of the Political Economy Analysis of the Persistent ‘Inefficiency Problem’ in the Electricity Distribution Sector
In the previous section, it was evidenced that the West African Electricity Distribution Sector has been persistently inefficient. In an attempt to understand the problem Chapter five conducts a PEA in order to unearth the behaviours of change agents as they react or respond to reforms that aimed at improving the electricity distribution sector of West Africa. Another objective perfecting these investigations was to understand how consumers respond to an inefficient system resulting in the key findings of theme three discussed in the section.

Consumers perceive the distribution system as inefficient and respond to its effects in many ways. Consumers in the period of reliable and relatively less costly power are expected to be used to some inefficient and uneconomical behavioural practices. They may never switch off their light bulbs during the day when there is enough natural daylight to enable vision. They may give less consideration if any at all to efficiency or energy consumption of stock of appliances they use in their homes, offices and even their commercial engagements. The quantitative results indicate that in the phase of high tariffs and unreliable power supply a
significant number (30%) of consumers become less reliant on the distribution company and fully or partly produces and consumes their own energy. They respond to the conditions by having alternative energy such as solar energy and invest in storage facilities to ensure they have a backup. Many others rely on small generating plants. Specifically with high tariffs, about 50% of the consumers react by reducing their energy consumption. A relatively smaller number of consumers prioritise efficiency when buying electrical appliance and exhibit some demand management skills. From the above consumer behaviour, there are good signs that due to their experience of an inefficient distribution sector, most have inculcated some conservation behaviour or thinking which could become a leverage for the introduction of clean and renewable energy options. For Ghana, it has come at a time where alternative energy is getting considerable attention and policy makers could take advantage of the situation to stimulate the private sector to invest into renewables.

What is more worrisome is that over the years, nearly a third of the consumers do not bother to report problems to the EDC or any third party dealing with consumer concerns. It is evidenced that consumers have lost confidence in the management of the EDC and accuse them of neglecting their concerns, involved in corruption and being wasteful. In this part, there was evidence of economic gains and incentives leading to some informal rules of the game where consumers are frustrated enough such that there is a growing “mediator or middleman “operations who connive with the EDC’s staff to extort moneys for services that should be done for free. The management of the EDC therefore has a herculean task of regaining the trust of its consumers and that will require serious internal reforms including a relook at the EDCs corporate culture.

This research also found that the causes of the inefficiency problem in the distribution sector goes beyond the EDC. The data collected and analysed produced six causal themes that are cultural, financial, technical, managerial, political and regulatory. Most of the issues underlying these themes come about because some informal rules have been gradually accepted as the norm. Some stakeholders that are powerful and influential in the wider Ghanaian society use their influence to enhance their gains which eventually causes more problems for the efficient running of the sector. The underlying theory of the applied PEA approach was confirmed in the investigations as there is a culture of patrimonialism and clientelism exhibited in the electricity distribution sector. Also, it is rather alarming how the
financial weakness of the EDC could affect the banking industry and the entire economy if immediate actions are not taken. Government of Ghana has since devised a taxing regime to collect funds to offset the debt on the balance sheet of the EDC. This is rather a reactionary solution and a more preventive measure should be found. Political interference affects the management of the company as well as the regulation of the sector and it is hard time government of Ghana began treating the EDC and the regulators as separate entities that are competent enough to make prudent economic and technical decisions.

In chapter five, internal and external interventions are analysed and recommended to solve the inefficiency problem. The internal interventions are supposed to be initiated by the management of the EDC while other agencies or parties are responsible for the external interventions. The denominator of these solutions rests in the drive for all stakeholders to perform their roles satisfactorily. A consensus must be reached that the issues are beyond any individual stakeholder and unless institutions perform their responsibilities the problem will always be a blame game and the vicious cycle regarding the problems will continue to exist. The World Bank’s Development Report (2004) regards service delivery in three relationships or interactions at the levels of policymakers, service providers and clients. In Ghana and in most West African states, the solutions proffered through reforms have concentrated on the Policymaker-service provider connection which is normally technical with less attention to the policymaker-client and the service provider-client relationships. Specifically, the utility-consumer and the politician-consumer interactions cannot be ignored when searching for a holistic approach to tackle the inefficiency problem in the electricity sector as suggested by Lal (2006). Therefore, an approach that is technical and flexible that takes into consideration the incentive structure of all these three interactions and the local politics would be able to build coalitions to support reforms in improving efficiency in the electricity distribution sector of Ghana.

6.5 Summary
This PhD project looked at three connected themes in efficiency studies with two cases applied in the West African Sector. The theoretical concepts of efficiency measuring techniques were reviewed in previous chapters and accordingly the proposed SFA based on Burr X distribution is constructed and tested. In terms of application, the SFA model was used to measure the efficiency levels of EDCs in West Africa which produces an expected result of
high inefficiency confirming the narratives in the public discourse. The political Economy Analysis methodology applied to the electricity distribution sector of Ghana revealed causes and possible interventions of the persistent ‘inefficiency problems’.

The wider implications of the different themes are discussed in this chapter and their linkages to the main aim of the project are well illustrated. The next or last chapter of this thesis presents concluding remarks of the thesis highlighting the research contributions, limitations, recommendation and future or further work.
Chapter 7
Conclusion and Recommendations

7.1 Main Research Contributions
This thesis aimed at understanding the concept of efficiency and the inefficiency problem of the West African electricity distribution sector. The centre of the discussion has been the deplorable state of the electricity distribution sector of West Africa. The sector is characterised by inadequate generation capacity, high demand and supply deficit, low access to electricity, high tariffs, poor quality of service, and high technical and commercial losses. The severity and complexity of the problem is reflected in the following questions:

- Why there are high losses in a sector of a high demand and supply deficit?
- Why there are high tariffs for a sector characterised by poor quality of service?
- Why there is a persistent “inefficiency problem” in a sector which has experienced several reforms and significant investments?

Thus the motivation of this thesis is drawn from the compelling desire to understand the contradictions above. First the concepts and foundations of efficiency was to enhance the understanding of how to measure it and measure it right. Subsequently it could be plausible to understand the causes of the inefficiency problem in the West African Region.

In the investigation of the best technique to measure efficiency of the distribution system, the stochastic frontier was more appealing but set out a problem or gap that was prudent to address. The debate surrounding which distributional assumption on the inefficiency term is preferred has remained inconclusive. The Burr X distribution based on its attributes and particularly being one of two distributions with two parameters was incorporated into the stochastic frontier model. Apart from Gamma SFA constructed by Greene (1990) the newly constructed Burr X SFA is the other model developed on a distribution with two parameters. So far, unlike the Gamma SFA which has identification problems as pointed out by Ritter and Simar (1997), the newly developed Burr x performs satisfactorily with cross-sectional data. It competed well with Rayleigh and Exponential stochastic frontier models. One observation that has been confirmed on similar tests is that the rankings of the firms in terms of efficiency remain nearly the same as the assumed statistical distributions vary and this research
confirms that too with spearman rank correlation that approximates 1 in the range of 0.95-1. However, it is also important to state that the panel models for Burr X SFA have not been developed yet and it may be too early to suggest it as a generally robust model. Furthermore, the investigations and tests conducted in assessing its performance against other SFA models could be improved upon and the lack of a much fairer test could be a limitation in the experiments conducted in Chapter three. Wang, Amsler and Schmidt (2011) propose the goodness of fit test in distribution assessment in stochastic frontier models and a review of their proposed methodology could enhance the test performed to allow a much firmer conclusion. Nonetheless, this Burr X SFA joins the list of stochastic models based distributional types to enrich the literature of efficiency and its measuring techniques.

In the second theme of the research, the stochastic cost efficiencies of the EDCs in West Africa was modelled. Using different stochastic frontier panel models, this study happens to be the first inter-country cost efficiency investigations conducted in the sub-region and in the electricity distribution sector. In order words, much as there may be efficiency studies within a country and different sectors, this work provides for the first time a cost efficiency analysis of EDCs in West Africa and therefore provides a baseline or benchmark in the region. Sarpong (2013) for example, conducted efficiency studies on the SBUs of electricity distribution companies in Ghana. The results of these investigations should expose the severity of the inefficiency problem as the region shows an average inefficiency of nearly 47%. The Nigerian EDCs proved to be the worst with a mean average inefficiency of 51% which is relatively high when compared to other EDCs Ghana, Togo and La Cote D’Ivoire. For the management of the EDCs and regulators, these finding could be used to set targets that will improve their efficiency levels. Peer review is another way of self-assessment which is very important in any industry and therefore even if the distribution companies do not belong to the same regulated market, the outputs of such reviews are still very important.

The last part of the thesis conducted an investigation to bring understanding to the persistent inefficiency problem that was confirmed by the studies conducted on the cost efficiency of the electricity distribution sector. Using a political economy analysis framework and ECG as a case study, it is perceived that informal rules are used to satisfy the interest of some stakeholders who gain politically or economically. The main contribution from this theme is that the results suggest that any intervention or reform should consider at its centre the
political economy of the problem as well as the technical and non-technical solutions. This research therefore gives a comprehensive approach to understanding the persistent inefficiency problem and adds to the discussion on regarding the solutions and interventions needed to eliminate the related issues of an inefficient distribution system. In terms of literature, it is one of the few studies that has utilised a mixed method underpinned by the theories of political economy in order to investigate a popular but complex problem. By this approach, other findings that could be considered to improve the management, regulation and formulation of policies were revealed. For example, it is possible to take advantage of the emerging energy conserving/energy saving attributes as well as the increasing adoption of renewable energy technologies by the consumers in order to improve the energy situation in the region.

7.2 Research Limitations
This research utilised the best data available in order to reach conclusions that are representative of the facts on the ground. There were definitely limitations in terms of the data collected or the data collection phase without which the findings of this research could have been much enhanced. In particular, certain variables could have been added to the models used in estimating the cost efficiencies of the EDCs. Some environmental factors such as size of area of operations, climatic data and data on transformer sizes and numbers could have made the assessment platform fairer as more heterogeneity is introduced in the models. Most of the cost variables were derived from financial reports which have different reporting styles and formats and even though this was taken into account during the data collection stage, there is still the possibility that some of the cost variables may have been less accurate due to conversion and approximating errors. Jamasb and Pollitt (2001) also confirm the above limitation and suggest that in international comparison the quality of data is impaired by the various accounting principles applied especially with the treatment of capital cost, operational expenses and depreciation. It is therefore important to note that had it not been for the paucity of data in other West African EDCs not included in this study, the results on the cost efficiency would have included more EDCs in the sub-region to offer findings that are more representative of West Africa. For the PEA of the “inefficiency problem” and in the quantitative analysis, a bigger sample size would have added more weight to the findings of the consumer attributes and reactions to an inefficient distribution system. However, since the main motive of that part of research was to get leading questions for further
investigations in the qualitative analysis, though the sample size may be a limitation in a wider context, in the specific case of this research it is adequate. Thus, it is possible to investigate how consumers respond to an inefficient distribution system by increasing samples sizes and injecting more diversity in the type of respondents to study certain trends and patterns related to specific groups, clusters or individuals.

As suggested earlier, using the half-normal distribution as a control distribution poses a limitation to the test methodology applied in chapter three. Other fairer and less biased methodologies could be explored to judge the performance of the various SFA models tested.

7.3 Future Work
In the light of the research conducted, there are developments of new ideas or research gaps that could add to this work.

Firstly, the same motive for developing panel models in the other classical SFA methods is also valid in the case of Burr X SFA and therefore any attempt at developing such panel models will be valuable. A future work in this regard will be developing the panel models of the Burr type x SFA in order to permit the study of efficiency of firms or units overtime. In this proposed work, the choice of the testing methodology could be improved upon by the considering the goodness of fit test as well as other tests to bring to a logical conclusion on the performance of the candidate models.

In chapter four, the approach adopted for measuring the efficiency levels of EDCs in West Africa was the stochastic cost frontier model (a parametric approach). Being the first study in this arena, it will be prudent to test the case of different models including non-parametric approaches to find out how the data behave with different models. That is to say, there could be a much better model at determining the efficiency levels of the West African EDCs. Also in these models, an inclusion of variables that can depict the performance of EDCs in terms of quality of service could add more weight to the findings so far. Variables such as hours of load shedding, blackouts, customer complaints, quality of power, hours of low voltages, health and safety incidents, quality of billing systems etc. could be added to boost up the employed efficiency measuring technique. The models could also include more environmental factors that can control for heterogeneity and offer a much fairer result, especially as these EDCs operate in different geographical areas. Research in future could therefore consider different parametric and non-parametric models which utilise variables
that are quality of service oriented as well as include environmental variables in order to understudy the behaviour of these different models on the data on West African EDCS.

In chapter five, this study applied the PEA framework to the inefficiency problem of the electricity distribution sector. In this research, one of the emerging issues was that some consumers in the face of an inefficient electricity distribution have developed some attributes or attitudes towards energy conservation and even generation of their own energy. These are definitely positive responds that the power sector authorities and policy makers could explore to introduce and enhance the use of new technologies and push the concept of community energy or other forms of decentralised energy that put less stress on the central distribution system. Therefore, in the future, a principal research on how to identify such attributes in a wider context as well as how to sustain and enhance these attributes even when the central distribution system improves could be very useful to the West African sub-region.

7.4 Summary
In this study, while attempting to understand the electricity supply landscape of West Africa, it was established and widely accepted that the sub region is faced with inadequate supply of electricity, high cost and unreliable supply of power. This issue is further compounded with the persistent inefficiency problem of the electricity distribution sector. This inefficiency problem always dominate the public discourse and yet apart from reports on technical and commercial losses and other partial efficiency indicators, there has yet to find a study which attempts to measure or determine empirically and holistically the level inefficiency in the region. To decide on what approach is holistic enough to measure the efficiency levels of the EDCs, this thesis reviewed the various techniques of measuring efficiency. In the process, there was a need to advance or enhance the stochastic frontier technique by incorporating the Burr X distribution as an assumed distribution of the technical inefficiency term u. The newly constructed Burr x Stochastic frontier model exhibits some competitive attributes in the cross-sectional form against other existing models which is a good place to commence modelling its panel equivalents.

Eventually, the stochastic cost frontier model was applied on a sample of West African EDCs and the various panel models analysed. With an indication of relatively inefficient West African Electricity Distribution Sector with a mean efficiency of 47%, it was prudent to investigate the reason behind the inefficiency problem. Given that there is adequate evidence
of failed electricity sector reforms in the midst of significant investments, a political economy analysis was one of the recommended approaches to investigate the sources of inefficiency and its possible interventions that focus on the dynamics of rents seeking linkages to the interest of some key stakeholders since the investigation is premised on the notion that some agents of change exhibit or utilise their influential and political controls to intentionally or unintentionally oppose reforms that target improving the efficiency levels of EDCs.

The findings have confirmed that the electricity distribution sector is perceived inefficient to the extent that some consumers have lost any hope in reversing the situation. This thesis makes also important recommendations that could be adopted by policy makers and regulators so as to reduce the inefficiency problem. One that is very important is the collaboration of all the stakeholders in the power industry to collectively face this issue of inefficiency and resist from the typical blame game. All stakeholders should be engaged to collectively play their roles earnestly and allow institutions to work.

Finally, this thesis proposes or suggests some areas of further research that could be executed to bring more understanding to the theory of efficiency measurement, the applications of efficiency measuring techniques as well as the policy implications or benefits of the findings in efficiency studies.
References


IDS (2005) Signposts to More Effective States: Responding to Governance Challenges in Developing Countries, Brighton: IDS


Appendices

Appendix 3A: Bo Mean Estimates for SFA Models Assessed

<table>
<thead>
<tr>
<th>n/scale</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1.09</td>
<td>1</td>
<td>0.93</td>
<td>0.89</td>
<td>0.89</td>
</tr>
<tr>
<td>50</td>
<td>1.04</td>
<td>0.98</td>
<td>0.94</td>
<td>0.91</td>
<td>0.97</td>
</tr>
<tr>
<td>100</td>
<td>1.03</td>
<td>0.99</td>
<td>0.93</td>
<td>0.94</td>
<td>1</td>
</tr>
<tr>
<td>250</td>
<td>1.01</td>
<td>0.97</td>
<td>0.93</td>
<td>0.96</td>
<td>1</td>
</tr>
<tr>
<td>500</td>
<td>1.01</td>
<td>0.96</td>
<td>0.94</td>
<td>0.98</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n/scale</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1.02</td>
<td>0.95</td>
<td>0.88</td>
<td>0.8</td>
<td>0.82</td>
</tr>
<tr>
<td>50</td>
<td>0.99</td>
<td>0.91</td>
<td>0.84</td>
<td>0.79</td>
<td>0.83</td>
</tr>
<tr>
<td>100</td>
<td>0.97</td>
<td>0.89</td>
<td>0.83</td>
<td>0.8</td>
<td>0.84</td>
</tr>
<tr>
<td>250</td>
<td>0.96</td>
<td>0.89</td>
<td>0.83</td>
<td>0.82</td>
<td>0.85</td>
</tr>
<tr>
<td>500</td>
<td>0.95</td>
<td>0.88</td>
<td>0.83</td>
<td>0.83</td>
<td>0.85</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n/scale</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1.3</td>
<td>1.2</td>
<td>1.16</td>
<td>1.08</td>
<td>1.12</td>
</tr>
<tr>
<td>50</td>
<td>1.27</td>
<td>1.2</td>
<td>1.12</td>
<td>1.16</td>
<td>1.21</td>
</tr>
<tr>
<td>100</td>
<td>1.23</td>
<td>1.16</td>
<td>1.13</td>
<td>1.15</td>
<td>1.25</td>
</tr>
<tr>
<td>250</td>
<td>1.17</td>
<td>1.14</td>
<td>1.14</td>
<td>1.21</td>
<td>1.25</td>
</tr>
<tr>
<td>500</td>
<td>1.15</td>
<td>1.11</td>
<td>1.12</td>
<td>1.23</td>
<td>1.26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n/scale</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.87</td>
<td>1</td>
<td>0.7</td>
<td>0.84</td>
<td>1.13</td>
</tr>
<tr>
<td>50</td>
<td>1.01</td>
<td>0.91</td>
<td>0.85</td>
<td>0.69</td>
<td>0.72</td>
</tr>
<tr>
<td>100</td>
<td>0.77</td>
<td>1</td>
<td>0.68</td>
<td>0.68</td>
<td>0.71</td>
</tr>
<tr>
<td>250</td>
<td>1.03</td>
<td>0.81</td>
<td>0.81</td>
<td>0.82</td>
<td>1.09</td>
</tr>
<tr>
<td>500</td>
<td>0.79</td>
<td>0.95</td>
<td>1.14</td>
<td>0.73</td>
<td>1</td>
</tr>
</tbody>
</table>
## Appendix 3B: B1 Mean Estimates for SFA Models Assessed

<table>
<thead>
<tr>
<th></th>
<th>B1 Mean Estimates for Normal-Half Normal SFA</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n/scale</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>20</td>
<td>0.98</td>
<td>1</td>
<td>1.01</td>
<td>1</td>
<td>1.01</td>
</tr>
<tr>
<td>50</td>
<td>1.01</td>
<td>0.99</td>
<td>0.99</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>100</td>
<td>1.01</td>
<td>0.99</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>250</td>
<td>1.01</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>500</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>B1 Mean Estimates for Normal-Exponential SFA</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n/scale</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>20</td>
<td>0.98</td>
<td>0.97</td>
<td>0.99</td>
<td>1.03</td>
<td>1.02</td>
</tr>
<tr>
<td>50</td>
<td>1</td>
<td>0.99</td>
<td>1</td>
<td>0.99</td>
<td>1.01</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>1.01</td>
<td>1</td>
<td>1</td>
<td>1.01</td>
</tr>
<tr>
<td>250</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>500</td>
<td>1</td>
<td>1</td>
<td>1.01</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>B1 Mean Estimates for Rayleigh SFA</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n/scale</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.99</td>
<td>1</td>
</tr>
<tr>
<td>50</td>
<td>1.01</td>
<td>0.99</td>
<td>0.99</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.01</td>
<td>1</td>
</tr>
<tr>
<td>250</td>
<td>1</td>
<td>1</td>
<td>0.99</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>500</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>B1 Mean Estimates for Normal-Burr x SFA</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n/scale</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>20</td>
<td>0.98</td>
<td>0.55</td>
<td>0.77</td>
<td>1.12</td>
<td>0.7</td>
</tr>
<tr>
<td>50</td>
<td>1.03</td>
<td>1</td>
<td>1.04</td>
<td>0.97</td>
<td>1.06</td>
</tr>
<tr>
<td>100</td>
<td>1.1</td>
<td>0.89</td>
<td>1.09</td>
<td>1.03</td>
<td>1.07</td>
</tr>
<tr>
<td>250</td>
<td>0.9</td>
<td>1.01</td>
<td>0.94</td>
<td>1.06</td>
<td>0.94</td>
</tr>
<tr>
<td>500</td>
<td>0.94</td>
<td>0.95</td>
<td>0.9</td>
<td>1.11</td>
<td>0.95</td>
</tr>
</tbody>
</table>
### Appendix 3C: Sigma u mean estimates for SFA Models Assessed

<table>
<thead>
<tr>
<th>n/scale</th>
<th>Sigma u Mean Estimates for Normal-Half Normal SFA</th>
<th>Sigma u Mean Estimates for Normal-Exponential SFA</th>
<th>Sigma u Mean Estimates for Normal-Rayleigh SFA</th>
<th>Sigma u Mean Estimates for Burr x SFA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>20</td>
<td>0.42</td>
<td>0.43</td>
<td>0.43</td>
<td>0.43</td>
</tr>
<tr>
<td>50</td>
<td>0.37</td>
<td>0.35</td>
<td>0.4</td>
<td>0.42</td>
</tr>
<tr>
<td>100</td>
<td>0.31</td>
<td>0.33</td>
<td>0.34</td>
<td>0.43</td>
</tr>
<tr>
<td>250</td>
<td>0.25</td>
<td>0.29</td>
<td>0.33</td>
<td>0.45</td>
</tr>
<tr>
<td>500</td>
<td>0.24</td>
<td>0.26</td>
<td>0.33</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>20</td>
<td>0.34</td>
<td>0.34</td>
<td>0.39</td>
<td>0.38</td>
</tr>
<tr>
<td>50</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.45</td>
</tr>
<tr>
<td>100</td>
<td>0.31</td>
<td>0.32</td>
<td>0.36</td>
<td>0.44</td>
</tr>
<tr>
<td>250</td>
<td>0.26</td>
<td>0.3</td>
<td>0.36</td>
<td>0.44</td>
</tr>
<tr>
<td>500</td>
<td>0.24</td>
<td>0.28</td>
<td>0.35</td>
<td>0.50</td>
</tr>
</tbody>
</table>
### Appendix 3D: Sigma v Mean Estimates for SFA Models Assessed

| Sigma v Mean Estimates for Normal-Half Normal SFA |  |
|---|---|---|---|---|---|
| n/scale | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 |
| 20 | 0.41 | 0.38 | 0.34 | 0.28 | 0.15 |
| 50 | 0.5 | 0.47 | 0.42 | 0.35 | 0.18 |
| 100 | 0.54 | 0.51 | 0.46 | 0.38 | 0.19 |
| 250 | 0.57 | 0.53 | 0.48 | 0.39 | 0.20 |
| 500 | 0.58 | 0.55 | 0.49 | 0.39 | 0.20 |

| Sigma v Mean Estimates for Normal-Exponential SFA |  |
|---|---|---|---|---|---|
| n/scale | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 |
| 20 | 0.5 | 0.47 | 0.42 | 0.35 | 0.19 |
| 50 | 0.55 | 0.53 | 0.48 | 0.41 | 0.25 |
| 100 | 0.57 | 0.54 | 0.5 | 0.42 | 0.26 |
| 250 | 0.59 | 0.56 | 0.51 | 0.43 | 0.26 |
| 500 | 0.59 | 0.56 | 0.51 | 0.43 | 0.26 |

| Sigma v Mean Estimates for Normal-Rayleigh SFA |  |
|---|---|---|---|---|---|
| n/scale | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 |
| 20 | 0.36 | 0.35 | 0.28 | 0.23 | 0.07 |
| 50 | 0.45 | 0.42 | 0.38 | 0.28 | 0.08 |
| 100 | 0.52 | 0.48 | 0.42 | 0.33 | 0.09 |
| 250 | 0.55 | 0.51 | 0.45 | 0.34 | 0.11 |
| 500 | 0.57 | 0.53 | 0.47 | 0.35 | 0.12 |

| Sigma v Mean Estimates for Normal-Burr x SFA |  |
|---|---|---|---|---|---|
| n/scale | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 |
| 20 | 0.51 | 0.35 | 0.29 | 0.29 | 0.18 |
| 50 | 0.48 | 0.46 | 0.39 | 0.28 | 0.19 |
| 100 | 0.52 | 0.44 | 0.42 | 0.37 | 0.24 |
| 250 | 0.54 | 0.43 | 0.4 | 0.32 | 0.16 |
| 500 | 0.55 | 0.45 | 0.37 | 0.31 | 0.17 |
Appendix 3D: R codes for Various SFA Models and Monte Carlo Simulation Analysis

Appendix 3D1: Normal- half normal SFA

```r
SFA_sim<-function(n,scale){
  # generate sample
  x <- runif(n, 0, 1)
  u <- abs(rnorm(n,sd=scale))
  v <- rnorm(n,sd=sqrt(0.4-scale^2))
  y <- 1+x+v-u

  logl <- function(theta){
    b0 <- theta[1]
    b1 <- theta[2]
    g <- theta[3]
    s2 <- theta[4]
    lx <- b0+b1*x
    e <- y-lx
    pn <- pnorm(-e*g/sqrt(s2))
    ret <- n*log(sqrt(2/pi))-n*log(sqrt(s2))+sum(log(pn))-sum(e^2)/(2*s2)
    return(ret)
  }
  thetastart <- c(1,1,scale,sqrt(0.4-scale^2))#c(0.5,0.5,0.5,0.5)
  o <- optim(thetastart,logl,control=list(fnscale=-1))
  #To obtain the ML-estimates of the variances, we convert the estimated parameters and estimates
  #of the variances
  b0.d <- o$par[1]
  b1.d <- o$par[2]
  g.d <- o$par[3]
  s2.d <- o$par[4]
  s2.u.d <- s2.d*g.d^2/(1+g.d^2)
  ## [1] 0.03225
}
s2.v.d <- s2.d/(1+g.d^2)

## [1] 0.004234

# Using the estimated regression parameters, calculate the residuals of the regression and finally obtain the estimated efficiency scores as:

# Jodrow et al (1982) estimator E(u/e)
ly.sfa <- b0.d+b1.d*x
e.d <- y-ly.sfa
mustar <- -e.d*s2.u.d / (s2.u.d + s2.v.d)
sigmastar <- sqrt(s2.u.d * s2.v.d / (s2.u.d + s2.v.d))
uu <- mustar + sigmastar*(dnorm(-mustar/sigmastar)/pnorm(mustar/sigmastar))

# technical efficiency
eta.d1<- mean((exp(-uu)-exp(-u))^2)

# thetastart <- c(0.5,0.5,0.5,0.5)
# calculate estimators

sigma_u <- sqrt(s2.u.d)
sigma_v <- sqrt(s2.v.d)
b0 <- b0.d
b1 <- b1.d

# return results
return(list("b0"=b0, "b"=b1, "sigma_u"=sigma_u, "sigma_v"=sigma_v, "MSE"=eta.d1))

n_grid<-c(20, 50, 100, 250, 500)
scale_grid<-c(0.2, 0.3, 0.4, 0.5, 0.6)
param_list=list("n"=n_grid, "scale"=scale_grid)

# run simulation:
MC_result<-MonteCarlo(func=SFA_sim, nrep=100, param_list=param_list)
MakeTable(output=MC_result, rows="n", cols="scale", digits=2, include_meta=FALSE)
collapse<-list( "mean", "mean", "mean", "mean", "mean")
MakeTable(output=MC_result, rows="n", cols="scale", digits=2, collapse=collapse, include_meta=FALSE)
Appendix 3D2: Normal – Exponential SFA

SFA_sim <- function(n, scale) {

  # generate sample
  x <- runif(n, 0, 1)
  u <- abs(rnorm(n, sd=scale))
  v <- rnorm(n, sd=sqrt(0.4-scale^2))
  y <- 1+x+v-u

  Likeli_exp <- function(theta) {

    b0 <- theta[1]
    b1 <- theta[2]
    sigmau <- theta[3]
    sigmav <- theta[4]
    lxd <- b0+b1*x

    epsilon <- y-lxd

    n <- length(y)
    ret <- (n* log(1/sigmau) + n/ 2*(sigmav^2/sigmau^2)
          + sum(log(pnorm((epsilon - (sigmav^2/ (sigmau)))/(sigmav)))))
          + sum(epsilon)/sigmau)
    return(ret)
  }

  # normal/exponential distribution estimates
thetastart2 <- c(1,1,scale, sqrt(0.4-scale^2))

op <- optim(thetastart2, Likeli_exp, control=list(fnscale=-1))

# tab1 <- round(op$par,3)

#names(tab1) <- names(tab1) <- c("b0","b1","sigmau","sigmav");tab1

#parameter estimates

b0.e <- op$par[1]

b1.e <- op$par[2]

su.e <- op$par[3]

sv.e <- op$par[4]

#tab <- round(c(b0.e,b1.e,su.e,sv.e),3)

# names(tab) <- c("b0","b1","su","sv");tab

#normal/exponentialinefficiency estimates

ly.sfae<- b0.e+b1.e*x
e.e <- y-ly.sfae
mu.e <- -1*e.e-(sv.e^2/su.e)
et.e <- mu.e + (sv.e*(dnorm(-mu.e/sv.e))/pnorm(mu.e/sv.e))
```R
eta.e <- mean((exp(-u)-exp(-et.e))^2)

sigma_u <- su.e
sigma_v <- sv.e
b0 <- b0.e
b1 <- b1.e

# return results
return(list("b0"=b0, "b"=b1, "sigma_u"=sigma_u, "sigma_v"=sigma_v, "MSE"=eta.e))
}

n_grid<-c(20, 50, 100, 250, 500)
scale_grid<-c(0.2, 0.3, 0.4, 0.5, 0.6)

param_list=list("n"=n_grid, "scale"=scale_grid)

# run simulation:
MC_result<-MonteCarlo(func=SFA_sim, nrep=100, param_list=param_list)

MakeTable(output=MC_result, rows="n", cols="scale", digits=2, include_meta=FALSE)

collapse<-list( "mean", "mean", "mean", "mean", "mean")
MakeTable(output=MC_result, rows="n", cols="scale", digits=2, collapse=collapse, include_meta=FALSE)

collapse<-list( "sd", "sd", "sd", "sd", "sd")
MakeTable(output=MC_result, rows="n", cols="scale", digits=2, collapse=collapse, include_meta=FALSE)
```
Appendix 3D3: Normal-Rayleigh SFA

SFA_sim<-function(n,scale){

  # generate sample
  x <- runif(n, 0, 1)
  u <- abs(rnorm(n,sd=scale))
  v <- rnorm(n,sd=sqrt(0.4-scale^2))
  y <- 1+x+v-u

  loglike.rayleigh = function(theta) {

    b0 <- theta[1]
    b1 <- theta[2]
    sigmav <- theta[4] #sigma v

    mu <- -e*sigmav^2/(sigmav^2 + sigmav^2)
    sigma2 <- (sigmav^2*sigmav^2)/(sigmav^2 + sigmav^2)

  }

}
rett <- -(n/2)*log(sigmav^2) -
   n*log(sigmau^2) + (n/2)*log(sigma2) + sum(log(sqrt(sigma2)*dnorm(mu/sqrt(sigma2)) +
       mu*pnorm(mu/sqrt(sigma2)))) + sum(mu^2/(2*sigma2)) + sum(e^2/(2*sigmav^2))

return(rett)

thetastart1 <- c(1,1,scale, sqrt(0.4-scale^2))# starting values for numerical analysis

opo <- optim(thetastart1,loglike.rayleigh, control=list(fnscale=-1))

#tab <- round(opo$par,3)

#names(tab) <- names(tab) <- c("b0","b1","sigma_u","sigma_v");tab

#parameter estimates

b0.r <- opo$par[1]

b1.r <- opo$par[2]

su.r <- opo$par[3]

sv.r <- opo$par[4]

# tab <- round(c(b0.r,b1.r,su.r,sv.r),3)
#names(tab) <- c("b0","b1","su","sv");tab

#Normal-Rayleigh efficiency estimation

ly.sfar <- b0.r+b1.r*x
y.sfa <- exp(ly.sfar)
e.r <- y-ly.sfar
mu.r <- -e.r*su.r^2/(su.r^2+sv.r^2)
sigma2.r <- (su.r^2*sv.r^2)/(su.r^2+sv.r^2)

et.r <- ((mu.r*sqrt(sigma2.r)*dnorm(mu.r/sqrt(sigma2.r)))+
  (sqrt(sigma2.r)*dnorm(mu.r/sqrt(sigma2.r))+mu.r*pnorm(mu.r/sqrt(sigma2.r))))/
  (sqrt(sigma2.r)*dnorm(mu.r/sqrt(sigma2.r))+mu.r*pnorm(mu.r/sqrt(sigma2.r)))
eta.r <- mean((exp(-u)-exp(-et.r))^2)

#thetastart <- c(0.5,0.5,0.5)
# calculate estimators

sigma_u <- su.r
sigma_v <- sv.r
b0 <- b0.r
b1 <- b1.r

# return results
return(list("b0"= b0, "b"=b1, "sigma_u"=sigma_u, "sigma_v"=sigma_v, "MSE"=eta.r))

n_grid<-c(20, 50, 100, 250, 500)
scale_grid<-c(0.2, 0.3, 0.4, 0.5, 0.6)

param_list=list("n"=n_grid, "scale"=scale_grid)

# run simulation:
MC_result<-MonteCarlo(func=SFA_sim, nrep=100, param_list=param_list)

MakeTable(output=MC_result, rows="n", cols="scale", digits=2, include_meta=FALSE)
collapse<-list( "mean", "mean", "mean", "mean", "mean")
MakeTable(output=MC_result, rows="n", cols="scale", digits=2, collapse=collapse, include_meta=FALSE)
collapse<-list( "sd", "sd", "sd", "sd", "sd")
MakeTable(output=MC_result, rows="n", cols="scale", digits=2, collapse=collapse, include_meta=FALSE)
Appendix 3D4: Normal –Burr Type X SFA

SFA_sim<-function(n,scale){

  # generate sample
  x <- runif(n, 0, 1)
  u <- abs(rnorm(n,sd=scale))
  v <- rnorm(n,sd=sqrt(0.4-scale^2))
  y <- 1+x+v-u

  L_burr <- function(theta){
    
    b0 <- theta[1]
    
    b1 <- theta[2]
    
    sigma_u <- theta[3]
    sigma_v <-theta[4]
    
    alpha <-theta[5]
    
    lxd <- b0+b1*x
    
    e <- y-lxd
    
    n <- length(x)
    
    lamda <- 1+(sigma_u^2/(2*sigma_v^2))
    
    a1 <- gamma(lamda+1)*gamma(alpha)/(lamda*gamma(lamda+alpha))
    
    z1 <- log(a1-(sqrt(pi)*sigma_u*e/(lamda*gamma(lamda))*exp(sigma_u^2*e^2/(4*sigma_v^4*lamda)))*pnorm(-sigma_u*e/(sigma_v^2*sqrt(2*lamda))) +

    ((alpha-1)*sqrt(pi)*sigma_u*e/((lamda+1)*gamma(lamda+1))*exp(sigma_u^2*e^2/(4*sigma_v^4*(lamda+1)))*pnorm(-sigma_u*e/(sigma_v^2*sqrt(2*(lamda+2))))))}
a2 <- sum(z1)

a3 <- n*log(alpha)-n*log(sqrt(2*pi))-n*log(sigma_v)

a4 <- -1/(2*sigma_v^2)

ans <- a2+a3+a4*sum(e^2)

return(ans)

thetastart2 <- c(1,1,scale, sqrt(0.4-scale^2),0.5)

opb <- optim(thetastart2,L_burr, control=list(fnscale=-1))

#tab1 <- round(opb$par,3)

#names(tab1) <- names(tab1) <- c("b0","b1","sigma_u","sigma_v","alpha");tab1

#parameter estimates

b0.b <- opb$par[1]

b1.b <- opb$par[2]

su.b <- opb$par[3]

sv.b <- opb$par[4]

alpha.b <- opb$par[5]
#tab <- round(c(b0.b,b1.b,su.b,sv.b, alpha.b),3)

# names(tab) <- c("b0","b1","su","sv","alpha");tab

#normal/Burr inefficiency estimates

ly.sfab <- b0.b+b1.b*x
#y.sfa <- exp(ly.sfab)
e.b <- y-ly.sfab
lamda.b <- 1+(su.b^2/(2*sv.b^2))
g.b <- su.b+(e.b*su.b/sv.b^2)

#c <- 1-(sqrt(pi)*su.b*e.b)*exp(su.b^2*e.b^2/(4*sv.b^4*lamda.b))*pnorm(-su.b*e.b/(sv.b^2*sqrt(2*lamda.b)))/(sv.b^2*sqrt(lamda.b))

# d <- ((alpha.b-1)/(lamda.b+1))*(1-(sqrt(pi)*su.b*e.b/(sv.b^2*sqrt(lamda.b+1)))*exp(su.b^2*e.b^2/(4*sv.b^4*(lamda.b+1)))*pnorm(-su.b*e.b/(sv.b^2*sqrt(2*(lamda.b+b2)))))

# a <- (su.b)*((sqrt(pi)*(2*lamda.b+b+(e.b^2*su.b^2/sv.b^4)))*exp(su.b^2*e.b^2/(4*sv.b^4*lamda.b)))*pnorm(-su.b*e.b/(sv.b^2*sqrt(2*(lamda.b+b2))))-

# b <- 2*(alpha.b-1)*su.b*(2*(sqrt(pi)*(2*(lamda.b+b1)+(e.b^2*su.b^2/sv.b^4)))*exp(su.b^2*e.b^2/(4*sv.b^4*(lamda.b+b1)))*pnorm(-su.b*e.b/(sv.b^2*sqrt(2*(lamda.b+b1))))-

#eta.b <- exp(-a/c) #exp[-E(u|e)]

mu.b <- -e.b*su.b^2/(su.b^2+sv.b^2)
sigma2.b <- (su.b^2*sv.b^2)/(su.b^2+sv.b^2)
et.b <- ((mu.b*sqrt(sigma2.b))*dnorm(mu.b/sqrt(sigma2.b)))+

(sqrt(sigma2.b)*dnorm(mu.b/sqrt(sigma2.b)))+mu.b*pnorm(mu.b/sqrt(sigma2.b)))
\[\text{eta.b} = \text{mean}((\exp(-u) - \exp(-\text{et.b}))^2)\]

\[\sigma_{uu} = \text{su.b}\]

\[\sigma_{vu} = \text{sv.b}\]

\[b0 = b0.b\]

\[b1 = b1.b\]

# return results
return(list("b0"=b0, "b"=b1, "sigma_u"=sigma_uu, "sigma_v"=sigma_vu, "MSE"=eta.b))

n_grid<-c(20, 50, 100, 250, 500)
scale_grid<-c(0.2, 0.3, 0.4, 0.5, 0.6)

param_list=list("n"=n_grid, "scale"=scale_grid)

# run simulation:
MC_result<-MonteCarlo(func=SFA_sim, nrep=10, param_list=param_list)

MakeTable(output=MC_result, rows="n", cols="scale", digits=2, include_meta=FALSE)

collapse<-list( "mean", "mean", "mean", "mean", "mean")

MakeTable(output=MC_result, rows="n", cols="scale", digits=2,
           collapse=collapse, include_meta=FALSE)

collapse<-list( "sd", "sd", "sd", "sd", "sd")

MakeTable(output=MC_result, rows="n", cols="scale", digits=2,
           collapse=collapse, include_meta=FALSE)
Appendix 4A: Pooled Normal – Half Normal SFA Estimates

Normal-Half Normal Stock Frontier Model

Dependent variable: TCPC
Log likelihood function: TCPC
Estimation based on N = 73, K = 7
Inf.Cr.AIC = 147.3 AIC/N = 2.018

Variance: Sigma-squared(\(\nu\)) = 0.9042
Sigma(\(\nu\)) = 0.30070
Sigma-squared(\(\sigma\)) = 0.63421
Sigma(\(\sigma\)) = 0.91335

Sigma = Sqr([s^2(u)+s^2(\(\nu\))]) = 0.9518
Gamma = sigma(u)^2/sigma(\(\nu\))^2 = 0.90221
Var[\(\sigma\)]/Var[\(\nu\)] = 0.77024

Stochastic Cost Frontier Model:

\[ e = v + u \]
-----[ Tests vs. No Inefficiency ]-----

LR test for inefficiency vs. OLS \(\nu\) only
Deg. freedom for sigma-squared(u): 1
Deg. freedom for heteroscedasticity: 0
Deg. freedom for truncation mean: 0
Deg. freedom for inefficiency model: 1

LogL when sigma(u)=0 = -68.47866

Chi-sq=2*[LogL(SF)-LogL(LS)] = 3.640
Kolm-Palm C*: 95%: 2.706, 99%: 5.412

LR test for sigma(\(\sigma\)) = 0 based on cib e

Chi-sq[j]=(N/2)*[m3/s^3]^2 = 1.154

Wald tests based on MLEs shown in table

<table>
<thead>
<tr>
<th>TCPC</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>z</th>
<th>Prob.</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
</table>

| Detemrministic Component of Stochastic Frontier Model.................

| Constant | 0.67222 | 1.12241 | .60 | .5693 | -1.52778 | 2.87201 |
| Y | .34030*** | .08348 | 4.11 | .0000 | .17940 | .50663 |
| PLPC | .50578*** | .17277 | 2.93 | .0034 | .16716 | .84439 |
| LF | -1.04474** | .19211 | -2.10 | .0358 | .75217 | .02876 |
| CD | -.02361 | .07712 | -.27 | .7893 | -.17179 | .13057 |

| Variance parameters for compound error.........................

| Lambda | 0.03739*** | .86909 | 3.49 | .0005 | 1.33402 | 4.74077 |
| Sigma | 0.96185*** | .01020 | 94.25 | .0000 | .94153 | .98458 |

***, **, * ===> Significance at 1%, 5%, 10% level.
Model was estimated on Apr 27, 2013 at 07:55:43 PM

| -> dstat; rhs=EZPOOL13

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Cases</th>
<th>Missing Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>EZPOOL13</td>
<td>.532983</td>
<td>.208451</td>
<td>.180192</td>
<td>.874072</td>
<td>73</td>
<td>0</td>
</tr>
</tbody>
</table>

238
Appendix 4B: Pooled Normal-Exponential SFA Estimates

Normal-Exponential Stoc. Frontier Model
Dependent variable: TCFC
Log likelihood function: -67.96199
Estimation based on N = 73, K = 7
Inf. Cr. AIC = 149.9 AIC/N = 2.054

Exponential frontier model
Variance: Sigma-squared(v) = 0.20726
Sigma-squared(u) = 0.15675
Sigma(v) = 0.18826
Sigma(u) = 0.44357

Stochastic Cost Frontier Model, e = v+u
----- [Tests vs. No Inefficiency] -----
LR test for inefficiency vs. OLS v only
Deg. freedom for sigma-squared(u): 1
Deg. freedom for heteroscedasticity: 0
Deg. freedom for truncation mean: 0
Deg. freedom for inefficiency model: 1
LogL when sigma(u)=0: -88.47866
Chi-sq=2*[LogL(SF)-LogL(LS)] = 1.033
Kodde-Palm C*: 95%: 2.706, 99%: 5.412
LM test for sigma(u) = 0 based on ols e
Chi-sq(1)=(N/6)*[m^3/s^3]^2 = 1.444

Wald tests based on MLs shown in table

<table>
<thead>
<tr>
<th>Deterministic Component of Stochastic Frontier Model</th>
<th>TCFC</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>z</th>
<th>Prob.</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.19069</td>
<td>1.17065</td>
<td>1.02</td>
<td>0.3091</td>
<td>-1.10374</td>
<td>3.48512</td>
</tr>
<tr>
<td>Y</td>
<td>0.29917***</td>
<td>0.08664</td>
<td>3.33</td>
<td>0.0024</td>
<td>0.10883</td>
<td>0.49941</td>
</tr>
<tr>
<td>PLFC</td>
<td>0.53605***</td>
<td>0.17422</td>
<td>3.08</td>
<td>0.0021</td>
<td>0.19453</td>
<td>0.87771</td>
</tr>
<tr>
<td>LF</td>
<td>-0.38129*</td>
<td>0.23100</td>
<td>-1.65</td>
<td>0.0988</td>
<td>-0.83403</td>
<td>0.07145</td>
</tr>
<tr>
<td>CD</td>
<td>-0.05260</td>
<td>0.07909</td>
<td>-0.67</td>
<td>0.5060</td>
<td>-0.20760</td>
<td>0.10241</td>
</tr>
</tbody>
</table>

| Variance parameters for compound error |-----------------|
| Sigma                                      | 2.25446* | 1.17874 | 1.92 | 0.0554 | -0.05192 | 4.56095 |
| | 0.15634 | 2.91 | 0.0036 | 0.14503 | 0.76160 |

***, **, * --> Significance at 1%, 5%, 10% level.
Model was estimated on Apr 27, 2018 at 08:01:27 PM

| -> dstat; rhz-EEPOOL2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Cases</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>EEPOOL2</td>
<td>.667324</td>
<td>.162899</td>
<td>.210497</td>
<td>.064627</td>
<td>73</td>
<td>0</td>
</tr>
</tbody>
</table>

239
Appendix 4C: Cost Efficiency Measurements for Nigerian EDCs

- **PHEDC Pooled Efficiency**
- **AEDC Pooled Efficiency**
- **YEDC Pooled Efficiency**
- **BEDC Pooled Efficiency**
- **Eko EDC Pooled Efficiency**
- **Enugu Pooled Efficiency**
- **IEDC Pooled Efficiency**
- **IKEDC Pooled Efficiency**
- **JEDC Pooled Efficiency**
- **KEDC Pooled Efficiency**
- **Kaduna Pooled Efficiency**
### Appendix 5A – Results of Structural Equation Model Estimations

lavaan (0.5-22) converged normally after 61 iterations

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of observations</td>
<td>57</td>
</tr>
<tr>
<td>Number of missing patterns</td>
<td>7</td>
</tr>
<tr>
<td>Estimator</td>
<td>ML</td>
</tr>
<tr>
<td>Minimum Function Test Statistic</td>
<td>135.555</td>
</tr>
<tr>
<td>Degrees of freedom</td>
<td>102</td>
</tr>
<tr>
<td>P-value (Chi-square)</td>
<td>0.015</td>
</tr>
</tbody>
</table>

Model test baseline model:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Function Test Statistic</td>
<td>443.295</td>
</tr>
<tr>
<td>Degrees of freedom</td>
<td>120</td>
</tr>
<tr>
<td>P-value</td>
<td>0.000</td>
</tr>
</tbody>
</table>

User model versus baseline model:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparative Fit Index (CFI)</td>
<td>0.896</td>
</tr>
<tr>
<td>Tucker-Lewis Index (TLI)</td>
<td>0.878</td>
</tr>
</tbody>
</table>

Loglikelihood and Information Criteria:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loglikelihood user model (H0)</td>
<td>-1334.325</td>
</tr>
<tr>
<td>Loglikelihood unrestricted model (H1)</td>
<td>-1266.548</td>
</tr>
<tr>
<td>Number of free parameters</td>
<td>50</td>
</tr>
<tr>
<td>Akaike (AIC)</td>
<td>2768.651</td>
</tr>
<tr>
<td>Bayesian (BIC)</td>
<td>2870.803</td>
</tr>
</tbody>
</table>
Sample-size adjusted Bayesian (BIC)  2713.625

Root Mean Square Error of Approximation:

RMSEA  0.076
90 Percent Confidence Interval  0.035  0.108
P-value RMSEA <= 0.05  0.123

Standardized Root Mean Square Residual:

SRMR  0.097

Parameter Estimates:

Information          Observed
Standard Errors      Standard

Latent Variables:

|                    | Estimate | Std.Err | z-value | P(>|z|) | Std.lv | Std.all |
|--------------------|----------|---------|---------|---------|--------|---------|
| Efficiency_attribute =~ |          |         |         |         |        |         |
| AIDS3              | 1.000    | 0.665   | 0.569   |         |        |         |
| AIDS4              | 0.697    | 0.267   | 2.606   | 0.009   | 0.463  | 0.399   |
| AIDS5              | 1.030    | 0.296   | 3.477   | 0.001   | 0.685  | 0.578   |
| AIDS6              | 1.211    | 0.300   | 4.042   | 0.000   | 0.805  | 0.715   |
| AIDS7              | 0.718    | 0.257   | 2.795   | 0.005   | 0.477  | 0.431   |
| AIDS8              | 1.111    | 0.272   | 4.082   | 0.000   | 0.739  | 0.739   |
| AIDS9              | 1.145    | 0.279   | 4.099   | 0.000   | 0.761  | 0.727   |
| AIDS10             | 1.047    | 0.294   | 3.562   | 0.000   | 0.696  | 0.599   |
| AIDS11             | 1.321    | 0.309   | 4.280   | 0.000   | 0.879  | 0.803   |
| Variable    | Estimate | Std.Err | z-value | P(>|z|) | Std.lv | Std.all |
|-------------|----------|---------|---------|--------|--------|---------|
| AIDS12      | 1.374    | 0.341   | 4.032   | 0.000  | 0.914  | 0.745   |
| Efficiency_benefit =~ |          |         |         |        |        |         |
| AEDS1       | 1.000    |         |         |        | 0.663  | 0.600   |
| AEDS2       | 1.318    | 0.292   | 4.520   | 0.000  | 0.874  | 0.789   |
| AEDS3       | 1.250    | 0.325   | 3.844   | 0.000  | 0.829  | 0.717   |
| AEDS4       | 2.861    | 1.520   | 1.882   | 0.060  | 1.898  | 0.281   |
| AEDS5       | 1.132    | 0.276   | 4.108   | 0.000  | 0.751  | 0.804   |
| AEDS6       | 1.134    | 0.302   | 3.758   | 0.000  | 0.752  | 0.629   |
| Efficiency_perception =~ |         |         |         |        |        |         |
| Effncy_ttrbts | 1.000 |         |         |        | 0.736  | 0.736   |
| Efficincy_bnft | 0.618 | NA      | 0.456   | 0.456  |         |         |

Intercepts:

| AIDS3       | 3.596    | 0.155   | 23.254  | 0.000  | 3.596  | 3.080   |
| AIDS4       | 3.425    | 0.155   | 22.091  | 0.000  | 3.425  | 2.949   |
| AIDS5       | 3.264    | 0.158   | 20.670  | 0.000  | 3.264  | 2.755   |
| AIDS6       | 4.032    | 0.150   | 26.894  | 0.000  | 4.032  | 3.580   |
| AIDS7       | 3.985    | 0.148   | 26.940  | 0.000  | 3.985  | 3.595   |
| AIDS8       | 4.091    | 0.139   | 30.719  | 0.000  | 4.091  | 4.088   |
| AIDS9       | 3.754    | 0.139   | 27.056  | 0.000  | 3.754  | 3.584   |
| AIDS10      | 3.807    | 0.154   | 24.749  | 0.000  | 3.807  | 3.278   |
| AIDS11      | 4.175    | 0.145   | 28.810  | 0.000  | 4.175  | 3.816   |
| AIDS12      | 3.940    | 0.163   | 24.135  | 0.000  | 3.940  | 3.212   |
| AEDS1       | 3.930    | 0.146   | 26.827  | 0.000  | 3.930  | 3.553   |
| AEDS2       | 4.298    | 0.147   | 29.298  | 0.000  | 4.298  | 3.881   |
| AEDS3       | 3.877    | 0.153   | 25.327  | 0.000  | 3.877  | 3.355   |

243
|        | Estimate | Std.Err | z-value | P(>|z|) | Std.lv | Std.all |
|--------|----------|---------|---------|--------|--------|---------|
| AEDS4  | 4.877    | 0.896   | 5.444   | 0.000  | 4.877  | 0.721   |
| AEDS5  | 4.070    | 0.124   | 32.902  | 0.000  | 4.070  | 4.358   |
| AEDS6  | 3.895    | 0.158   | 24.611  | 0.000  | 3.895  | 3.260   |
| Effcncy_ttrbts | 0.000 |        |         |        | 0.000  | 0.000   |
| Efficincy_bnft | 0.000 |        |         |        | 0.000  | 0.000   |
| Effcncy_prcptn | 0.000 |        |         |        | 0.000  | 0.000   |

Variance:

|        | Estimate | Std.Err | z-value | P(>|z|) | Std.lv | Std.all |
|--------|----------|---------|---------|--------|--------|---------|
| AIDS3  | 0.921    | 0.184   | 4.999   | 0.000  | 0.921  | 0.676   |
| AIDS4  | 1.134    | 0.220   | 5.168   | 0.000  | 1.134  | 0.841   |
| AIDS5  | 0.935    | 0.189   | 4.956   | 0.000  | 0.935  | 0.666   |
| AIDS6  | 0.620    | 0.135   | 4.609   | 0.000  | 0.620  | 0.489   |
| AIDS7  | 1.001    | 0.195   | 5.130   | 0.000  | 1.001  | 0.815   |
| AIDS8  | 0.455    | 0.102   | 4.476   | 0.000  | 0.455  | 0.455   |
| AIDS9  | 0.518    | 0.117   | 4.443   | 0.000  | 0.518  | 0.472   |
| AIDS10 | 0.864    | 0.175   | 4.947   | 0.000  | 0.864  | 0.641   |
| AIDS11 | 0.425    | 0.109   | 3.914   | 0.000  | 0.425  | 0.355   |
| AIDS12 | 0.669    | 0.155   | 4.316   | 0.000  | 0.669  | 0.445   |
| AEDS1  | 0.783    | 0.166   | 4.708   | 0.000  | 0.783  | 0.640   |
| AEDS2  | 0.462    | 0.135   | 3.417   | 0.001  | 0.462  | 0.377   |
| AEDS3  | 0.649    | 0.161   | 4.024   | 0.000  | 0.649  | 0.486   |
| AEDS4  | 42.155   | 8.014   | 5.265   | 0.000  | 42.155 | 0.921   |
| AEDS5  | 0.308    | 0.095   | 3.234   | 0.001  | 0.308  | 0.353   |
| AEDS6  | 0.862    | 0.186   | 4.634   | 0.000  | 0.862  | 0.604   |
| Effcncy_ttrbts | 0.202 | NA   |         | 0.458  | 0.458  |
| Efficincy_bnft | 0.349 | NA   |         | 0.792  | 0.792  |
| Effcncy_prcptn | 0.240 | NA   |         | 1.000  | 1.000  |

R-Square:

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>Value</td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>AIDS3</td>
<td>0.324</td>
</tr>
<tr>
<td>AIDS4</td>
<td>0.159</td>
</tr>
<tr>
<td>AIDS5</td>
<td>0.334</td>
</tr>
<tr>
<td>AIDS6</td>
<td>0.511</td>
</tr>
<tr>
<td>AIDS7</td>
<td>0.185</td>
</tr>
<tr>
<td>AIDS8</td>
<td>0.545</td>
</tr>
<tr>
<td>AIDS9</td>
<td>0.528</td>
</tr>
<tr>
<td>AIDS10</td>
<td>0.359</td>
</tr>
<tr>
<td>AIDS11</td>
<td>0.645</td>
</tr>
<tr>
<td>AIDS12</td>
<td>0.555</td>
</tr>
<tr>
<td>AEDS1</td>
<td>0.360</td>
</tr>
<tr>
<td>AEDS2</td>
<td>0.623</td>
</tr>
<tr>
<td>AEDS3</td>
<td>0.514</td>
</tr>
<tr>
<td>AEDS4</td>
<td>0.079</td>
</tr>
<tr>
<td>AEDS5</td>
<td>0.647</td>
</tr>
<tr>
<td>AEDS6</td>
<td>0.396</td>
</tr>
<tr>
<td>Efficncy_ttrbts</td>
<td>0.542</td>
</tr>
<tr>
<td>Efficincy_bnft</td>
<td>0.208</td>
</tr>
</tbody>
</table>

> # fit indices

```r
> fit.indices <- c("chisq", "df", "cfi", "rmsea", "srmr", "mfi")
> fitMeasures(trait.fit1, fit.indices)

  chisq    df   cfi   rmsea   srmr   mfi
135.555 102.000 0.896  0.076 0.097 0.745
```
Appendix 5B: Questionnaire used for consumer survey
Efficiency studies on the Electricity Distribution Sector of West Africa

Political Economy Analyses: efficiency of the electricity distribution sector of West Africa.

Hello, my name is Richard Oduro, a postgraduate researcher carrying out a research on the efficiency of the electricity distribution sector of West Africa. This research is a major requirement for the award of a Doctor of Philosophy (Ph.D.) degree at the University of Surrey, UK. Please answer all the questions to the best of your ability. I can guarantee in no uncertain terms that the information you will provide will be anonymised, handled in confidence – and used unreservedly, for its intended purpose. Filling the questionnaire will take about 20 minutes of your time. If you have any difficulty in the process of responding to the questionnaire, please do not hesitate to ask. Thank you.

Email: r.oduro@surrey.ac.uk

Top of Form

Do you have an idea on the major changes or reforms in the electricity distribution sector of your country?

1. Do you have an idea on the major changes or reforms in the electricity distribution sector of your country?
   - Yes
   - No

Do you understand the role of reforms on efficiency, affordability and accessibility of electric power?

2. Do you understand the role of reforms on efficiency, affordability and accessibility of electric power?
   - Yes
   - No

What is your perception on the efforts made through reforms for achieving an efficient distribution sector?

3. What is your perception on the efforts made through reforms for achieving an efficient distribution sector?
   - Low pace
   - Normal pace
   - Fast pace
No opinion
<table>
<thead>
<tr>
<th>Cause of Inefficiency</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Voltage is a major cause of inefficiency</td>
<td>Agree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>Inadequate supply of power is a major cause of inefficiency</td>
<td>Agree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>Irregular Meter reading is a major cause of inefficiency</td>
<td>Agree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>Heavy electricity bills is a major cause of inefficiency</td>
<td>Agree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>Unfenced transformers is a major cause of inefficiency</td>
<td>Agree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>Defective connections is a major cause of inefficiency</td>
<td>Agree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>Unusual power cut is a major cause of inefficiency</td>
<td>Agree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>Improper working of transformers is a major cause of inefficiency</td>
<td>Agree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
</tbody>
</table>
What would be one outstanding thing that could cause a huge transformation with regards to efficiency in the distribution system?

4. What would be one outstanding thing that could cause a huge transformation with regards to efficiency in the distribution system?

Please indicate how much you agree with the following statements concerning your perception of the attributes of an inefficient distribution system – using a scale of 1 to 5, where; 1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree.
5. Please indicate how much you agree with the following statements concerning your perception of the attributes of an inefficient distribution system – using a scale of 1 to 5, where; 1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree.

What do you do when you are confronted with any of the problems in question 5?

6. What do you do when you are confronted with any of the problems in question 5?
   - I report to the Electricity Distribution Company
   - I don’t know what to do
   - I don’t bother reporting
   - I report to the regulatory institutions overseeing the electricity distribution industry
   - Other (please specify)

Have you ever made an official complaint to the EDC (Electricity Distribution Company) or any regulatory body overseeing the EDC?

7. Have you ever made an official complaint to the EDC (Electricity Distribution Company) or any regulatory body overseeing the EDC?
   - Yes (please go to the next question)
   - No (please go to question 10)

How many times have you sent complaints regarding any of the problems in Q5?

8. How many times have you sent complaints regarding any of the problems in Q5?
   - Once
   - More than once
   - Several
   - Never

Was your problem solved?

9. Was your problem solved?
   - Yes on time
What have you done differently in managing your energy use after the increase in electricity prices?

10. What have you done differently in managing your energy use after the increase in electricity prices?

- Reduced consumption
- Increased consumption
- Wholly or partly produce and consume electric power
- Nothing
- Changed jobs or line of business to increase income
- Changed electric appliances or wiring to more efficient ones

Is there a single intervention you consider that could lead to an improved and efficient electricity distribution sector; such as a particular operational tool or policy? (Please give details)

11. Is there a single intervention you consider that could lead to an improved and efficient electricity distribution sector; such as a particular operational tool or policy? (Please give details)

Please indicate how much you agree with the following statements concerning your perception of the benefits of an efficient distribution system – using a scale of 1 to 5, where; 1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree

<table>
<thead>
<tr>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neither disagree nor agree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>One of the benefits of an efficient distribution sector is lower cost of power to consumers</td>
<td>Strongly disagree</td>
<td>One of the benefits of an efficient distribution sector is lower cost of power to consumers</td>
<td>Disagree</td>
<td>One of the benefits of an efficient distribution sector is lower cost of power to consumers</td>
</tr>
</tbody>
</table>
Aside the above what do you think are the benefits of an efficient electricity distribution sector

12. Please indicate how much you agree with the following statements concerning your perception of the benefits of an efficient distribution system – using a scale of 1 to 5, where; 1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Strongly agree</th>
<th>Agree</th>
<th>Neither agree nor disagree</th>
<th>Disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>One of the benefits of an efficient distribution sector is less corruption</td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>One of the benefits of an efficient distribution sector is more financial stability of Private Power Producers or Power Producers in general</td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>One of the benefits of an efficient distribution sector is reliable energy source to the industrial and commercial sectors</td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>One of the benefits of an efficient distribution sector is more financial stability of Private Power Producers or Power Producers in general</td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>One of the benefits of an efficient distribution sector is more financial stability of Private Power Producers or Power Producers in general</td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>Efficiency of the benefits of an efficient distribution system</td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>One of the benefits of an efficient distribution sector is reliable energy source to the industrial and commercial sectors</td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>Efficiency of the benefits of an efficient distribution system</td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>One of the benefits of an efficient distribution sector is reliable energy source to the industrial and commercial sectors</td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>Efficiency of the benefits of an efficient distribution system</td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>One of the benefits of an efficient distribution sector is reliable energy source to the industrial and commercial sectors</td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither agree nor disagree</td>
<td>Agree</td>
<td>Strongly agree</td>
</tr>
</tbody>
</table>
13. Aside the above what do you think are the benefits of an efficient electricity distribution sector

The main problem in the efficient management of EDCs in your country is?

14. The main problem in the efficient management of EDCs in your country is?

- Insufficient skilled labour to implement efficiency reforms
- Insufficient transformers, sub-stations and less durable cables
- Technical constraints that aid in inefficiency. (e.g. systems are incompatible)
- Financial inefficiency (e.g. debt management problems)
- Corrupt operational workers
- Corrupt managerial staff

Please indicate how much you agree with the following statements concerning your perception of the political factors that affect the efficiency of the distribution system using a scale of 1 to 5, where; 1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree

15. Please indicate how much you agree with the following statements concerning your perception of the political factors that affect the efficiency of the distribution system using a scale of 1 to 5, where; 1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree

<table>
<thead>
<tr>
<th></th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neither disagree nor agree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>The process of implementing the efficiency reforms has been frustrated by the political interests at the local level. Strongly disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The process of implementing the efficiency reforms has been frustrated by the political interests at the local level. Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The process of implementing the efficiency reforms has been frustrated by the political interests at the local level. Neither disagree nor agree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The process of implementing the efficiency reforms has been frustrated by the political interests at the local level. Agree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The process of implementing the efficiency reforms has been frustrated by the political interests at the local level. Strongly agree</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither disagree nor agree</td>
<td>Agree</td>
<td>Strongly agree</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>---------</td>
<td>---------------------------</td>
<td>-------</td>
<td>--------------</td>
<td></td>
</tr>
</tbody>
</table>
 Many powerful people benefit more from the current distribution system than they would from a more efficient electricity distribution sector.  
| Many powerful people benefit more from the current distribution system than they would from a more efficient electricity distribution sector. |
| Many powerful people benefit more from the current distribution system than they would from a more efficient electricity distribution sector.  
| Many powerful people benefit more from the current distribution system than they would from a more efficient electricity distribution sector.  
| Many powerful people benefit more from the current distribution system than they would from a more efficient electricity distribution sector.  
| Many powerful people benefit more from the current distribution system than they would from a more efficient electricity distribution sector.  

Which organisations or individuals, not currently involved in the electricity distribution sector would be most influential if they could be convinced to join a coalition to promote efficiency?

16. Which organisations or individuals, not currently involved in the electricity distribution sector would be most influential if they could be convinced to join a coalition to promote efficiency?

Which organisations or individuals, if any, are most keen to oppose efficiency reforms in electricity distribution?

17. Which organisations or individuals, if any, are most keen to oppose efficiency reforms in electricity distribution?

Why do you think these organisations or individuals oppose efficiency reforms?

18. Why do you think these organisations or individuals oppose efficiency reforms?

What organisations are most important in providing "effective scrutiny" of the process of efficient distribution of electricity to ensure best practice?

19. What organisations are most important in providing "effective scrutiny" of the process of efficient distribution of electricity to ensure best practice?

- The Press
- The Parliament
Please give suggestions relating to how the electricity distribution sector can become more efficient in your country. Also kindly say whether your EDC should be privatised or not with reasons.

20. Please give suggestions relating to how the electricity distribution sector can become more efficient in your country. Also kindly say whether your EDC should be privatised or not with reasons.

Kindly provide us with the name of the Electricity Distribution Company serving you.

21. Kindly provide us with the name of the Electricity Distribution Company serving you.

Please provide your contacts below if you care for an interview. Thank you very much.

22. Please provide your contacts below if you care for an interview. Thank you very much.

Done