UNIVERSITY OF GHANA

COLLEGE OF HUMANITIES

THE IMPACT OF OWNERSHIP AND VERTICAL INTEGRATION ON THE PERFORMANCE OF PETROLEUM FIRMS

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DEPARTMENT OF OPERATIONS AND MANAGEMENT INFORMATION SYSTEMS

JULY 2017

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THIS THESIS IS SUBMITTED TO THE DEPARTMENT OF OPERATIONS AND MANAGEMENT INFORMATION SYSTEMS, UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MPHIL OPERATIONS MANAGEMENT DEGREE

DEPARTMENT OF OPERATIONS AND MANAGEMENT INFORMATION SYSTEMS

JULY 2017

DECLARATION

I do hereby declare that this work is the result of my own research and has not been presented by anyone for any academic award in this or any other university. All references used in the work have been fully acknowledged.

I bear sole responsibility for any shortcomings.

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CERTIFICATION

I hereby certify that this thesis was supervised in accordance with procedures laid down by the University of Ghana.

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DEDICATION

To Joyce Adagsana Asuah and Daniel Akwesi Agyapong

ACKNOWLEDGEMENT

To God be the glory for He has indeed been faithful. I owe it all to the almighty God for His grace and wisdom and for seeing me through another phase of life.

My deepest gratitude goes to my principal supervisor, Dr. Kwaku Ohene-Asare and Co-supervisor Dr. Anthony Afful-Dadzie, both of the Department of Operations and Management Information Systems of the University of Ghana Business School, for their meticulous guidance, constructive criticisms and sacrificial support which made this work possible. I cannot forget the valuable contribution of Mr Charles Turkson to the completion of this work. I truly appreciate his advice, time and comments offered to refine this work. Further appreciation goes Dr. Francis Y. Banuro, Dr. Amin Karimu, Mr Abeeku S. Edu and to all other lecturers and staff of the Department of Operations and Management Information Systems for their support.

I sincerely appreciate Dr. Daniel Agyapong, Dr John G. Gatsi and Prof. G. K. T. Oduro, all of the University of Cape Coast whose immense support and encouragement have seen me through this programme.

I am really grateful to Mr Leonard Prah, Mr Abu Sadiq Williams and all my course mates of the MPhil Operations Management class for their support throughout this programme. Much appreciation to Mr Godwill Agordor and Ms Charlotte Semonno for their time to proofread and review this work.

Finally, my heartfelt thanks goes to my parents, siblings, colleagues and friends who have supported me in diverse ways to make this work possible.

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LIST OF ABBREVIATIONS AND ACRONYMS

BCC	Banker Charnes and Cooper
BP	British Petroleum
CCR	Charnes Cooper and Rhodes
CNPC	China National Petroleum Corporation
CRS	Constant Returns to Scale
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DTGR	Dynamic Technology Gap Ratio
EIA	Energy Information Administration
FP	Fully Private
FSO	Fully State-Owned
Geomean	Geometric Mean
HI	Highly Integrated
IEA	International Energy Agency
IGO	Intergovernmental Organizations
IOC	International Oil Company
LI	Least Integrated
MaSO	Majority State-Owned
MiSO	Minority State-Owned
MTR	Meta Technology Ratio
NIOC	National Iranian Oil Company
NOC	National Oil Company
OAPEC	Organization of Arab Petroleum Exporting Countries
OECD	Organization for Economic Cooperation and Development
ONGC	Oil and Natural Gas Corporation

OPEC	Organization of the Petroleum Exporting Countries
PDV	Petróleos de Venezuela
PIW	Petroleum Intelligence Weekly
PRT	Property Rights Theory
RBV	Resource-Based View
SFA	Stochastic Frontier Analysis
SI	Semi Integrated
Std. Dev	Standard Deviation
TE	Technical Efficiency
TGR	Technology Gap Ratio
UK	United Kingdom
USA	United States of America
VI	Vertical Integration
VRS	Variable Returns to Scale

ABSTRACT

The petroleum industry is one of the essential industries globally. State participation and vertical integration are some of the most prevailing phenomena in the industry. This study sought to assess the impact of ownership and vertical integration on the performance of petroleum firms. Petroleum firms were categorized into four different clusters, based on ownership types, comprising fully private, minority state owned, majority state owned and fully state owned for the assessment on ownership. The firms were again grouped into least integrated, semi integrated and highly integrated based on their level of forward vertical integration for the assessment of vertical integration in the industry. These groupings help to determine the specific levels of state ownership or vertical integration that is helpful or detrimental to the performance of petroleum firms.

In order to assess the performance of these groups of oil firms which might face different production technologies in a dynamic fashion while accounting for carryover variables such as oil and gas reserves, the Metafrontier framework was incorporated into the Dynamic Slack Based Measure (DSBM) of DEA to propose a DSBM-Metafrontier model.

Using a 10-year data of 32 petroleum firms globally, it was found that fully state-owned firms were the best performers followed by fully private, majority state-owned and lastly, minority state-owned firms. This is an indication that not all types of state-owned petroleum firms are outperformed by private petroleum firms. Firms with shared ownership between state and private have a lesser comparative advantage in the industry than those firms with full private or full state ownership. On vertical integration, semi integrated firms topped the list followed by least integrated and lastly, highly integrated firms. The study also reveals that though integration could be beneficial, it is a costly strategy and can impact negatively on technical efficiency. Vertical integration should therefore be done in moderation if it must be embarked upon.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

The oil and gas industry, also known as the petroleum industry, is one of the most crucial industries globally as most economies depend on it (Barros & Assaf, 2009; Eller, Hartley, & Medlock, 2011; Ike & Lee, 2014). Indeed, individual households, power, transportation, and manufacturing sectors depend on oil based products for their daily operations (Devold, 2013; Francisco, de Almeida, & da Silva, 2012; Ismail et al., 2013). Even the sturdy development of emerging economies such as China and India is likely to further increase the heavy dependence on oil (Barros & Assaf, 2009). Besides, the World Trade Organization (WTO), reports that the total annual value of oil and related trade is about $615 billion, representing 9.8% of the total global commodities trade (Ismail et al., 2013). Again, petroleum firms count among the largest firms in the world, dominating the top ten (10) of the Fortune 500 company rankings (Fortune Magazine, 2016). This explains the rigorous and continuous academic research in this area.

Government intervention by way of state-owned National Oil Companies (NOCs) is one of the prominent features of the global petroleum industry (Al-Obaidan & Scully, 1993; Barros & Managi, 2009; Eller et al., 2011). State ownership of oil firms could be in varying degrees from full ownership, majority or minority state ownership. Prior to the 1970s, the international oil industry was dominated by private International Oil Companies (IOCs) until recently when the industry is overtaken by NOCs (Ike & Lee, 2014). This development might probably be because governments have deemed the oil industry too important an industry to be left in the control of private IOCs (Mommer, 2002). Previous studies, however, posit that state ownership of oil companies contributes greatly to inefficiency (Al-Obaidan & Scully, 1991; Eller et al., 2011; Ike

& Lee, 2014; Wolf, 2009). However, the question as to what extent of government ownership is good or bad for oil firms has been left unanswered by these studies.

The oil and gas industry is also an industry characterized by vertical integration. Vertical integration is an integral part of supply chain management where businesses seek to satisfy their customers efficiently by linking their upstream and downstream activities in order to maximize their profits (Chima, 2007). In their effort to withstand competition and minimize high transaction costs that characterize the oil markets, some petroleum companies have attempted to own parts of their supply chain instead of relying on other players in the industry (Guan & Rehme, 2012). Though vertical integration has been seen as an essential way of dealing with high transaction cost, reducing business risks and providing strategic independence (Guan & Rehme, 2012), it has received little attention in the oil efficiency literature. As yet, only Al-Obaidan and Scully (1993); Eller et al. (2011) and Ike and Lee (2014) have attempted to investigate its effects on the efficiency of oil firms but none of them did it in a dynamic setting. In the business world, however, businesses are concerned about long term planning and investment as they intend to exist into the foreseeable future (Tone & Tsutsui, 2010). Therefore, a dynamic assessment of efficiency is more suitable for performance evaluation than single period optimization model. Also, Ike and Lee (2014) only considered vertical integration as a control variable which does not adequately assess such an important subject.

Due to its importance, the petroleum industry has attracted a number of efficiency studies. Some of these studies have applied stochastic frontier methods while others have applied data envelopment analysis techniques. That notwithstanding, oil efficiency and productivity studies have not been able to account for non-radial input excesses and output shortfalls as well as the interconnecting activities that will enable appropriate long term performance assessment (Hung, He, & Lu, 2014; Tone & Tsutsui, 2010). This could lead to over estimating the efficiencies of these oil firms where non-radial slacks might be accounted for as efficiency. Also, studies have ignored group specific differences that may exist among petroleum firms despite the fact that these group differences can affect the performance of the firms involved.

This study addresses the above issues and to achieve effective analysis and credible results, interconnecting activities and group dynamics are considered using the Dynamic Slack Based Measure (DSBM) of Tone and Tsutsui (2010) and the metafrontier analysis of Battese, Rao, and O'Donnell (2004) on the basis of vertical integration and extent of state ownership.

1.2 Problem Statement

Several oil and gas efficiency and productivity studies exist (Al-Obaidan & Scully, 1991; 1993; 1995; Barros & Assaf, 2009; Cuñado & de Gracia, 2003; Eller et al., 2011; Hawdon, 2003; Ike & Lee, 2014; Ismail et al., 2013; Ohene-Asare, Turkson, & Afful-Dadzie, 2015; Sueyoshi & Goto, 2012a, 2012b; Thompson, Lee, & Thrall, 1992; Wolf, 2009). Yet, this study identifies some gaps in literature. First, although a number of studies recommend private ownership over state ownership except Sueyoshi and Goto (2012a), only Wolf (2009) has attempted to compare the efficiency of oil firms on the basis of the typologies of government ownership. The degree of ownership could vary such as fully state-owned, majority state-owned, minority state-owned or fully private or even state agency and state minority owned oil firms (Chen, Firth, & Xu, 2009; Chen & Chen, 2012; Cuervo-Cazurra, Inkpen, Musacchio, & Ramaswamy, 2014; Li, Cui, & Lu, 2014; Wolf, 2009). Chen et al. (2009), for instance, investigated the relative efficiency of various forms of state-owned listed firms versus private listed firms in China and observed that private listed firms are superior to some categories of state-owned firms but not superior to other categories of state-owned firms. This implies that there may be differences among the performances of various typologies of state-owned firms that need to be explored.

Second, few studies have examined the impact of vertical integration on efficiency in the oil industry and none has assessed the impact of vertical integration on dynamic efficiency in the oil industry. While topical issues in oil efficiency literature include state versus private ownership (Al-Obaidan & Scully, 1991; Eller et al., 2011; Ike & Lee, 2014; Wolf, 2009) and multinational operations, (Al-Obaidan & Scully, 1991; Eller et al., 2011; Ike & Lee, 2014; Ohene-Asare et al., 2015), the issue of vertical integration has received little attention from previous studies. Only Al-Obaidan and Scully (1993) and Ike and Lee (2014) have considered vertical integration in the oil sector. Studies have indicated that effective supply chain management enables companies to lower the resources required to provide the required level of customer service and to improve customers service through increased product availability and reduction in order cycle time (Chima, 2007; Potter, Childerhouse, Banomyong, & Supatn, 2011). Vertical integration is also believed to help in reducing transaction costs, uncertainties and improving strategic independence (Guan & Rehme, 2012). Considering the fact that the oil industry is characterized by vertical integration (Chima, 2007), more in-depth studies on this subject has become imperative. Of the few studies in the sector, Al-Obaidan and Scully (1993) tested the impact of vertical integration on economic efficiency of petroleum refining firms from 1979-1982 but they used stochastic frontier analysis which sets average performers as the benchmarks instead of the best performers. Also, although the study population was downstream companies, the study used barrels of crude oil produced as one of its outputs. However, barrels of crude oil produced is not a typical output of petroleum refining firms. Ike and Lee (2014) as well as Eller et al. (2011) only included vertical integration as a control variable which does not adequately assess such an important subject. This therefore creates a gap for in-depth investigation into whether indeed there exists dynamic performance differences among least integrated, semi integrated and highly integrated oil firms.

Third, previous DEA studies in the petroleum industry have failed to consider carry-over activities which are interconnecting activities between different operational periods (Hung et al., 2014; Tone & Tsutsui, 2010; Wanke, Barros, & Faria, 2015). In the oil industry, oil reserves and gas reserves are usually carried over from one operational period to another if not exhausted in the previous period, hence they do not pertain to only one period's operations. Treating them as inputs used uo in a particular period might make firms with higher reserves appear inefficient since they will be assumed to use more inputs relative to their output. This is why their usage as inputs (Eller et al., 2011; Ike & Lee, 2014; Sueyoshi & Goto, 2012b; Thompson, Lee, & Thrall, 1992) could lead to erroneous conclusions. The traditional DEA model, cannot effectively assess long-term efficiency changes since it ignores the effect of linkages between two successive periods. Conversely, the dynamic DEA model provides a more reliable assessment of time-specific dynamic efficiencies over long time periods, making it more suitable than a single period static assessment (Tone & Tsutsui, 2010). The traditional DEA models applied by some studies in the industry (Eller et al., 2011; Ike & Lee, 2014; Sueyoshi & Goto, 2012b; Thompson et al., 1992; Wolf, 2009) also fail to incorporate non-radial slacks. Although Ike and Lee (2014) applied the Slack Based Measure which captures non-radial slacks, it does not incorporate carry-over activities. The Dynamic Slack Based Measure Approach by Tone and Tsutsui (2010) applied in this study for the first time, to the best of the author's knowledge in the oil industry, addresses these issues of non-radial slacks and carry-overs.

Lastly, there is no DEA model, to the best of the author's knowledge, that measures group efficiency over time in the presence of carry-overs. This study seeks to measure group dynamic efficiency on the basis of vertical integration and typologies of government ownership. However, an examination of the DEA literature reveals that no study has so far come up with a model that incorporates the DSBM of Tone and Tsutsui (2010) and Metafrontier approach of Battese and

Rao (2002); Battese et al. (2004); O'Donnell, Rao, and Battese (2008) to assess group dynamic efficiency. The firms in the industry could be categorized based on ownership, diversification, vertical integration and size among others. It is worth noting that different groups could exhibit possible technology heterogeneity originating from differences in infrastructure, resource endowment, firm-specific characteristics and other environmental factors (Oh & Lee, 2010). The metafrontier approach is able to incorporate group heterogeneity but fails to assess the dynamic efficiency. Meanwhile, although the original dynamic model (DSBM) by Tone and Tsutsui (2010) does a great job of considering linkages, it fails to account for group heterogeneity. Again, though previous studies have assessed group dynamic performance using the Metafrontier Malmquist Productivity Index (Chen & Yang, 2011; Oh & Lee, 2010), Metafrontier Cost Malmquist Productivity Index and Metafrontier Profit Malmquist Productivity Index (Huang, Juo, & Fu, 2015; Thanassoulis, Shiraz, & Maniadakis, 2015), these studies did not consider the effect of interconnecting activities. The need to provide an extension to the dynamic model to assess group efficiency in a dynamic fashion has therefore, become necessary for the progress of this study.

1.3 Research Contributions

The study makes important contributions to policy, practice and literature. Policy-wise, the findings and recommendations of this study will provide the oil industry regulators such as Organization of the Petroleum Exporting Countries (OPEC); International Energy Agency (IEA); Organization for Economic Cooperation and Development (OECD); and Organization of Arab Petroleum Exporting Countries (OAPEC) with insights into potential avenues for policy enhancement on issues of ownership and vertical integration in the oil industry. The study is good for oil industry management who may be interested in knowing whether carry-over activities and non-radial slacks serve as key performance indicators. For practice, the study helps to ascertain the potential wastages in the international oil industry while catering for carry-over activities with the aim of making managers better informed about their true performance over time. Assessing the degree of state-ownership will also help the regulators of National Oil Companies (NOCs) determine the level of state control that is healthy for the performance based on the recommendations of this study. Also, managers of petroleum companies who might want to assume control of other aspects of their supply chain through vertical integration will be better guided by the findings of this study on their decision making.

To academic literature, this study contributes in three ways. First, this is the premier study to develop a group dynamic efficiency model that incorporates group heterogeneities and carry-overs. The study extends existing literature by proposing a DSBM-Metafrontier approach to concurrently handle inter-connecting activities and group dynamics in efficiency assessment. Second, it is the first time assessment of the impact of the typologies of government ownership on dynamic performance of oil firms using DSBM-Metafrontier analysis. Lastly, the study is also the first oil efficiency study to assess the impact of vertical integration on dynamic performance of oil firms.

1.4 Research Questions

The following research questions will be answered

1. Which oil firms are dynamically efficient?
2. Does the degree of state ownership affect the dynamic efficiency of oil firms?
3. What is the impact of vertical integration on dynamic efficiency of oil firms?
4. What DEA model is appropriate for assessing group dynamic efficiency?

1.5 Research Objectives

The general objective of this study is to assess the impact of ownership and vertical integration on the performance of oil firms while accounting for non-radial slacks, carry-overs and group heterogeneity. Specifically, the study seeks to:

1. assess the dynamic efficiency of oil firms
2. examine the impact of the degree of state ownership on dynamic efficiency of oil firms
3. analyse the impact of vertical integration on dynamic efficiency of oil firms
4. propose a model extension to the DSBM and Metafrontier to assess group dynamic efficiency

1.6 Research Scope and Limitations

Although this study contributes to academic research, practice and policy, it is not devoid of some limitations regarding method, data and time. Methodologically, the study uses DEA, which is outlying distribution-free, and hence, may statistically be constrained due to the presence of outliers and sampling variations that may bias the results. This issue can be dealt with via bootstrapping or resampling techniques. Still, bootstrapping approximates the true frontier and is not a complete solution to the problem. Yet, we adopt SZAL which is used to purge the results off possible sampling variations and biases. In terms of data, it would have been statistically interesting to obtain data from a larger sample for this study since there are numerous oil companies worldwide but in this study only a sample size of 32 firms is used. This is as a result of the requirement of dynamic slack based measure of Tone and Tsutsui (2010) that the sample must be a balanced panel. This implies that a firm lacking data on just one variable for a single year had to be deleted and this constrained the number of firms as well as the number of years considered in the study. This notwithstanding, the 32 firms chosen constitute a good representation of the largest 50 oil firms reported in the fortune magazine throughout the period under consideration sourced from the Energy Intelligence Weekly. Lastly, the study is limited by the availability of funds to acquire up-to-date data for better analysis.

1.7 Thesis Structure

The study consists of six chapters. Chapter one describes the background, research problem, research objectives and questions, contributions of the study as well as proposed methodology and limitations of the study. Chapter two analyzes and synthesizes related and relevant literature including theoretical and empirical reviews. Chapter three discusses the context of the study whereas in Chapter Four, the population, sample and data collection procedure and analysis techniques used as well as the approach and design of the study are discussed. The data and their analysis and discussions are presented in the fifth chapter. The final chapter discusses the findings of the study and provides recommendations for policy and future research.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter presents a review of relevant theoretical and empirical literature on vertical integration, ownership and efficiency of oil firms and a resulting conceptual framework. The theoretical review presents the theoretical background relating to ownership and vertical integration of oil firms. The second part reviews empirical studies on ownership, vertical integration and efficiency in the petroleum industry. Insights from the previous sections are organized into a conceptual framework in the last section.

2.1 Theoretical Review

There exists a number of theories that explain the concepts of ownership of firms and vertical integration and their relationship with the performance of firms. In this study, property rights and agency theories are adopted to explain the ownership and performance nexus whereas the issue of vertical integration is studied using the transaction cost theory and resource-based view. These are discussed below.

2.1.1 Ownership and firm performance

The link between state ownership and corporate performance has attracted research interest from the time of Adam Smith's observation that ‘‘characters do not exist who are more distant than the sovereign and the entrepreneur’’ (Ike & Lee, 2014). There have been a number of theories to explain this relationship including the property rights theory, agency theory, public choice theory and theories of regulation (Wolf, 2009). This study anchors on the property rights theory and the agency theory to investigate the performance dissimilarities between state ownership and private ownership of petroleum companies. These are discussed below in detail.

2.1.1.1 Property rights theory (PRT)

Debates on the relative efficiency of private versus public enterprise has an extended history in economic literature (Crain & Zardkoohi, 1978). The property rights perspective in economics is one of the main theories that underlies the belief in public ownership inefficiency (Yu, 2013). The classical property rights theory is traceable to the early works of Coase (1960), Alchian (1965), Demsetz (1964, 1966, 1967) and Alchian and Demsetz (1973) which has subsequently led to the proposition of a "modern property rights theory" following the works of Grossman and Hart (1986) and (Hart & Moore, 1990) (Kim & Mahoney, 2010). The property rights theory is suitable for explaining business phenomena such as joint ventures and institutional change. Indeed, the theory is at the interface of organization theory, economics and law (Kim & Mahoney, 2005).

Alchian (1965) defines property rights as the rights of persons to use some resources with the support of the force of social custom, etiquette, ostracism and formal legally enacted laws supported by state powers of violence and punishment. This definition is conceptually wide and stresses the legal facet of property rights and the social norms that govern (business) conduct, such as corporate culture and reputation (Kim & Mahoney, 2005). Yet, the property rights theory is concerned with the economic rights of the individual or entity in the property (Kim & Mahoney, 2010). Furubotn and Pejovich (1972) therefore, describes all economic activities encompassing trade and production as the exchange of bundles of property rights. Libecap (1989) views property rights as the rights to use, to earn income from, and to transfer or exchange the assets and resources while Hart and Moore (1990) believe that this right includes the ability to exclude others from the usage of that resource. Thus, it is worth noting that, the property rights to use a resource may be held separately from the property rights to buy or sell that same resource (Kim & Mahoney, 2010). From the above-mentioned, it can be deduced that different individuals may hold different partitions of rights to particular aspects of a single resource (i.e. shared ownership). Hence, the

PRT, resolves the potential struggle and rivalry that may arise in these situations by clarifying that if two or more parties who hold different partitions of the rights to a property fail to co-exist peacefully, property rights must be partitioned into suitable bundles and allocated to the party with the ability to generate the most benefits from the resource (Coase, 1960; Demsetz, 1967). For example, if two oil firms have the right to drill oil from a particular well but fail to co-exist, the right of drilling must be assigned to that party who is capable of generating higher economic gains from this well. This principle of allocation to the highest-valued use of the PRT is believed to serve as an incentive to utilize resources more efficiently (Demsetz, 1967).

The greater the divergence of the property rights structure of a firm from the free enterprise system described by Alchian and Demsetz (1973), the greater the likelihood that resources will be allocated on political basis instead of on the principle of allocation to the highest-valued use (Al-Obaidan & Scully, 1991). Meanwhile, the theory asserts that property rights in the private sector are more clearly defined than in the public sector, and consequently, the motivation for pursuing profit by private owners leads to more effective monitoring of management performance (Alchian, 1965; Yu, 2013).

Studies posit that due to the numerous agency problems inherent in state-owned firms the likelihood of misallocation of resources is higher and will translate into higher inefficiency (Al-Obaidan & Scully, 1993). For example, state-owned firms may be expected to corporate with politicians to achieve employment policies, reduce reliance on imports, restrict their investments to certain areas and all these may lead to misallocation of resources instead of allocation according to the highest-valued use. Some studies argue that as public managers are less likely to share in the costs or rewards from effective performance than their colleagues in private firms, the opportunity cost of economic inefficiency is reduced (Crain & Zardkoohi, 1978). This, coupled with the lack of proper monitoring mechanisms afford managers of public firms a greater chance to amass wealth for themselves to the detriment of the employer (citizen). Therefore, managerial activities such as coordinating, organizing and planning productive activity are expectedly decreased in the public enterprise (Yu, 2013). There is an added effect of non-transferability of property rights that can affect resource allocation of managers in public entities. The lack of a market mechanism through which the future costs of current decisions are capitalized into the present value of the firm implies that resources allocation will be skewed extremely towards short-term objectives (Al-Obaidan & Scully, 1991; Crain & Zardkoohi, 1978). That is, public officials can only enjoy the direct benefits of their decisions during their occupancy of office whilst the consequences of these decisions can span further than their political tenure, hence, do not affect their net worth aside from the costs they bare as taxpaying citizens. This argument suggests that resource allocation in politically managed firms will tend to be prejudiced against long-term capital investment and towards utilization of factors of production for short-term goals which might not maximize value for employers.

From the views examined above, it is expected that the higher the extent of state control in a particular firm, the higher the tendency to misallocate resources and hence the higher the inefficiency.

2.1.1.2 Agency theory

Propounded by Jensen and Meckling (1976), the agency theory has been widely applied by scholars in a number of fields, including economics, accounting, finances, sociology, organizational behavior, and political science (Eisenhardt, 1989). The agency theory describes an agent as an individual or entity hired by one or more person(s) known as the principal(s) and compensated under a contract to achieve desired results for the principal. The principal gives away some decision-making authority to the agent to act on his/her behalf (Eisenhardt, 1989; Jensen & Meckling, 1976; Petersen, 1993). To execute the assigned responsibilities, the agent chooses an action which has certain consequences called outcomes which affect the wellbeing of both parties (Petersen, 1993). Elected representatives and citizens, employees and employers, and company managers and stockholders (Kiser, 1999) are all examples of the agency contract. In each of the above scenarios, the former is the agent who is expected to act in the interest of the principal whilst the latter is the principal (Miles, 2012). The agency theory is described by Kim and Mahoney (2005) as one that works within various constraints to optimize a desired organizational outcome.

Eisenhardt (1989) argues that agency theory aims at rectifying two likely problems in agency relationships: First, the agency problem that arises when the goals of the principal conflicts with those of agent, and the principal finds it very expensive or difficult to monitor the activities of the agent. The problem here is that the principal is unable to verify if the agent has acted in the right manner. The second problem is that of risk sharing which emerges when the principal and agent have divergent orientations towards risk. The difficulty in this case is that the principal and the agent may prefer different actions due to the differences in their risk preferences.

The agency theory acknowledges that once both parties seek to maximize their utility (which are mostly conflicting), there is bound to be a conflict of interest between the objectives of the principal and those of the agent because of the difficulty involved in reconciling the conflicting interests of both parties (Eisenhardt, 1989; Hartley & Medlock, 2012; Jensen & Meckling, 1976). For instance, in the corporate setting, stockholders who are the owners of diversified portfolios of a firm usually delegate financial and other decision making to corporate managers who are expected to act in the best interest of such stockholders (Crutchley & Hansen, 1989). The agency problem arises, where shareholders expect management to take decisions that will maximize shareholder value diversifying firm-specific risks, while management may also be interested in maximizing their own needs, by pursuing risk aversive options that will increase their own wealth at the stockholders' expense (Al-Obaidan & Scully, 1991).

Previous studies have noted that the management of the agency problem is more complicated in state-owned companies than their private sector counterparts (Ding, Zhang, & Zhang, 2007; Eller, Hartley, & Medlock III, 2011; Ohene-Asare et al., 2015). Aside the existing owner-manager conflicts, there exists some other conflicts among the controlling (majority) shareholders and the minority shareholders since the majority shareholders might have some dominating interests which might not be in the interest of the other shareholders (Ding et al., 2007). In the case of companies with majority state-ownership, firms may be forced to embark on non-economic goals such as employing local or political figures to occupy leading positions, employing excessively to reduce unemployment, or even pursue certain social and political objectives which are detrimental to the efficiency of such firms in order to favour their political goals (Al-Obaidan & Scully, 1991; Hartley & Medlock, 2008). This obviously is not in the best interest of investors who are interested in maximizing their returns.

It must be noted that political authorities who exercise the controlling authority are themselves not the true owners of such authority (Cuervo-Cazurra et al., 2014; Ding et al., 2007). The citizens are the true owners of such authority which is delegated to politicians through elections. Whilst the citizenry may be interested in sustainability of the firm into the long term, politicians, in their bid to retain power for their government, may embark on policies and goals that shift resource utilization away from the future toward the present (Eller et al., 2011), creating a conflict of interest between those two parties (Cuervo-Cazurra et al., 2014).

This inherent conflict in the principal-agent relationship requires that some measures be put in place in order to align the agent's interest to that of the principal. To this end, there is an important question that must be addressed, who will monitor the monitor? (Alchian & Demsetz, 1972). Though, it is generally difficult for the principal to always ensure that the agent acts in the principal's best interest, three ways have been suggested to help curtail the agency problem. They include board independence (to separate oversight responsibility from management to ensure objective monitoring of managers); agent equity ownership (shares of the company are owned by managers to serve as incentive for effective performance); and market for corporate control (ill-behaved managers are disciplined by an active merger and acquisition market); (Crutchley & Hansen, 1989; Dalton, Hitt, Certo, & Dalton, 2007; Eisenhardt, 1989).

From the foregoing, although both privately owned and state-owned companies suffer adversely from the agency problem, companies with majority state control are likely to suffer more from the agency problems than their private counterparts (Eller et al., 2011).

2.1.2 Vertical integration and firm performance

2.1.2.1 Transaction cost theory

Systematic exploration of transaction cost issues commenced with the traditional works of Coase (1937) and Williamson (1971, 1979, 1986) (Hennessy, 1996). Transaction cost economics explains firm behavior based on the cost of transactions in economic relationships among actors. Simply put, the theory looks at whether a firm should buy something or make it instead (Miles, 2012). Transaction costs arise from the presence of information asymmetries and imperfect contracting alongside opportunism and asset specificity (Williamson, 1985).

Asset specificity refers to the degree to which assets that are suitable for a transaction are channeled to it and the opportunity costs for using those same assets for the next-best alternative (Williamson, 1985). Williamson (1985) identified four types of asset specificity including site, physical, human, and dedicated specificity. Site specificity refers to highly immobile assets that remain in place to save transportation and inventory costs. Physical specificity refers to equipment and machinery that are specific to a particular transaction. Human specificity refers to human capital or other employee education and training that is specific to this relationship while dedicated specificity refers to substantial investments that were made only for this transaction and have no value outside this transaction (Miles, 2012). In a transaction, opportunistic behaviors are triggered when one party has specific assets. This puts the other contracting party at risk and requires costly contractual safeguards to deter those negative behaviors (Miles, 2012; Poppo & Zenger, 1998). Asset specificity the presence of imperfect and asymmetric information in contracts which lead to opportunistic behavior by economic actors are identified as the main sources of transaction costs (Cuervo-Cazurra et al., 2014). The basic unit of analysis in transaction cost theory is the transaction. A transaction is said to have occurred when a good or service is transferred across the boundary of an organizational (Miles, 2012).

The theory emphasizes transaction costs as one of the principal factors that determine the structure of an industry. Indeed Coase (1937) suggested that transactions will be organized within the organization if doing so incurs lesser cost than the cost of buying from the market. He cited that the costs of continuous re-contracting with an externa firm or manager can be comparatively higher than just signing a long-term contract with one employee who agrees to execute the orders of the employer. Barkema and Cook (1993) argue that integration and the use of contract arrangements are effective tools in reducing or eliminating two types of costs, namely, the search cost of procuring a large, steady supply of raw product, and the risk cost of procuring inferior raw product

(Hennessy, 1996). For businesses to consistently meet the demands of their customers, they also need consistent and reliable sources of raw materials but finding such reliable suppliers could be quite challenging and costly. Customers are usually unable to accurately assess the quality of suppliers and can be opportunistically exploited by suppliers (Eisenhardt, 1989). Customers are faced with risk where suppliers without the required skills to provide certain quality levels might misrepresent themselves by making false quality claims leading to adverse selection (Mishra, Heide, & Cort, 1998). Consequently, firms may resort to vertical integration in order to avoid these costs. Furthermore, Frank and Henderson (1992) identify transaction costs as a reason for vertical integration in U.S. food industry. Deterministic transaction costs as discussed by Coase could, therefore, be a source of the move towards increased vertical integration (Hennessy, 1996). In a world of zero transaction costs, transactions would be instant and efficient. However, if transaction costs are positive and non-negligible, transactions will expectedly be slow, and in some instances may result in failure to reach a contractual agreement (North, 1990). Williamson (1979) points out that the transaction costs theory focuses on matching transactional characteristics with appropriate governance mechanisms such as integration along the supply chain. Therefore, the theoretical insight of this theory is that in a world of positive transactions costs, a comparative assessment of different modes of organizing economic activities is needed (Kim & Mahoney, 2005).

From the views above, we can deduce that vertical integration is the response to high transaction costs arising from opportunistic behavior, supplier unreliability, technology spill over and economies of scale (Al-Obaidan & Scully, 1993). Vertical integration can therefore, be viewed as the result of the relatively high cost of using external markets to transact. A few studies, however argue that in the face of rapid technological change which renders upstream capabilities obsolete, the benefits of integration are considerably reduced hence, integration might not be the solution to the problem of high transaction costs (Afuah, 2001). They argued that in industries where the rate of technological change is high, firms are better off not being vertically integrated.

2.1.2.2 Resource-based view (RBV)

Resource-based view assesses performance disparities of firms on the basis their resources (Peteraf & Barney, 2003). Attributable to Penrose (1959), the theory explains how a firm's resources influence its growth; and particularly, where growth is constrained by resource inadequacy (Barney, Wright, & Ketchen Jr, 2001). The theory defines an organization's uniqueness and position in competitive situations in the environment (Hoopes, Madsen, & Walker, 2003). The theory's main focus is on how the firms out-compete their competitors based on their strength, competence and resources (Barney, 1991; Miles, 2012; Wernerfelt, 1984). The resource-based view makes two main assumptions: first, firms in a particular industry may vary in their resources, and second, there may not be perfect mobility of these resources across firms. The implication here is that organizational distinctions in resources can be very enduring (Barney, 1991). The focus the RBV is on efficiency-based differences, rather than other ways in which organizations could differ, such as collusion, strategic behaviors and market power (Peteraf & Barney, 2003).

The resource-based theory revolves around the central idea that firms compete against each other using their capabilities and resources (Barney, 1991; Wernerfelt, 1984). Wernerfelt (1984) describes a resource as anything that could be perceived as a strength for a firm while Caves (1980) defines resources as any tangible or intangible assets that are semi-permanently attached to the firm. Employee knowledge, skills, and abilities; brand names; machinery and technology; efficient procedures and processes; contracts; and capital are all examples of resources (Miles, 2012; Wernerfelt, 1984). Porter (1981) argues that a firm' s resources epitomizes strengths that enable it to compete better and to realize its vision, mission, strategies, and goals.

The argument therefore, is that a firm has a competitive advantage when it uses a profitable, value-creating strategy that is not being used by competing firms (Barney, 1991) and if competitors are unable to learn about that strategy and copy it, the firm is said to have a sustainable competitive advantage (SCA) (Miles, 2012). The unit of analysis in resource-based theory is the business level (Peteraf & Barney, 2003). In the oil industry, firms with wide range of resources might want to explore these resources fully in order to attain a competitive advantage over their competitors, the efficient and arguably obvious result will be assume control over other aspects of their supply chain via vertical integration (Teece, 1982). The resource-based view thus, provides a framework to explain some of the reasons why firms engage in vertical integration. In this study, we explore how beneficial or detrimental the move towards owning other parts of the supply chain is on the efficiency of oil firms.

2.2 Empirical Review

There exist a number of oil efficiency studies, most of which are on ownership and a few others on multinationality and vertical integration. This section reviews these studies and how they relate to the current study.

2.2.1 Frontier efficiency analysis in the petroleum industry

The efficiency of the global petroleum industry has received attention from academic scholars for quite some time now. Both parametric and non-parametric techniques have been extensively applied in efficiency assessment in the oil and gas industry. Prominent among the techniques applied in the industry are the Stochastic Frontier Analysis (SFA) and non-parametric Data Envelopment Analysis (DEA). Authors such as Al-Obaidan and Scully (1991); (1993); (1995) and Managi, Opaluch, Jin, and Grigalunas (2006) have employed SFA whilst Barros and Assaf (2009); Barros and Managi (2009); Francisco et al. (2012); Hawdon (2003); Ike and Lee (2014); Ismail et al. (2013); Sueyoshi and Goto (2012, 2012a); Thompson, Dharmapala, Rothenberg, and Thrall (1994); (1996) have found the DEA more suitable for efficiency assessment and yet still, others (Eller et al., 2011; Kashani, 2005; Price & Weyman-Jones, 1996) have found it more beneficial to combine the two methods in order to yield the maximum advantages from the two methods. Regression analysis and Aigner and Chu deterministic frontier analysis are also some of the notable techniques applied in the industry which require several assumptions which are sometimes unrealistic in real-world contexts (Chase, 2012).

Oil efficiency studies have considered varying units of analysis ranging from country-level analysis (Hawdon, 2003; Lee, Park, & Kim, 1999), petroleum companies (Eller et al., 2011; Ike & Lee, 2014; Thompson, Dharmapala, Humphrey, Taylor, & Thrall, 1996; Wolf, 2009), oil blocks (Barros & Assaf, 2009; Barros, Managi, & Matousek, 2009), oil refineries (Francisco et al., 2012) as well as drilling wells (Managi, Opaluch, Jin, & Grigalunas, 2005; Managi et al., 2006).

Issues that have been of interest to researchers in the industry include state versus private ownership, privatization, state intervention, regulation, environmental efficiency, multinational operations, vertical integration and the effects of other factors on performance. Ownership and vertical integration which are of primary interest to this study are discussed in-depth in the subsequent sections. Meanwhile, closely related to the issue of government ownership are state intervention (Kashani, 2005), privatization (Price & Weyman-Jones, 1996) and regulation (Hawdon, 2003; Kashani, 2005).

These studies generally suggest that government intervention in the industry translates into inefficiency for the affected firms. For instance using data on 37 Gas Fields in Norway from 1972-2000 Kashani (2005) found that gas fields operated by independent companies exhibited higher efficiencies than those with some level of state interference. They therefore argued that a reduction in state interventions would bring about an improvement in efficiency. In a similar study by the same author, on the effect of regulation on the efficiency of the UK continental shelf petroleum industry, it was revealed that the removal of government restrictions could result in significant improvement in efficiency (Kashani, 2005). Meanwhile, Price and Weyman-Jones (1996) had employed both SFA and DEA in their study and found that the efficiency in the UK gas industry increased remarkably after the privatization as against the pre-privatization scores. Multinationality has also attracted the attention of Al-Obaidan and Scully (1993).

Multinationality seems to have mixed effects as it brings about both advantages and disadvantages. For example, in comparing the efficiencies of 44 oil firms (multinational and local) from the period 1979-1983, they found that local firms out-perform multinationals in technical and economic efficiency. They further argued that multinational oil firms lose about 15% of their technical efficiency due to transaction diseconomies. Multinational oil firms however, exhibit higher scale efficiencies than local firms probably because of their ability to spread investment costs over a large number of firms. Albeit these studies present useful findings, the validity and relevance of these findings for present industry practice becomes questionable since the data used for these studies are quiet outdated. The latest dataset used to study the issues above was from the period 1972-2000 by Kashani (2005). Studies in this industry using more recent data and techniques and taking into consideration changes in industry dynamics over the period have become imperative since technology change over time and industry dynamics render the findings far-fetched.

Another important theme for consideration is environmental efficiency. The petroleum sector is one of the environmentally impacting industries (Francisco et al., 2012) making environmental assessment in the industry very important. Nevertheless, only a few researchers (Ismail et al., 2013; Sueyoshi & Goto, 2012, 2012a) have given attention to the subject. These scholars argue that due to the environmentally impacting nature of the industry, estimating only technical efficiency without consideration of the negative environmental impact could lead to misleading results. More studies are necessary on this subject since environmental assessment is a major policy issue in the world (Sueyoshi & Goto, 2012a).

A few researchers have also shown interest in technology and productivity change. Barros and Antunes (2014); Managi et al. (2006) focused on technological change, productivity change and comparison of Malmquist and Luenberger indices. Barros and Managi (2009) have also juxtaposed Growth Accounting against Productivity Methods. Thompson, Dharmapala, Rothenberg, and Thrall (1994) explored the integration of DEA and other methods like Assurance Region (AR) and Cone Ratio (CR) in assessing efficiency and performance of international oil companies while Thompson et al. (1996) have provided conceptual and methodological contributions for efficiency assessment in the industry.

Other more contextual studies have thrown more light on specific parts of the industry. Barros and Assaf (2009); Barros and Managi (2009); Barros and Antunes (2014) have given more insights into the Angolan oil blocks whereas Managi, Opaluch, Jin, and Grigalunas (2005) and Managi et al. (2006) have provided useful insights into drilling wells in the Gulf of Mexico.

2.2.2 Ownership and firm performance in the petroleum industry

The subject of state ownership versus private ownership has inspired many empirical studies although such studies in the petroleum industry are limited. The petroleum industry is characterized by heavy state involvement probably due to its importance (Mommer, 2002). The question however is whether this involvement has a positive, negative or no impact on the performance of petroleum firms. Survey of existing literature reveals that state-owned NOCs underperform their counterpart Private IOCs. For instance, the heavily cited paper, Al-Obaidan and Scully (1991) assessed the efficiency of 44 oil companies comprising both NOCs and IOCs between 1979 and 1983. Controlling for multinationality and vertical integration, the study observed that state-owned petroleum firms (NOCs) were only 63–65% as efficient in generating revenue as the private oil firms. They indicated that by simply being converted to private IOCs, NOCs could produce the same level of output using less than half of their current input levels. However, in terms of scale and allocative efficiency, both categories performed equally. This implies that, although private petroleum firms are more efficient at converting inputs into outputs and generating revenue, there is little difference in how state and private firms manage the effect of the size of operation and also, how well these firms choose the mix of resources for production (Ohene-Asare et al., 2015). In their study however, Al-Obaidan and Scully (1991) basically considered firms that were vertically integrated hence excluded OPEC member NOCs which includes certain major oil firms such as Saudi Aramco. They argued that only a small portion of their crude produced is processed and that their performance is due to accident of geography rather than resource allocation. Nevertheless, this could lead to failure to provide an all-encompassing conclusion since these firms are influential in the petroleum industry (Brémond, Hache, & Mignon, 2012).

Although Wolf (2009) filled this gap by including OPEC member NOCs in their assessment of performance and efficiency of state versus private oil companies using regression analysis over the period 1987–2006, their findings were no different from those of Al-Obaidan and Scully (1991). Apart from their observation that NOCs are less efficient and less profitable than their private counterparts, they further observed that OPEC membership had a significantly negative impact on the performance of OPEC member NOCs. This was attributable to production quota policy of OPEC members which has a negative impact on firm performance (Turkson, 2015). However, Wolf (2009) employed a panel model with firm-specific intercept terms, and a pooled ordinary least squares estimator that ignores firm-specific heterogeneity. Regardless of the extent of government ownership throughout the study period, all firms that did change ownership were treated similarly. One notable thing in (Wolf)'s work that makes it the closest to this study is that state ownership was sub-grouped into fully state-owned, minority state-owned and majority state-owned. This is very useful in determining the level of state-ownership which could be beneficial or detrimental to performance (Chen et al., 2009). Although intuitive, the study basically focused on private ownership against state ownership in its analysis whilst less was mentioned about the typologies of state ownership. Therefore, it is still unclear as to what level of government ownership is recommended over the other ownership types. Aside that, the study did not take into consideration possible technology heterogeneity that the firms in different groups may face as a result of differences in availability of resources, infrastructure and other firm specific differences that might exist among these groups (Oh & Lee, 2010). These considerations and short comings are addressed in this study.

Eller et al. (2011) addressed the methodological shortcoming in Wolf (2009) by employing both DEA and SFA in their analysis. In SFA the error terms are assumed to have time-invariant firm-specific components, drawn from a distribution that is strictly nonnegative, which represent deviations in firm efficiency from the efficient frontier (Aigner, Lovell, & Schmidt, 1977; Hartley & Medlock, 2012; Meeusen & Vandenbroeck, 1977). Since imposing numerous assumptions could distort the conclusions if the additional assumptions are inappropriate, DEA was also applied. They used a three-year panel data (2002-2004) with the inclusion of OPEC member NOCs and emerged with findings consistent with those of Wolf (2009) and Al-Obaidan and Scully (1991). They found that the extent of government ownership has a negative impact on the performance of oil firms. The study however, failed to report efficiency scores of OPEC member firms included in the sample. Their poor performance could be blamed on political pressure on

NOCs to sell products to domestic consumers at subsidized prices, and to pursue other non-commercial government objectives which can negatively affect the ability of a NOC to generate revenue (Al-Obaidan & Scully, 1991; Eller et al., 2011; Wolf, 2009).

Ike and Lee (2014) improved upon Eller et al. (2011) by increasing the time horizon (2003-2010) as well as reporting on the efficiency of OPEC member NOCs using DEA. Yet, their findings further endorsed those of the previous studies—NOCs performed poorly in relation to IOCs. As earlier observed by Wolf (2009), OPEC member NOCs were among the worst performers. Their study would have been more interesting if interconnecting variables such as oil reserves and gas reserves, which are not just used in one period but flows from one period to the other as explained by Thompson et al. (1994), were considered and treated as such in their analysis.

Sueyoshi and Goto (2012a); (2012b) have also contributed to this discourse. Although more conceptual, their study which focused on differences in environmental impact of NOCs versus IOCs and found that NOCs outperformed IOCs in terms of operational and environmental efficiency and natural disposability whereas IOCs outperformed NOCs in terms of managerial disposability.

Studies reviewed so far have generally established that aside the profit maximization objective, state-owned NOCs pursue other multiple goals which counter the achievement of the profit maximization objective (Dewenter & Malatesta, 2001). Some of these objectives include securing national energy reserves, creating employment, providing subsidized products for the citizens, and other politically motivated goals (Ike & Lee, 2014). This implies that resources in these institutions are not likely to be allocated according to the principle of the highest valued use as required by the property rights theory, hence the resulting lower performance. It has also been noted that unlike the Private IOCs, NOCs serve more masters which is likely to increase the adverse consequences of the agency problem (Eller et al., 2011).

2.2.3 Vertical integration and firm performance in the petroleum industry

Vertical integration has received very little attention in the oil efficiency literature. Although the subject has attracted the attention of some oil efficiency researchers including Al-Obaidan and Scully (1993), Wolf (2009), Eller et al. (2011) and Ike and Lee (2014), as yet, only Al-Obaidan and Scully (1993) have extensively investigated the link between vertical integration and efficiency in the petroleum industry. Comparing the efficiency of 44 oil companies comprising both NOCs and IOCs between 1979-1983 on the basis of their degree of vertical integration, Al-Obaidan and Scully (1993) found that backward vertical integration improves scale efficiency and brings about significant reduction in the business risk. This could probably be because vertically integrated firms are able to spread investment costs over a wide range of operations as suggested by the resource based view. However, vertical integration was also found to reduce both technical and overall economic efficiency of petroleum firms. This becomes a mixed blessing such that although it can be adopted to circumvent the possible uncertainty related to crude oil supply, opportunistic behavior by suppliers as well as minimize closure risk (Al-Obaidan & Scully, 1993; Guan & Rehme, 2012), the study reveals vertical integration as a costly strategy.

The estimated net cost of vertical integration in the downstream sector of the industry was calculated as 38% reduction in the overall efficiency of the firm. This results could further buttress the claim of the industrial organization perspective that as the size of the firm increases the internal cost of operation of the firm increases as well hence vertical integration is seen as a costly strategy (Al-Obaidan & Scully, 1993). Though insightful, more current and thorough studies on this subject are warranted to provide findings consistent with technological change and other industry dynamics that could render the findings of Al-Obaidan & Scully (1993) less relevant for current practice.

Although, Eller et al. (2011) gave a thought to vertical integration in their study, it was included as a mere control variable and received no painstaking analysis. Nevertheless, they found that, a positive relationship exists between the degree of vertical integration and the revenue efficiency of a firm. The argument could be that, a more integrated firm can sell higher valued products as compared to the unintegrated firm. It must be noted however, that the study did not account for the higher capital inputs such as refineries, transport infrastructure, retail outlets, and so on that may be needed to support the activities of vertically integrated firms which could be the reason why these firms appeared more efficient. Similarly Ike and Lee (2014) in investigating the efficiency differences between NOCs and IOCs controlled for vertical integration. However, contrary to the results of Eller et al. (2011) they found that vertical integration has a negative impact on efficiency. In their view, this could be due to the too many objectives of vertically integrated oil companies engaging in both upstream and downstream activities, which can limit their production abilities. They also cited overstaffing as a possible result of vertical integration, which could make a firm appear inefficient. Wolf (2009) merely used vertical integration as one of the basis to compare fully private, minority state-owned, majority state-owned and fully state-owned oil firms. In order to reap the benefits of vertical integration at a minimal cost, firms should only integrate up to the point where the cost of integration does not outweigh the benefits of doing so.

From the above it is clear that the debate on the impact of vertical integration on the performance of oil firms is far from converging. This study seeks to contribute to the ongoing debate on the subject.

2.3 Conceptual Framework

This study assesses the effect of vertical integration and degree of government ownership on the dynamic efficiency of oil firms. The literature reviewed reveals that a relationship exists between ownership and efficiency of oil firms as well as between vertical integration and efficiency. We observed from the literature that government ownership generally has a negative relationship with the efficiency of oil firms. We also observed that even though vertical integration could result in scale efficiency, it is a costly strategy and can have negative effects on the technical and economic efficiency of oil firms. From these findings, the conceptual framework below, has been developed to serve as a guide for this study.

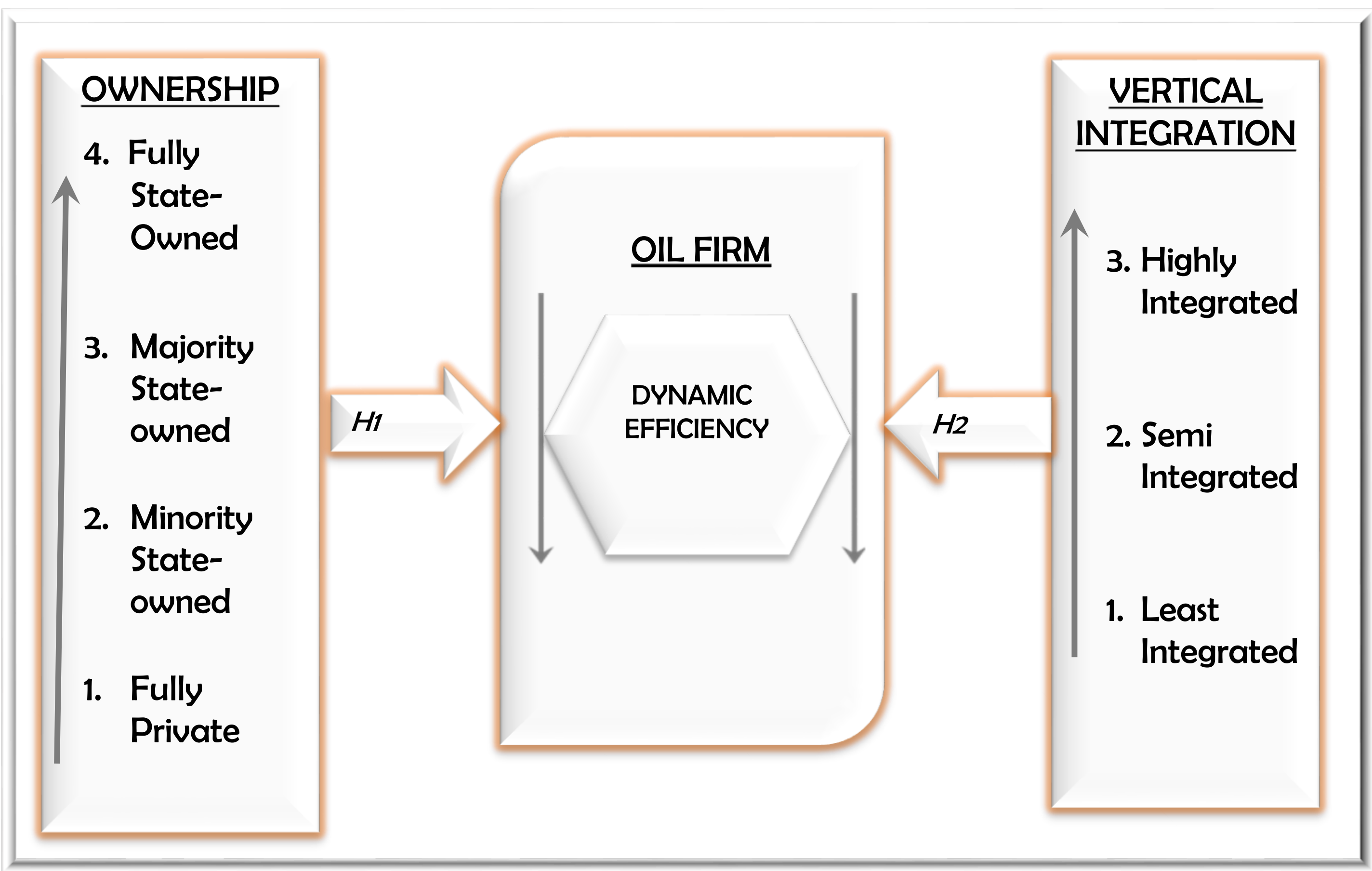

Figure 2.1: Conceptual Framework

Source: Author (2017)

Based on the framework, two hypotheses have been formulated:

Hypothesis 1: *there is a negative relationship between the degree of state-ownership and dynamic efficiency of oil firms.*

Similar to the findings of previous studies it is expected that higher levels of state-ownership of oil firms will result in lesser efficiencies.

Hypothesis 2: *there is a negative relationship between the degree of vertical integration and dynamic efficiency of oil firms.*

As discovered by the few studies vertical integration although positively contributes to scale efficiency, has a negative impact on technical efficiency. It is hence, hypothesized that this study will result in a similar finding.

2.4 Conclusion

This chapter presented the theoretical and the empirical reviews and subsequently, a conceptual framework. In the theoretical review, two theories (agency theory and the property rights theory) underpinning the link between ownership and efficiency were reviewed while the transaction cost theory and resource based view were used to explain the motivation for vertical integration. The empirical review section, reviewed efficiency studies in the petroleum industry that are of interest to this study while the last section which stemmed from the previous sections developed a conceptual framework to guide the study.

CHAPTER THREE

CONTEXT OF THE STUDY

3.0 Introduction

This chapter presents the contextual setting for the study. An overview of the global petroleum industry is presented in the subsequent sections. A synopsis of the industry is presented first, followed by discussions on the value chain of the industry as well as environmental impact of the industry and lastly, the major players in the industry. These expositions provide a fair idea of the petroleum industry, its activities and other issues worth noting.

3.1 Synopsis of the Petroleum Industry

The petroleum (oil and gas) industry is one of the major industries worldwide providing about 60% of the overall petroleum needs (Petroleum Online, 2017). Due to the capital intensive nature of the industry (Szilas, 1986), oil firms count among the largest.

Since Organization of Petroleum Exporting Countries (OPEC) is one of the strong organizations in the industry, an analysis of OPEC reports over the period under study reveals that over the years, the oil and gas industry has experienced some interesting trends worth noting. In the 2000s, the oil market was dominated by OPEC firms as they almost had a monopoly. 2001 saw low oil prices due to the mild recession in the America resulting partly from the September 11 attacks, failure to adhere to production falloffs, and participation of non-OPEC oil firms in the exploration and production of crude oil. For the period 2002 and 2003, oil prices were within OPEC's desired price range probably due to members' compliance to production falloffs and a significant reduction in Venezuela's export coupled with the slow recovery of the US economy (EIA, 2004; OPEC, 2002, 2003). During this period, uncertainty and price volatility characterized the oil market. From 2004 to 2006 the oil prices on the average were quite high resulting from an increase in demand from emerging economies such as Asia and the Middle East whilst production levels remained unchanged among OPEC member states. The global economic recession in 2008 and 2009 brought about interesting trends, prices first shot up unsustainably and later dropped drastically due to contraction in the demand for oil (OPEC, 2008). This brought a fall in the growth global GDP by 3% and a fall in the growth of energy consumption by 1.2%. In 2010, oil prices rose due to growth in demand, gradual recovery from the recession and uncertainty in supply. Also, oil production from non-OPEC countries rose considerably as compared to the previous years (Jaffe, Medlock III, & Soligo, 2011)

3.2 Petroleum Industry Value Chain

A usual oil and gas industry supply chain is composed of an exploration phase at the wellhead, crude procurement and storage logistics, transportation to the oil refineries, refinery operations, and distribution and transportation of the final products (Saad, Udin, & Hasnan, 2013). These activities can be classified into three important phases, namely, the upstream sector, which engages in exploration, development and production of crude oil or natural gas; downstream, which refines the crude oil and gas into usable products for consumers and the midstream sector, which engages in the transportation activities, linking the two major sectors. The midstream sector links the upstream sector to downstream sector as well as downstream sector to consumers using channels such as pipelines, tankers among others. The petroleum industry value chain can be depicted as shown in figure 3.1.

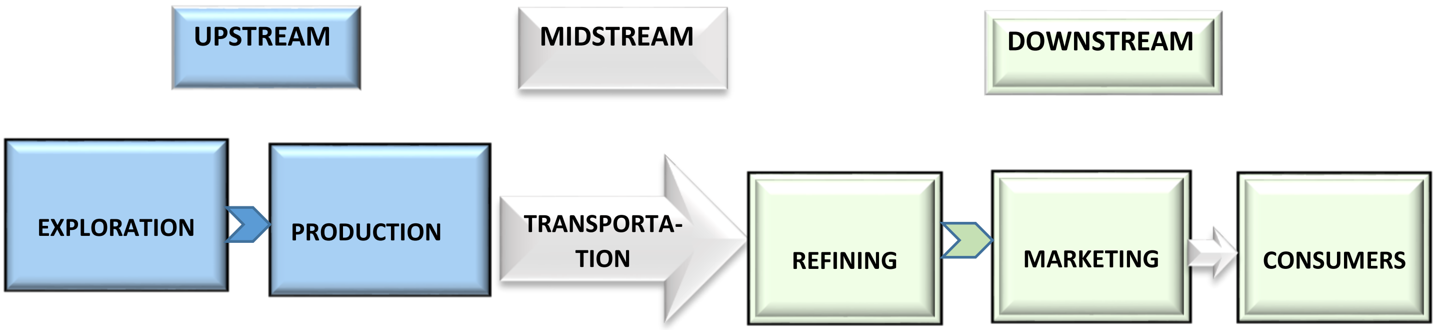

Figure 3.1: Petroleum Industry Value Chain

Source: Adapted from Devold (2013) and Wolf (2009)

3.2.1 Upstream sector

The upstream sector is the part of the value chain that mainly deals in the exploration, evaluation, production and decommissioning as well as sale of crude oil and natural gas (Al-Obaidan & Scully, 1991). Exploration includes prospecting, seismic and drilling activities that are undertaken prior to the decision of whether or not to develop an oil field. Exploration is done in order to identify hydrocarbon bearing rocks which are termed as prospects (Devold, 2013). This sector uses inputs such as labor, assets, capital to produce outputs such as crude oil and gas. The production of oil and gas can take place either onshore or offshore. Offshore production occurs where oil wells are operated on the continental shelf, sometimes in water hundreds of feet deep whereas the onshore production and exploration refers to the development of oil wells and gas fields on the mainland.

The sector also deals with crude oil reserves and gas reserves considered in this study as carryovers even though several studies have treated these as inputs. In this study it is argued that since oil and gas reserves are not used up in one period but carried forward to subsequent periods (Thompson et al., 1994) they should be treated as interconnecting variables instead of inputs which are accounted for in one period. The US Security Exchange Commission defines proven reserves as the estimated quantities of crude oil, natural gas and natural gas liquids, which geological and engineering data demonstrated with reasonable certainty as recoverable in the future years from known reservoirs given the prevailing economic and operating conditions (Jaffe et al., 2011). OPEC (2015) reported about 200,363 billion standard cubic meterss of natural gas and 1,489,865 million barrels of proven crude oil reserves. In spite of the tremendous advancement in science and technology of discovering fossil fuel deposits, the discovery rates for new oil reserves is dwindling fast; For every 4 barrels used, only one is found (Jaffe et al., 2011).

3.2.2 Midstream sector

The midstream operations are sometimes classified within the downstream sector, but these operations comprise a distinct sector of the petroleum industry. The midstream sector of the industry is mainly concerned with transporting crude and gas extracted by the upstream companies to refineries through various channels such as pipelines and tankers as well as transporting the refined products from downstream companies to customers. The midstream sector involves all activities between the oil well head and the refinery. The major inputs for the midstream segment include tanker capacity, pipeline length, labor, capital assets and unprocessed oil and gas (Kim, Lee, Park, & Kim, 1999). Whereas outputs include customer numbers, revenue and quantity of oil and gas deliveries (Kim et al., 1999).

3.2.3 Downstream sector

The downstream sector also referred to as the refining phase is the segment whose activities revolves around the refining of crude and gas into marketable products with defined specifications such as gasoline, diesel or feedstock for the petrochemical industry. This segment also ensures that refined product are made available to customers by engaging in storage and establishing distribution terminals (Devold, 2013; OPEC, 2012). It is at this segment of the value chain that the oil and gas extracted from the upstream sector are converted into useable forms for various consumers. The inputs typically used in this sector include capital assets, labor to produce output such as aviation fuel, gasoline, liquefied petroleum gas, as well as other petrochemical products like tires and rubber and consequently, revenue.

3.3 Environmental Impact of the Petroleum Industry

Despite its enormous importance, the petroleum industry is one of the most environmentally impacting industries worldwide (Francisco et al., 2012). Both the upstream and downstream operations in petroleum industry can generate a large amount of oily wastes (Hu, Li, & Zeng, 2013). Oil and gas exploration and production have harmful impacts on the soil, water, air and living things at large (Kharaka & Hanor, 2003). These impacts arise primarily from the improper disposal of some of the large volumes of saline water produced with oil and gas, from accidental hydrocarbon and produced-water spillages, and from abandoned oil wells (Veil, Puder, Elcock, & Redweik Jr, 2004). The exploration of oil and gas is accompanied by emissions of harmful gasses such as carbon di-oxide and other greenhouse gasses as well as spilling of oils on water surfaces, which cause considerable damage to the ecosystems and climate. This makes environmental assessment in the industry very necessary, however, only few researchers including Sueyoshi and Goto (2012), Francisco et al. (2012) and Ismail et al. (2013) have given the subject a thought in the industry. Future studies could explore mechanisms to minimize these occurrences and their impacts as well as sustainability issues in the industry.

3.4 Participants in Petroleum Industry

The oil and gas industry is made of a number of players such as countries, intergovernmental organizations and oil and gas companies. Although this this study focuses on oil and gas companies, a gist of these players has been provided to better appreciate the activities in the industry.

3.4.1 Countries and intergovernmental organizations (IGOs)

Oil is an indispensable commodity with little or no substitutes. There are also limited number of suppliers of oil hence it is an ideal product for cartelization. The rise of IGOs is tied to a shifting balance of power from the multinational oil companies to the oil producing countries. With the lack of exploration expertise, production technology, refining capability, and distribution networks, oil producing countries were unable to contest the supremacy of the oil companies prior to World War II. Although Mexico wrestled control of its oil industry from foreigners in 1938, it quickly retreated from the profitable international market due to inadequate capital for investment. However, around the time of World War II the oil exporting countries began seeking better terms in their oil contracts, hence, the birth of IGOs. The primary aim of IGOs is to harness complementary forces from member to countries in order to better promote their interests and development as well as contribute to economic, social, and environmental wellbeing at both regional and global levels (Dorussen & Ward, 2008; Escobar & Le Chaffotec, 2015). The petroleum industry, being one of the vital industries, is not devoid of the activities of these IGOs. Below are some IGOs whose activities border greatly on the industry.

3.4.1.1 The Organization of the Petroleum Exporting Countries (OPEC)

The Organization of the Petroleum Exporting Countries (OPEC) was established in Baghdad in September 1960, by five countries viz., Islamic Republic of Iran, Saudi Arabia, Kuwait, Venezuela and Iraq. The membership of the organization later increased gradually as other nine countries namely, Qatar, Indonesia, Libya, the United Arab Emirates, Algeria, Nigeria, Ecuador, Gabon and Angola joined at various points in time (OPEC, 2017). Some members such as Ecuador, Indonesia, and Gabon have at some points in time suspended their membership to the organization and later re-joined. Currently, Indonesia has suspended its OPEC membership hence, the membership of

OPEC stands at 13 countries instead of 14. In the first five years of its existence, OPEC had its headquarters in Geneva, Switzerland, and afterwards, the headquarters was relocated to Vienna, Austria. As with any cartel, the aim of OPEC, is to impose supply limits with the hope of maintaining prices at the desired levels. The oil industry has been afflicted by production booms and dipping prices ever since Colonel Drakes' discovery of oil at Titusville, Pennsylvania in 1859. Just as the major oil companies such as the “seven sisters” colluded from the 1920's to the 1960's to prevent the decline in prices, OPEC members meet recurrently to set production levels in the hope of safeguarding prices and ensuring fair return on investment for investors. During these meetings/conferences, members negotiate decisions concerning OPEC policy, notably production volumes, expected prices and investments undertaken by each country to afford the production scheme (Escobar & Le Chaffotec, 2015).

Additionally, OPEC fosters technological cooperation, sharing of technical knowledge and reserves data to help member countries’ operations. OPEC also launched the OPEC Fund for International Development (OFID), which is mainly dedicated to developing and poor countries. Yet, some member countries: Algeria, Libya, Nigeria, Venezuela, Iraq, and Iran do receive assistance from the OFID (Escobar & Le Chaffotec, 2015). Finally, the bargaining power that OPEC has established for its affiliates may be considered a mutual asset. In all of these, OPEC indirectly helps its member countries reinforce their institutions and develop economically.

3.4.1.2 Organization of Arab Petroleum Exporting Countries (OAPEC)

The Organization of Arab Petroleum Exporting Countries (OAPEC) was formed by an enactment by Kuwait, Libya (Kingdom of Libya at the time) and the Kingdom of Saudi Arabia on January 9, 1968 in Beirut. The state of Kuwait was chosen for the Organizations' domicile and headquarters. By 1982 the Organization was joined by Algeria, Kingdom of Bahrain, Egypt, Iraq, Qatar, Syria, Tunisia and United Arab Emirates which brought the membership to 11. The primary goal of OAPEC is to foster cooperation of its members in various forms of economic activity in the petroleum industry, to build closest ties among members in this field, to determine ways and means of protecting the legitimate interests of its members in the industry, to unify efforts to ensure the flow of petroleum to its consumption markets on equitable and reasonable terms, and to create suitable environment for capital and expertise invested in the petroleum industry in member countries (OAPEC, 2017).

Identifying that petroleum is the major and basic source of its members' income, OAPEC is concerned with the progress and prosperity of the world petroleum industry by nurturing close and fruitful cooperation among its members. It is guided by the belief in the importance of building an integrated petroleum industry as a cornerstone for future economic integration amongst Arab countries and contributes to the effective use of the resources of member countries through sponsoring joint ventures. OAPEC performs its functions and duties through four main organs: The Council of Ministers which is the supreme authority of the Organization, in charge of drawing up its general policy, directing its activity, and laying down governing rules; the Executive Bureau to assist; the General secretariat and a Judicial Board.

3.4.1.3 The Former Soviet Union (FSU)

The Former Soviet Union (FSU) is a product of the disbanding of the Union of Soviet Socialist Republic (USSR) in December 1991 due to a general economic stagnation and depression and its aftermath. The Union is made of 15 independent states including Estonia, Lithuania, Latvia, Belarus, Russia, Kazakhstan, Georgia, Azerbaijan, Ukraine, Armenia, Moldova, Turkmenistan, Uzbekistan, Kyrgyzstan and Tajikistan. The State Planning Committee, commonly known as Gosplan broke down leading to a disruption in the inter-republic economic connections, which led to even more serious breakdown of the post-Soviet economies. Most of the former Soviet states began the transition to a market economy in 1990-1991 and made efforts to rebuild and restructure their economic systems, which triggered a severe transition decline in Gross Domestic Product (GDP) by over 40% between 1990 and 1995. The initial transition decline was eventually arrested by the cumulative effect of market reforms, and after 1995 the economy in the post-Soviet states began to recover, with GDP switching from negative to positive growth rates. By 2007, 10 of the 15 post-Soviet states had reached GDP greater than what they had in 1991.

3.4.1.4 The International Energy Agency (IEA)

The IEA was established in 1974 in response to the 1973/4 oil crisis and its repercussions. The original founding members of the IEA were Austria, Belgium, Canada, Denmark, Germany, Ireland, Italy, Japan, Luxembourg, The Netherlands, Norway, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the United States. The Agency was joined in the succeeding years by Greece, New Zealand, Australia, Portugal, Finland, France, Hungary, Czech Republic, Republic of Korea, Slovak Republic, Poland and Estonia. IEA consequently, has a current membership of 29 countries (IEA, 2017). The broad mandate of IEA borders on energy security and energy policy co-operation among affiliate countries.

IEA's policy decisions and its framework were firmly anchored in its treaty called the "Agreement on an International Energy Program". Hosted in Paris, the Agency aims at becoming the focal point for energy co-operation on such issues as security of supply, long-term policy, information transparency, energy and the environment, research and development and international energy relations (IEA, 2017). The initial role of IEA was to help countries co-ordinate a collective response to major distractions in oil supply via the release of emergency oil stocks to the markets. IEA campaigns for policies that will boost the reliability, affordability and sustainability of energy in its 29 member countries and beyond. The IEA currently focuses on four main areas including energy security, economic development, environmental awareness and worldwide engagement with non-affiliate countries, particularly major oil producers and consumers to find solutions to shared energy and environmental concerns.

3.4.2 Petroleum firms

Petroleum firms are corporate bodies in the industry that engage in various value creating activities be it downstream, upstream or midstream sector. The oil companies are either owned fully by the state, fully by private bodies or partly by the state and partly by private entities. The oil industry was previously dominated by private IOCs until recently when the industry is overtaken by NOCs (Ike & Lee, 2014). This development might perhaps be because governments have considered the petroleum industry too important an industry to be left in the control of private IOCs (Mommer, 2002). Indeed Energy Intelligence's annual ranking of the world's top 50 oil and gas companies published in PIW for 2013, 2014, and 2015 have revealed that state-owned oil companies are retaining their dominant position in the global petroleum industry. The top three spots in 2015 for instance, were held by national oil companies and over 60% of the top 25 oil firms are majority state-owned oil firms (Energy Intelligence, 2015). Table 3.1 below presents the top 10 oil and gas companies in the world as reported in the PIW ranking for 2013.

Table 3.1: Top 10 Global Petroleum Companies

Position	Company	Country	% of State Ownership	Degree of VI	Oil '000 b/d	Gas 'MMcf/d
1	Saudi Aramco	Saudi Arabia	100	HI	9988	10700
2	NIOC	Iran	100	SI	3680	15486
3	ExxonMobil	US	0	HI	2185	12322
4	CNPC	China	100	LI	3050	9047
5	PDV	Venezuela	100	HI	2905	4456
6	BP	UK	0	HI	2056	7393
7	Royal Dutch Shell	Netherlands	0	HI	1633	9449
8	Gazprom	Russia	50	LI	930	47050
9	Chevron	US	0	HI	1764	5071
10	Total	France	0	HI	1220	5880

b/d= Barrels per day, MMcf/d= Million Cubic Feet per day

Source: Energy Intelligence (2014)

3.5 Conclusion

This chapter provided insights into the operations of the petroleum industry. An overview of the petroleum industry, the value chain of the industry, as well as the environmental impact of the industry have been highlighted. The major players in the industry were also discussed.

CHAPTER FOUR

METHODOLOGY

4.0 Introduction

This chapter discusses the procedures, techniques and methods used to achieve the objectives of this study. The chapter explains the research design, sampling and sources of data, data collection procedures, estimation techniques as well as the various methods employed in analyzing the data. The chapter explains how to estimate group dynamic efficiency using linear-programming-based techniques that are widely used in Management Science.

4.1 Research Design

This study seeks to assess the impact of vertical integration and ownership on the dynamic efficiency of oil firms using quantitative data and techniques. To allow objective analysis and conclusions, the positivist paradigm is adopted as a guide to the study (Creswell, 2013; Saunders, Lewis, Thornhill, & Wang, 2009). Thus, a quantitative approach is used to examine collected data using statistical procedures and hypothesis testing. This approach allows us to generalize and replicate the findings of the study (Creswell, 2013). A panel dataset is used to enable the assessment of efficiency changes over time (Wooldridge, 2013).

4.2 Sampling and Sources of Data

The population for this study consists of global petroleum companies: private and state-owned, operating in one or more countries. Petroleum companies are classified into three types: upstream companies which are mainly involved in the exploration, production and sale of crude oil; the midstream companies which are mainly involved in the purchases, storage, transportation and sale of crude and other products to the processing and marketing companies and the downstream companies which are involved in processing and marketing crude products to consumers (Al-

Obaidan & Scully, 1991). This study focuses on the upstream companies, however, since most of the oil companies undertake value-creating activities in both upstream and downstream segments, they are sometimes labeled as integrated oil companies. These integrated companies are selected because they control both the upstream and downstream segments of the industry (Sueyoshi & Goto, 2012b).

This study used a balanced panel dataset of 32 international oil and gas companies from the period 2001 to 2010 to assess group dynamic efficiency of oil firms. The data are sourced from the annual rankings of Energy Intelligence's Petroleum Intelligence Weekly (PIW). These companies are part of the top 50 oil companies globally selected annually by PIW and ranked on the basis of oil reserves, gas reserves, oil production, gas production, product sales, and refining capacity (Energy Intelligence, 2013). Net income, total assets, number of employees and percentage of government ownership are also included in order to permit meaningful comparisons of all types of oil companies (Energy Intelligence, 2013). The sample size of 32 is due to the fact that the DSBM applied in the study requires a balanced data panel (Tone & Tsutsui, 2010). Therefore, a firm with missing data on just one variable for a single year had to be dropped from the study. It is worth noting that PIW is a preferred data source because all firms on this list are globally known companies with numerous years of active involvement in the oil and gas industry (Sueyoshi & Goto, 2012a).

4.3 Frontier Efficiency Analysis

The measurement of technical efficiency is based on the conceptual approach of Debreu (Debreu, 1951) and Koopmans (1951) as first implemented by Farrell (1957). This approach was substantially extended by Charnes, Cooper, and Rhodes (1978) who referred to the technique as Data Envelopment Analysis (DEA) under constant returns to scale and later by Banker, Charnes, and Cooper (1984) (BCC) to handle variable returns to scale. DEA is a nonparametric optimization approach to evaluating the relative efficiency of homogeneous decision making units (DMUs) that use multiple inputs to produce multiple outputs (Banker et al., 1984; Charnes et al., 1978). Using the minimum extrapolation principle based on linear programming techniques, DEA assesses the relative efficiency of homogeneous DMUs based on a constructed frontier (Thanassoulis, 2001). The DMUs on the frontier (the boundary of the technology set) are classified as the efficient ones whilst those DMUs in the interior of the technology set are labeled inefficient (Cook, Tone, & Zhu, 2014). The technique goes further to identify the sources of inefficiency for the dominated units and sets improvement targets as well as role models which can be emulated by these dominated DMUs (Avkiran, 1999). DEA is thus referred to by a number of scholars as an important means for performance evaluation and benchmarking analysis (Cooper, Seiford, & Zhu, 2011; Fried, Lovell, & Schmidt, 2008).

DEA is favoured in this study over other widely used techniques such as ratios and Stochastic Frontier Analysis (SFA) because of a number of reasons. First, unlike ratios and SFA, DEA has the ability to simultaneously deal with several inputs and several outputs (Banker et al., 1984; Charnes et al., 1978; Wanke et al., 2015). Second, DEA unlike ratios, is unit invariant; it is able to work with different units of measurements without the need for calibration (Lovell & Pastor, 1995; Pastor, 1996; Tone, 2001), hence it is possible to work with the number of employees, currency, number of barrels, number of bags et cetera all in the same study without the need to standardize all measurement to the same units. Third, whereas parametric analysis such as SFA requires the specification of functional forms and random error terms in order to estimate the efficiency of DMUs (Fried et al., 2008; Hartley & Medlock, 2012), DEA does not require any of such in its analysis which makes it preferable since these functions and errors are difficult to specify and could lead to erroneous conclusions if not appropriately specified. Finally, the technique is able to break down efficiency into many constituents such as technical, cost, revenue and profit efficiencies. This decomposition is very beneficial to managerial decision making as it helps to specifically identify the key sources of inefficiency in the oil industry. In spite of the numerous benefits of DEA, the technique is not without some challenges. DEA has been criticized as being an outlier methodology since the extreme data points usually form the frontier. Indeed, when there are outliers in the dataset, the frontier can be influenced by these outliers. Additionally, DEA is nonparametric in nature and sometimes researchers and management face the problem of economic interpretation. This shortcoming is however minimized by bootstrapping methods which help to make statistical deductions and also to handle sampling variations and serial correlation of DEA scores (Simar & Wilson, 1998; Simar & Wilson, 1999; Simar & Wilson, 2000).

4.4 Metafrontier Analysis

Since its inception, DEA has received several extensions. The metafrontier analysis is one of such extensions. Introduced by Battese and Rao (2002), enhanced by Battese et al. (2004) and further enhanced by O'Donnell, Rao, and Battese (2008), the metafrontier analysis helps to address some difficulties that accompany the assessment of efficiency of heterogeneous DMUs. While other methods such as ANOVA and second stage regression may be useful in providing some inferences on the impact of environmental variables, combining heterogeneous DMUs may distort the efficiency results (Assaf, Barros, & Josiassen, 2010). The metafrontier approach is therefore, considered a more appropriate approach to employ in assessing the efficiency differences of groups. This is necessary as different groups could exhibit possible technology heterogeneity (Oh & Lee, 2010) originating from differences in infrastructure, resource endowment, firm-specific characteristics and other environmental and institutional factors (O'Donnell et al., 2008).

Metafrontier analysis is based on the metaproduction function of Hayami (1969) and Hayami and Ruttan (1970). The meta-production function has some advantages but fails to account for inherent differences across groups (Battese et al., 2004). Therefore, the metafrontier approach overcomes this limitation allowing comparison across heterogeneous groups (Battese & Rao, 2002; O'Donnell, Rao, & Battese, 2008). Oil firms are in different groups based on their ownership status or their degree of integration along the supply chain and hence, are faced with different production capabilities such as the quality of physical and human capital, economic infrastructure and resource endowment. Therefore, the metafrontier also referred to as pooled or common frontier, envelopes all other group frontiers and creates an overarching frontier for all observations (O'Donnell et al., 2008) to enable a fair comparison. It then measures two different efficiency scores for each DMU; efficiencies relative to the metafrontier (meta efficiency) and relative to the group frontier (group efficiency) from which the technology gap ratio is then calculated.

Following Battese et al. (2004) and O'Donnell et al. (2008), given a nonnegative output vector *y* and input vector *x*, the meta-technology set is defined as:

$$T = \{(x, y) : x \geq 0; y \geq 0; x \text{ can be used to produce } y\} \quad (1)$$

The output-oriented technical efficiency of a DMU relative to the metafrontier (Meta efficiency) $(TE_0^M(x, y))$ based on a VRS assumption, can be defined as follows:

$$
\begin{aligned}
& TE_0^M(x,y) = Max\ \varnothing_o^* \\
& \quad s.t: \\
& \quad \sum_{k=1}^{K}\sum_{j=1}^{n} y_{rj}^k.\lambda_j^k \geq \varnothing y_{ro} \qquad \forall r = 1,\ldots,\ \ \mathrm{s} \\
& \quad \sum_{k=1}^{K}\sum_{j=1}^{n} x_{ij}^k.\lambda_j^k \leq x_{io} \qquad \forall i = 1,\ldots,\ \ m \\
& \quad \sum_{k=1}^{K}\sum_{j=1}^{n} \lambda_{jt}^k = 1 \qquad t = 1,\ldots, \mathrm{T} \\
& \quad \sum_{k=1}^{K}\sum_{j=1}^{n} \lambda_j^k \geq 0 \qquad j = 1,\ldots,\ \ n
\end{aligned}
\tag{2}
$$

It is worth noting that the output oriented Farrell meta efficiency score for inefficient DMUs is greater than 1 because it measures the ratio of expected output to actual output, for easy interpretation, the inverse of the score, the Shephard (1970) distance function is used to restrict the scores between zero and unity. A firm is said to be technically efficient if $\varnothing$ (that is, the reciprocal of the Farell score) is equal to unity and inefficient if $\varnothing$ is less than 1. In the model (2) above, y_{rj}^k represents the amount of the r^{th} output produced by the j^{th} DMU of group k whereas x_{ij}^k represents the amount of the i^{th} input used by the j^{th} DMU in group k. Where m is the number of inputs and s is the number of outputs for a set of n number of DMUs. Also, λ_j^k is the weight assigned to the j^{th} DMU in group k, it shows the importance of DMUj in determining the efficiency of DMUo. $\varnothing$ is equivalent to TE_0^M which estimates the level of output augmentation needed by to make it efficient.

$\sum_{k=1}^{K}\sum_{j=1}^{n} \lambda_j^k = 1$ is the VRS assumption, without which the model assumes CRS.

The efficiencies DMUs within the sub-groups in the meta-technology can be estimated. To do this, the DMUs are now divided into K groups (where $K > 1$). The production technology defined in equation (1) can be redefined for the k^{th} group as:

$$T^{k} = \{(x, y) : x \geq 0; y \geq 0; \text{ } x \text{ can be used by DMUs in group } k \text{ to produce } y \} \quad (3)$$

The VRS group-specific technical efficiency, $TE_0^k(x, y)$, can then be formulated for a DMU relative to its group frontier as defined in equation (4):

$$\begin{aligned}
& TE_0^k(x, y) = Max\ \varnothing_0^* \\
& s.t: \\
& \sum_{j=1}^{n} y^k{}_{rj} . \lambda_j^k \geq \varnothing y_{ro} && \forall r = 1 \ ,..., \ \ s \\
& \sum_{j=1}^{n} x^k{}_{ij} . \lambda_j^k \leq . x_{io} && \forall i = 1 \ ,..., \ \ m \\
& \sum_{j=1}^{n} \lambda_j^t = 1 && t = 1,..., \text{T} \\
& \lambda_j^k \geq 0 && j = 1 \ ,..., \ \ n
\end{aligned} \quad (4)$$

Where $\varnothing$, is the technical efficiency score relative to the group k's frontier.

From the meta efficiency and the group efficiency scores, the Technology Gap Ratio [TGR] (Battese et al., 2004) or Meta Technology Ratio [MTR] (O'Donnell et al., 2008) can be computed. The output oriented technology gap ratio of a DMU in group k, $\text{TGR}_0^k(x, y)$, is the ratio of the DMU's Meta technical efficiency score to its group technical efficiency.

$$\text{TGR}_0^k(x, y) = \frac{TE_0^M(x, y)}{TE_0^k(x, y)} \quad (5)$$

The value of TGR ranges between zero and one and measures the deviation from the metafrontier (available technology irrespective of group) due to membership to a particular group k. In other words, it measures how distant, a particular DMU is from the metafrontier due to its membership to a particular group *k*. The meta technical efficiency of a firm can therefore, be decomposed as its technology gap ratio $\times$ its technical efficiency (O'Donnell et al., 2008) as shown in equation (6) below:

$$TE_0^M(x,y) = \mathrm{TGR}_0^k(x,y) \times TE_0^k(x,y) \tag{6}$$

This decomposition is useful as it allows policy makers to better understand the source of any inefficiency and to properly target efficiency improvement programmes (O'Donnell et al., 2008)

4.4.1 Hypothetical example

A hypothetical data of 9 DMUs belonging to three Clusters, least integrated (LI), semi integrated (SI) and highly integrated (HI) all under the umbrella degree of vertical integration (VI) as presented in Table 4.1 are used to illustrate the Meta-frontier approach. Assume each firm uses 1 input (Labour) to produce 2 outputs (Oil and Gas).

Table 4.1: Hypothetical Data of Different Levels of Vertically Integrated Oil Firms

DMUs	VI	LABOUR	OIL PRODUCED	GAS PRODUCED
L1	LI	1	14	8
L2	LI	1	11	9
L3	LI	1	10	7
S1	SI	1	11	5
S2	SI	1	9	9
S3	SI	1	10	10
H1	HI	1	8	10
H2	HI	1	11	8
H3	HI	1	6	7

A graphical illustration this dataset is presented in Figure 4.1 below;

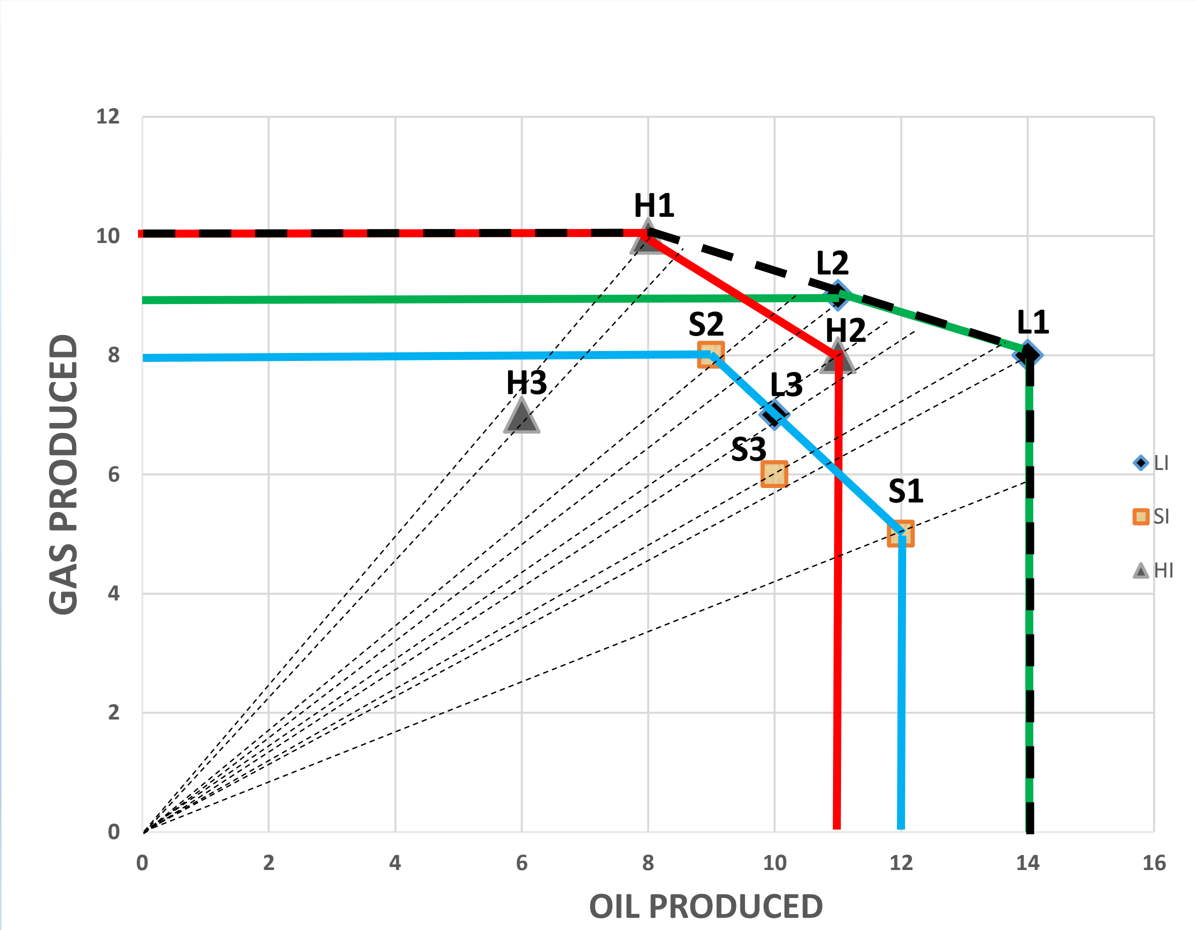

Figure 4.1: Output Oriented DEA Frontiers for Hypothetical Data

Source: Author (2017)

From the graph we have three frontiers representing the three groups of oil firms; least integrated (LI), semi integrated (SI) and highly integrated (HI) as shown in the legend. The dotted frontier shows the overarching frontier that envelops all the three frontiers. It is called the metafrontier. The meta efficiency score of a firm is obtained by measuring the distance to the metafrontier divided by the distance to the firm whilst the group score is obtained by measuring the distance to the group frontier divided by the distance to the firm. For example firm L3's group efficiency is estimated as 10/10 =1, indicating that it is efficient within its group. Its meta efficiency score is estimated as 12.2/10 = 1.22 (or 0.8149, taking the reciprocal for easier interpretation), indicating that it is not efficient relative to the metafrontier. Using these two scores, we calculate the technology gap ratio as 0.8149/1= 0.8149. This implies that, firm L3 produces about 81.49% of the potential output given the technology available to the industry as a whole (Battese et al., 2004). Firm L3 is therefore not taking full advantage of the technology available to the industry and should put in place measures to allow it tap fully into the industry technology. The same can be done for all the oil firms in the sample. This can be modelled and analyzed as shown below:

Output-oriented VRS model for DMU L3 relative to LI frontier

$$
\begin{aligned}
& TE_{L3}^{LI}(x,y) = Max\ \varnothing^{*} \\
& \quad \text{s.t} \\
& 14\lambda_{L1} + 11\lambda_{L2} + 10\lambda_{L3} \geq 10\varnothing \\
& 8\lambda_{L1} + 9\lambda_{L2} + 7\lambda_{L3} \geq 7\varnothing \\
& \lambda_{L1} + \lambda_{L2} + \lambda_{L3} \leq 1 \\
& \lambda_{L1} + \lambda_{L2} + \lambda_{L3} = 1 \\
& \lambda_{j} \geq 0
\end{aligned} \tag{7}
$$

$$\Rightarrow TE_{L3}^{LI}(x,y) = 1$$

Output-oriented VRS model for DMU L3 relative to Metafrontier

$$
\begin{aligned}
& TE_{L3}^{META}(x,y) = Max\ \varnothing^{*} \\
& \quad \text{s.t} \\
& 14\lambda_{L1} + 11\lambda_{L2} + 10\lambda_{L3} + 11\lambda_{S1} + 9\lambda_{S2} + 10\lambda_{S3} + 8\lambda_{H1} + 11\lambda_{H2} + 6\lambda_{H3} \geq 10\varnothing \\
& 8\lambda_{L1} + 9\lambda_{L2} + 7\lambda_{L3} + 5\lambda_{S1} + 9\lambda_{S2} + 10\lambda_{S3} + 10\lambda_{H1} + 8\lambda_{H2} + 7\lambda_{H3} \geq 7\varnothing \\
& \lambda_{L1} + \lambda_{L2} + \lambda_{L3} + \lambda_{S1} + \lambda_{S2} + \lambda_{S3} + \lambda_{H1} + \lambda_{H2} + \lambda_{H3} \leq 1 \\
& \lambda_{L1} + \lambda_{L2} + \lambda_{L3} + \lambda_{S1} + \lambda_{S2} + \lambda_{S3} + \lambda_{H1} + \lambda_{H2} + \lambda_{H3} = 1 \\
& \lambda_{j} \geq 0
\end{aligned} \tag{8}
$$

$$\Rightarrow TE_{L3}^{META}(x,y) = 1.22 \text{ or } 0.8149$$

The group-specific efficiencies (GE) as well as the meta-efficiencies (ME) and TGRs for all DMUs are presented in Table 4.4. For output orientation as in this case, the inverse of the TGR is used in order to ensure that the values are bounded by 0 and 1.

Table 4.2: Output Oriented Meta Efficiencies, Group Specific Efficiencies and TGRs

NO.	DMU	Cluster	Score Metafrontier	Score Group frontier	Technology Gap Ratio
1	L1	LI	1	1	1
2	L2	LI	0.9565	1	0.9565
3	L3	LI	0.7865	0.7865	1
4	S1	SI	0.6897	1	0.6897
5	S2	SI	0.8571	0.9	0.9523
6	S3	SI	1	1	1
7	H1	HI	0.8889	1	0.8889
8	H2	HI	0.88	1	0.88
9	H3	HI	0.5753	0.672	0.8561

From the results in Table 4.2 above, DMU L1 is efficient relative to its group frontier as well as to the metafrontier, hence its TGR is unity implying that it loses nothing by belonging to group LI. The same applies to DMUs S3 but for DMU L3, although it is inefficient relative to both the metafrontier and its group frontier which implies it has taken full advantage of the technology available to the industry as a whole and thus loses nothing by virtue of its membership to group LI. On the other hand, all other DMUs with a TGR of less than one are not taking full advantage of the industry-wide technology, thus they are inefficient due to their membership to the various groups.

4.5 Dynamic Slack-Based Measure (DSBM)

DEA techniques can be classified as radial and non-radial and static or dynamic. Whereas the radial models only permit proportional changes in both inputs and/or outputs in an effort to reach the efficient frontier, the non-radial models sanction both proportional and non-proportional changes in inputs and/or outputs. The CCR and BCC models are examples of radial models while among others, the Additive model (Charnes, Cooper, Golany, Seiford, & Stutz, 1985); Range adjusted measure (Cooper, Park, & Pastor, 1999); Geometric distance function (Portela & Thanassoulis, 2005); Hyperbolic distance function of Russell (1985); Directional distance function (Chambers, Chung, & Färe, 1996); Slack-based measure (SBM) (Tone, 2001) and Dynamic Slack-based Measure (DSBM) (Tone & Tsutsui, 2010) are examples of non-radial models. The radial measures require that the ratio in which inputs are reduced (outputs are augmented) simultaneously be kept fixed while the non-radial models ignore the fixed proportion of input reduction or output augmentation (Cooper, Pastor, Aparicio, & Borras, 2011). The non-radial measures therefore, have more discriminatory power than the radial models and account for both radial and non-radial slacks (wastages in the production process) in estimating efficiency.

The static DEA techniques assess the efficiency of Decision Making Units (DMUs) at a particular point in time aiming at optimization in a single period whereas the dynamic measures are able to assess not just one period efficiency but the performance over time of DMUs. A DMU is simply a unit of assessment converting inputs into outputs whose performance is to be evaluated. The dynamic measures are usually preferred because in the business world, subject to the going concern concept which assumes that the business will remain in operation for the foreseeable future (Hung, He, & Lu, 2014), a long time planning and investment is of paramount importance, hence, a sole period optimization model is not suitable for performance assessment (Tone & Tsutsui, 2010). Dynamic measures of performance include DSBM of Tone and Tsutsui (2010); Window Analysis of Klopp (1985); Malmquist productivity change index (MPI) of Färe, Grosskopf, Lindgren, and Roos (1992); Biennial Malmquist Productivity index (BMI) by Pastor, Asmild, and Lovell (2011) among others

In this study the DSBM of Tone and Tsutsui (2010) is selected due to its advantages over the traditional radial models and its ability to assess dynamic performance (i.e. performance over long period of time). DSBM not only considers both radial and non-radial slacks in its dynamic assessment, but is also able to incorporate carry-over activities (linkages) connecting successive operational periods which is ignored by the other dynamic measures. Carry-over activities, also referred to as linkages or interconnecting activities, are inter-temporal activities that link consecutive operational periods such that they do not affect only one period's operations but the subsequent period's as well (Lu, Wang, & Kweh, 2014; Wanke et al., 2015). For instance, in the petroleum sector, oil and gas reserves that are not exhausted in one period are carried over to the next (Thompson et al., 1994), hence, they should be accounted for in both periods.

Carry-overs have been grouped into four categories: desirable (good), undesirable (bad), free and fixed (Tone & Tsutsui, 2010). Desirable (good) links are treated as outputs since they are favourable and link value is restricted to be not less than the observed one. Undesirable links are treated as inputs since businesses would desire to minimize them and link value is restricted to be not greater than the observed one. Comparative excess in links in this category is accounted as inefficiency. Discretionary (free) link refers to carry-overs that the DMU can handle freely. Its value can be increased or decreased from the observed one. Non-discretionary (fixed) link refers to carry-over that is beyond the control of DMU. Their values are determined by environmental factors that are not controlled by the DMU and hence are fixed at the observed level (Fethi & Pasiouras, 2010). Free and fixed links have an indirect effect on the efficiency score through the continuity condition between two terms. In the oil industry, desirable carry-overs may be oil and gas reserves while undesirable carry-over activities may relate to carbon dioxide (CO_2) emissions, fire outbreaks, exploration expenses and oil spillages. The DSBM can be developed in any orientation (input oriented, output oriented or non-oriented) (Tone & Tsutsui, 2010). The dynamic production process of the oil and gas industry is depicted in figure 4.1 below:

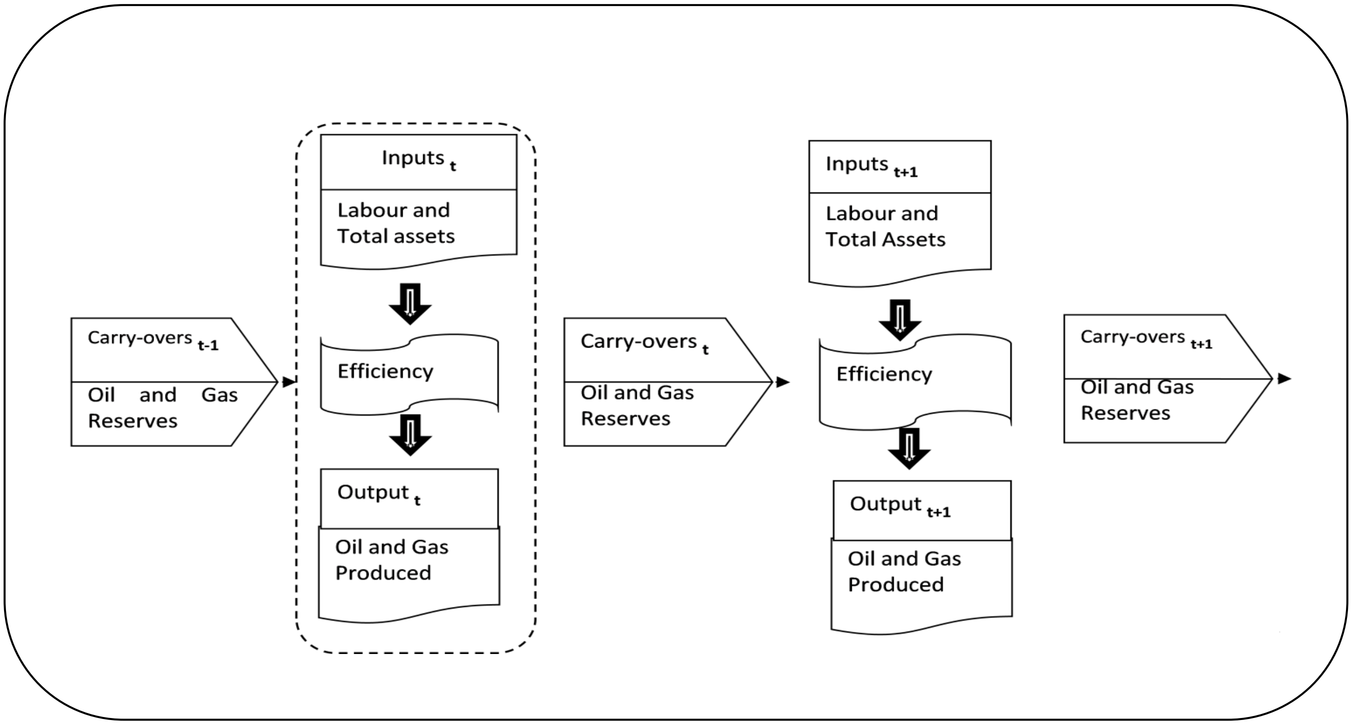

Figure 4.2: Dynamic Production Process in the Oil and Gas Industr

Source: Author's Analysis (2017)

At term *t-1*, the oil firm use a certain amount of inputs (labour and total assets) to generate outputs (oil and gas produced). Carryovers (oil and gas reserves) from *t-1* are then carried forward to term *t*, which also employs an amount of inputs to produce outputs. Carryovers from term *t* are also carried forward to term *t+1* in that order.

4.5.1 Production possibility set and models

Following Tone and Tsutsui (2010), let's assume that *n* DMUs (*j*: 1,…, *n*) over time period *T* (*t*: 1,…,T) that use *m* (*i*: 1,…,*m*) common inputs to produce *s* outputs (*r*: 1,…,*s*) with p nondiscretionary (fixed) inputs (*i*=1,…,*p*), *q* nondiscretionary (fixed) outputs (*r*: 1,…,*q*). Let x_{ijt} (*i*

= 1,...,m), x_{ijt}^{fix} (i=1,..., p), y_{rjt} (r=1,..., s) and y_{rjt}^{fix} (r=1,...,q) denote the observed (discretionary) input, non-discretionary input, (discretionary) output and non-discretionary output values of DMU j at term t, respectively. Where the four category links are denoted as z^{good}, z^{bad}, z^{free} and z^{fix}. In order to identify them by term (t), DMU (j) and item (i, r *or* c), where i relates to inputs, r to outputs and c to carryovers. Let's use, for example, the notation z_{cjt}^{good} (c = 1,…, *ngood*; j= 1,..., n; t=1,..., T) for denoting good link values where *ngood* is the number of good links and y_{rjt} (r = 1,…,s; j= 1,..., n; t=1,..., T) for denoting output r of DMU j in term t where s is the number of discretionary outputs and z_{cjt}^{bad} (c = 1,…,*nbad*; j= 1,..., n; t=1,..., T) to denote bad link c of DMU j in term t where *nbad* is the number of bad links. These are all observed values up to the term T. The production possibilities (x_{it}, x_{it}^{fix}, y_{rt}, y_{rt}^{fix}, z_{ct}^{good}, z_{ct}^{bad}, z_{ct}^{free} and z_{ct}^{fix}) are defined by:

$$
\begin{aligned}
&\sum_{j=1}^{n} x_{ijt}\lambda_j^t \le x_{it}\left(i=1,\ldots,m; t=1,\ldots,T\right)\\
&\sum_{j=1}^{n} x_{ijt}^{fix}\lambda_j^t = x_{it}^{fix}\left(i=1,\ldots,p; t=1,\ldots,T\right)\\
&\sum_{j=1}^{n} y_{rjt}\lambda_j^t \ge y_{rt}\left(r=1,\ldots,s; t=1,\ldots,T\right)\\
&\sum_{j=1}^{n} y_{rjt}^{fix}\lambda_j^t = y_{rt}^{fix}\left(r=1,\ldots,q; t=1,\ldots,T\right)\\
&\sum_{j=1}^{n} z_{cjt}^{good}\lambda_j^t \ge z_{ct}^{good}\left(c=1,\ldots,ngood; t=1,\ldots,T\right)\\
&\sum_{j=1}^{n} z_{cjt}^{bad}\lambda_j^t \le z_{ct}^{bad}\left(c=1,\ldots,nbad; t=1,\ldots,T\right)\\
&\sum_{j=1}^{n} z_{cjt}^{free}\lambda_j^t : z_{ct}^{free}\left(c=1,\ldots,nfree; t=1,\ldots,T\right)\\
&\sum_{j=1}^{n} z_{cjt}^{fix}\lambda_j^t = z_{ct}^{fix}\left(c=1,\ldots,nfix; t=1,\ldots,T\right)\\
&\sum_{j=1}^{n} \lambda_j^t = 1\left(t=1,\ldots T\right) \qquad (9)\\
&\lambda_j^t \ge 0,\left(j=1,\ldots,n : t=1,\ldots,T\right)
\end{aligned}
$$

where $\lambda_t \in R^n (t = 1,..., T)$ represents the intensity vector for the term *t*, and *ngood*, *nbad*, *nfree* and *nfix* are the number of good, bad, free and fixed links respectively. The last constraint corresponds to the variable returns to scale assumption (Tone & Tsutsui, 2010). Without it, the model will exhibit constant returns to scale.

The continuity of link flows (carry-overs) from term *t* to *t*+1 is assured by the condition:

$$\sum_{j=1}^{n} z_{cjt}^{\alpha} \lambda_j^t = \sum_{j=1}^{n} z_{cjt}^{\alpha} \lambda_j^{t+1} \left(\forall c : t = 1,...T - 1 \right) \quad (10)$$

Where the symbol α = *good*, *bad*, *free* or *fix*. This constraint is important for the dynamic model formulation because it connects term *t* and term *t*+1.

For production, the possibility set is:

$$\sum_{j=1}^{n} x_{ijt}\lambda_j^t + s_{it}^- = x_{iot}\left(i=1,\ldots,m; t=1,\ldots,T\right)$$
$$\sum_{j=1}^{n} x_{ijt}^{fix}\lambda_j^t = x_{iot}^{fix}\left(i=1,\ldots,p; t=1,\ldots,T\right)$$
$$\sum_{j=1}^{n} y_{rjt}\lambda_j^t - s_{rt}^+ = y_{rot}\left(r=1,\ldots,s; t=1,\ldots,T\right)$$
$$\sum_{j=1}^{n} y_{rjt}^{fix}\lambda_j^t = y_{rot}^{fix}\left(r=1,\ldots,q; t=1,\ldots,T\right)$$
$$\sum_{j=1}^{n} z_{cjt}^{good}\lambda_j^t - s_{ct}^{good} = z_{cot}^{good}\left(c=1,\ldots,ngood; t=1,\ldots,T\right)$$
$$\sum_{j=1}^{n} z_{cjt}^{bad}\lambda_j^t + s_{ct}^{bad} = z_{cot}^{bad}\left(c=1,\ldots,nbad; t=1,\ldots,T\right)$$
$$\sum_{j=1}^{n} z_{ijt}^{free}\lambda_j^t + s_{ct}^{free} = z_{cot}^{free}\left(c=1,\ldots,nfree; t=1,\ldots,T\right)$$
$$\sum_{j=1}^{n} z_{cjt}^{fix}\lambda_j^t + s_{ct}^{fix} = z_{cot}^{fix}\left(c=1,\ldots,nfix; t=1,\ldots,T\right)$$
$$\sum_{j=1}^{n} \lambda_j^t = 1\left(t=1,\ldots T\right) \qquad (11)$$
$$\lambda_j^t \geq 0, s_{it}^- \geq 0, s_{rt}^+ \geq 0, s_{ct}^{good} \geq 0, s_{ct}^{bad} \geq 0, \text{ and } s_{ct}^{free} : free \ \left(\forall i, \forall r, \forall c, t\right)$$

where s_{it}^-, s_{rt}^+, s_{ct}^{good}, s_{ct}^{bad}, and s_{ct}^{free} are slack variables symbolizing, input excess, output shortfall, link shortfall, link excess and link deviation respectively.

The output oriented overall efficiency, $\varnothing_o^*$ is given by:

$$\varnothing^* = Max\frac{1}{T}\sum_{t=1}^{T} w^t\left[1+\frac{1}{s+ngood}\left(\sum_{r=1}^{s}\frac{w_r^+ s_{rt}^+}{y_{rot}} + \sum_{c=1}^{ngood}\frac{s_{ct}^{good}}{z_{cot}^{good}}\right)\right] \qquad (12)$$

Subject to:

Equations (9) and (10) where w_r^+ is the weight assigned to output r and satisfies the condition:

$$\sum_{r=1}^{s} w_r^+ = s \qquad (13)$$

$\left[1+\frac{1}{s+ngood}\left(\sum_{r=1}^{s}\frac{w_r^+ s_{rt}^+}{y_{rot}}+\sum_{c=1}^{ngood}\frac{s_{ct}^{good}}{z_{cot}^{good}}\right)\right]$ is the output oriented efficiency for a single term t and w^t is the weight assigned to term *t*.

The DSBM objective function (12) is an extension the output oriented SBM model of Tone (2001) with shortfalls in outputs and desirable (good) links as the main targets of evaluation. Although desirable links are not outputs, they exhibit similar features as outputs (that is, they are favourable hence more is better), therefore, shortfalls in desirable links are accounted for in the objective function in the same way as output shortfalls. As shown in equation (10), they perform the function of connecting two sequential terms. Each term in square brackets of the objective function (12) relates to the output oriented efficiency of the term *t* as measured by the shortfalls in outputs and desirable links. The output oriented efficiency for term *t* is equal to unity if all slacks are zero, which means that the firm is efficient in that period. Hence, the overall efficiency, the right-hand side of (12) is the weighted average of term efficiencies over the entire terms under consideration and is greater than or equal to 1. For an oil firm to be overall efficient, it must be efficient for all the T terms under consideration. It is worth noting that the output oriented Farrell efficiency score for inefficient DMUs is greater than 1 because it measures the ratio of expected output to actual output, for easy interpretation, the inverse of the score, the Shephard (1970) distance function score is usually used. Since we define the overall efficiency by its reciprocal, the overall output efficiency is between 0 and 1. A detailed explanation of the DSBM can be found in Tone and Tsutsui (2010).

To illustrate the dynamic efficiency model above, consider in Table 4.3, a two-year hypothetical dataset of 6 oil firms employing an input (X) to produce output (Y) and carryover (Z) respectively.

Table 4.3: Illustrative Data for Hypothetical Oil Firms

Oil Firm	Year	DMU	X	Y	Z
Apache	1	A1	15	60	12
BP	1	B1	20	60	10
Shell	1	C1	20	35	20
Chevron	1	D1	5	40	20
Eni	1	E1	10	60	18
Lukoil	1	F1	15	60	11
Apache	2	A1	15	70	18
BP	2	B2	30	65	15
Shell	2	C2	15	50	20
Chevron	2	D2	15	40	25
Eni	2	E2	30	50	23
Lukoil	2	F2	20	45	20

Source: Author (2017)

The dynamic efficiency scores of the various oil firms were estimated using the MaxDEA Pro 6 software as presented in Table 4.4 below:

Table 4.4: Output Oriented DSBM for a 2-Year Period with a Free Link

NO.	OIL FIRM	TERM EFFICIENCY		OVERALL EFFICIENCY
		YEAR 1	YEAR 2	
1	Apache	1	1	1
2	BP	0.9091	0.9286	0.963
3	Shell	0.8642	0.7143	0.6422
4	Chevron	1	0.8	0.8889
5	Eni	1	0.9091	0.9524
6	Lukoil	0.9565	0.6429	0.7826

The dynamic efficiency scores presented in Table 4.4 indicate that only Apache is overall efficient. As mentioned earlier, the overall score as depicted in the table represents the aggregate score of each bank over the two-year period. For a DMU to be efficient, it has to be efficient for all the two periods under consideration. Therefore, DMUs like Chevron and Eni who were efficient in only year 1 but inefficient in year 2 as well as those that were inefficient for the two years are overall inefficient.

4.6 Proposed DSBM-Metafrontier Model

Despite its ability to incorporate carry-over activities in assessing efficiency overtime, the DSBM of Tone and Tsutsui (2010) is not able to incorporate group dynamics in its assessment. Meanwhile, the meta-frontier approach of Battese and Rao (2002); Battese et al. (2004); O'Donnell et al. (2008), which is able to assess efficiency differences among groups whilst accounting for the differences in their technology sets, does not account for carry-over activities. This section, in accordance with the last objective of this study, combines the DSBM and Metafrontier to provide an extended model of the DSBM named DSBM-Metafrontier model for assessing the efficiency of DMUs categorized into different groups (for example: fully private, minority state-owned, majority state-owned and fully state-owned oil firms) due to technology heterogeneity while accounting for interconnecting activities that link successive periods (for instance: oil reserves and gas reserves). This model extension is necessary for the progress of the current study which seeks to assess group dynamic efficiency on the basis of ownership and vertical integration.

4.6.1 Production possibility set and model specification

Suppose that there are n DMUs (j: 1,…, n) categorized into K groups (k =1,…, K) showing some technological heterogeneities, over time period T (t: 1,…,T). Assume that the DMUs use m (i: 1,…,m) common inputs to produce s outputs (r: 1,…,s) with p nondiscretionary (fixed) inputs

(i=1,…,p), and q nondiscretionary (fixed) outputs (r:1,…,q). The four types of carryovers (links) namely good links, bad links, free links and fixed links are denoted as z^{good}, z^{bad}, z^{free} and z^{fix} respectively. In order to identify them by term (t), DMU (j), group *(k)* and variable (i, r or c), where i relates to inputs and r to outputs and c to carryovers/links, let's use, for example, the notation z_{cjt}^{kgood} (c = 1,…,$ngood$; j = 1,..., n; t=1,..., $T,k=1,…;K$) to denote good link c of DMU j belonging to group k in term t, where $ngood$ is the number of good links for all observed values up to the term T. Similarly, y_{rjt}^{kfix} (r=1,..., q; j = 1,..., n; t=1,..., T) denotes fixed output r of DMU j belonging to group k in term t. Let x_{ijt}^{k} (i = 1,...,m; j = 1,..., n; t=1,..., T) denote the observed (discretionary) input values of DMU j of group k at term t, x_{ijt}^{kfix} (i=1,..., p; j = 1,..., n; t=1,..., T) denote the non-discretionary input values of DMU j of group k at term t, y_{rjt}^{k} (r=1,..., s; j = 1,..., n; t=1,..., T) denote the (discretionary) output r of DMU j of group k at term t and z_{cjt}^{kfree} (c=1,...,$nfree$; j = 1,..., n; t=1,..., T) denote the discretionary carryover values of DMU j of group k at term t where $nfree$ is number of free (discretionary) links. Based on the above, the dynamic meta technology (x_{it}^{k}, x_{it}^{kfix}, y_{rt}^{k} , y_{rt}^{kfix}, z_{ct}^{kgood}, z_{ct}^{kbad}, z_{ct}^{kfree} and z_{ct}^{kfix}) can be defined by:

$$\sum_{k=1}^{K}\sum_{j=1}^{n} x_{ijt}^{k}\lambda_{jt}^{k} \le x_{it} \left(i=1,\ldots,m;t=1,\ldots,T\right)$$
$$\sum_{k=1}^{K}\sum_{j=1}^{n} x_{ijt}^{kfix}\lambda_{jt}^{k} = x_{it}^{fix} \left(i=1,\ldots,p;t=1,\ldots,T\right)$$
$$\sum_{k=1}^{K}\sum_{j=1}^{n} y_{rjt}^{k}\lambda_{jt}^{k} \ge y_{rt} \left(r=1,\ldots,s;t=1,\ldots,T\right)$$
$$\sum_{k=1}^{K}\sum_{j=1}^{n} y_{rjt}^{kfix}\lambda_{jt}^{k} = y_{rt}^{fix} \left(r=1,\ldots,q;t=1,\ldots,T\right)$$
$$\sum_{k=1}^{K}\sum_{j=1}^{n} z_{cjt}^{good}\lambda_{jt}^{k} \ge z_{ct}^{good} \left(c=1,\ldots,ngood;t=1,\ldots,T\right)$$
$$\sum_{k=1}^{K}\sum_{j=1}^{n} z_{cjt}^{kbad}\lambda_{jt}^{k} \le z_{ct}^{bad} \left(c=1,\ldots,nbad;t=1,\ldots,T\right)$$
$$\sum_{k=1}^{K}\sum_{j=1}^{n} z_{cjt}^{kfree}\lambda_{jt}^{k} : z_{ct}^{free} \left(c=1,\ldots,nfree;t=1,\ldots,T\right)$$
$$\sum_{k=1}^{K}\sum_{j=1}^{n} z_{cjt}^{kfix}\lambda_{jt}^{k} = z_{ct}^{fix} \left(c=1,\ldots,nfix;t=1,\ldots,T\right)$$
$$\sum_{k=1}^{K}\sum_{j=1}^{n} \lambda_{jt}^{k} = 1\left(t=1,\ldots T\right) \tag{14}$$
$$\lambda_{jt}^{k} \ge 0,\left(j=1,\ldots,n:t=1,\ldots,T;k=1,\ldots,K\right)$$

where $\lambda_t \in R^n(t = 1,\ldots, T)$ represents the intensity vector for the term *t*, and *ngood*, *nbad*, *nfree* and *nfix* are the number of good, bad, free and fixed links respectively. The last constraint is the variable returns to scale assumption (Tone & Tsutsui, 2010). Without it, the model assumes constant returns to scale.

The continuity of link flows (carry-overs) from term *t* to *t*+1 is assured by the condition:

$$\sum_{k=1}^{K}\sum_{j=1}^{n} z_{cjt}^{\alpha k}\lambda_{jt}^{k} = \sum_{k=1}^{K}\sum_{j=1}^{n} z_{cjt}^{\alpha k}\lambda_{jt+1}^{k}\left(\forall c : t=1,\ldots T-1\right) \tag{15}$$

Where the symbol α = *good*, *bad*, *free* or *fix*. This constraint is important for the dynamic model formulation because it connects term *t* and term *t*+1.

The output oriented DSBM meta efficiency of DMU$_o$, $\varnothing_o^M$ is given by:

$$\varnothing_0^M = Max\frac{1}{T}\sum_{t=1}^{T} w^t\left[1+\frac{1}{s+ngood}\left(\sum_{r=1}^{s}\frac{w_r^+ s_{rt}^+}{y_{rot}}+\sum_{c=1}^{ngood}\frac{s_{ct}^{good}}{z_{cot}^{good}}\right)\right] \quad (16)$$

Subject to:

$$\sum_{k=1}^{K}\sum_{j=1}^{n} x_{ijt}^k\lambda_{jt}^k + s_{it}^- = x_{iot}\left(i=1,\dots,m;t=1,\dots,T\right)$$

$$\sum_{k=1}^{K}\sum_{j=1}^{n} x_{ijt}^{kfix}\lambda_{jt}^k = x_{iot}^{fix}\left(i=1,\dots,p;t=1,\dots,T\right)$$

$$\sum_{k=1}^{K}\sum_{j=1}^{n} y_{rjt}^k\lambda_{jt}^k - s_{rt}^+ = y_{rot}\left(r=1,\dots,s;t=1,\dots,T\right)$$

$$\sum_{k=1}^{K}\sum_{j=1}^{n} y_{rjt}^{kfix}\lambda_{jt}^k = y_{rot}^{fix}\left(r=1,\dots,q;t=1,\dots,T\right)$$

$$\sum_{k=1}^{K}\sum_{j=1}^{n} z_{cjt}^{kgood}\lambda_{jt}^k - s_{ct}^{good} = z_{cot}^{good}\left(c=1,\dots,ngood;t=1,\dots,T\right)$$

$$\sum_{k=1}^{K}\sum_{j=1}^{n} z_{cjt}^{kbad}\lambda_{jt}^k + s_{ct}^{bad} = z_{cot}^{bad}\left(c=1,\dots,nbad;t=1,\dots,T\right)$$

$$\sum_{k=1}^{K}\sum_{j=1}^{n} z_{ijt}^{kfree}\lambda_{jt}^k + s_{ct}^{free} = z_{cot}^{free}\left(c=1,\dots,nfree;t=1,\dots,T\right)$$

$$\sum_{k=1}^{K}\sum_{j=1}^{n} z_{cjt}^{kfix}\lambda_{jt}^k + s_{ct}^{fix} = z_{cot}^{fix}\left(c=1,\dots,nfix;t=1,\dots,T\right)$$

$$\sum_{k=1}^{K}\sum_{j=1}^{n} \lambda_{jt}^k = 1\left(t=1,\dots T\right)$$

$$\sum_{k=1}^{K}\sum_{j=1}^{n} z_{cjt}^{k\alpha}\lambda_{jt}^k = \sum_{k=1}^{K}\sum_{j=1}^{n} z_{cjt}^{k\alpha}\lambda_{jt+1}^k\left(\forall c: t=1,\dots T-1\right) \quad (17)$$

$$\lambda_j \ge 0, s_{it}^- \ge 0, s_{rt}^+ \ge 0, s_{ct}^{good} \ge 0, s_{ct}^{bad} \ge 0, \text{ and } s_{ct}^{free} : free \left(\forall i,\forall r,\forall c,t\right)$$

where s_{it}^-, s_{rt}^+, s_{ct}^{good}, s_{ct}^{bad}, and s_{it}^{fcee} are slack variables symbolizing, input excess, output shortfall, link shortfall, link excess and link deviation respectively and α = *good*, *bad*, *free* or *fix*.

w_r^+ in equation (16) is the weight assigned to output *r* and satisfies the condition:

$$\sum_{r=1}^{s} w_{r}^{+} = s \qquad (18)$$

$\left[1+\frac{1}{s+ngood}\left(\sum_{r=1}^{s}\frac{w_r^+ s_{rt}^+}{y_{rot}}+\sum_{c=1}^{ngood}\frac{s_{ct}^{good}}{z_{cot}^{good}}\right)\right]$ is the output oriented efficiency for a single term t and w^t is the weight assigned to term *t*.

The DSBM-Metafrontier incorporates the metafrontier framework into the output oriented DSBM of Tone and Tsutsui (2010) where shortfalls in outputs and desirable (good) links are the main targets of evaluation. Although desirable links are not outputs, they exhibit similar features as outputs (that is, they are favourable hence more is better), therefore, shortfalls in desirable links are accounted for in the objective function in the same way as output shortfalls. As shown in equation (15), they perform the function of connecting two sequential terms. Each term in square brackets of the objective function (16) relates to the output oriented efficiency of the term *t* as measured by the shortfalls in outputs and desirable links. The output oriented efficiency for term *t* is equal to unity if all slacks are zero, which means that the firm is efficient in that period. Hence, the overall DSBM efficiency, the right-hand side of (16) is the weighted average of term efficiencies over the entire terms under consideration and is greater than or equal to 1. For an oil firm to be overall efficient, it must be efficient for all the T terms under consideration. It is worth noting that the output oriented Farrell efficiency score for inefficient DMUs is greater than 1 because it measures the ratio of expected output to actual output, for easy interpretation, the inverse of the score, the Shephard (1970) distance function score is usually used. Since we define the overall efficiency by its reciprocal, the overall output efficiency is between 0 and 1. A detailed explanation of the DSBM can be found in Tone and Tsutsui (2010). A graphical illustration of the DSBM Metafrontier function is shown in Figure 4.3

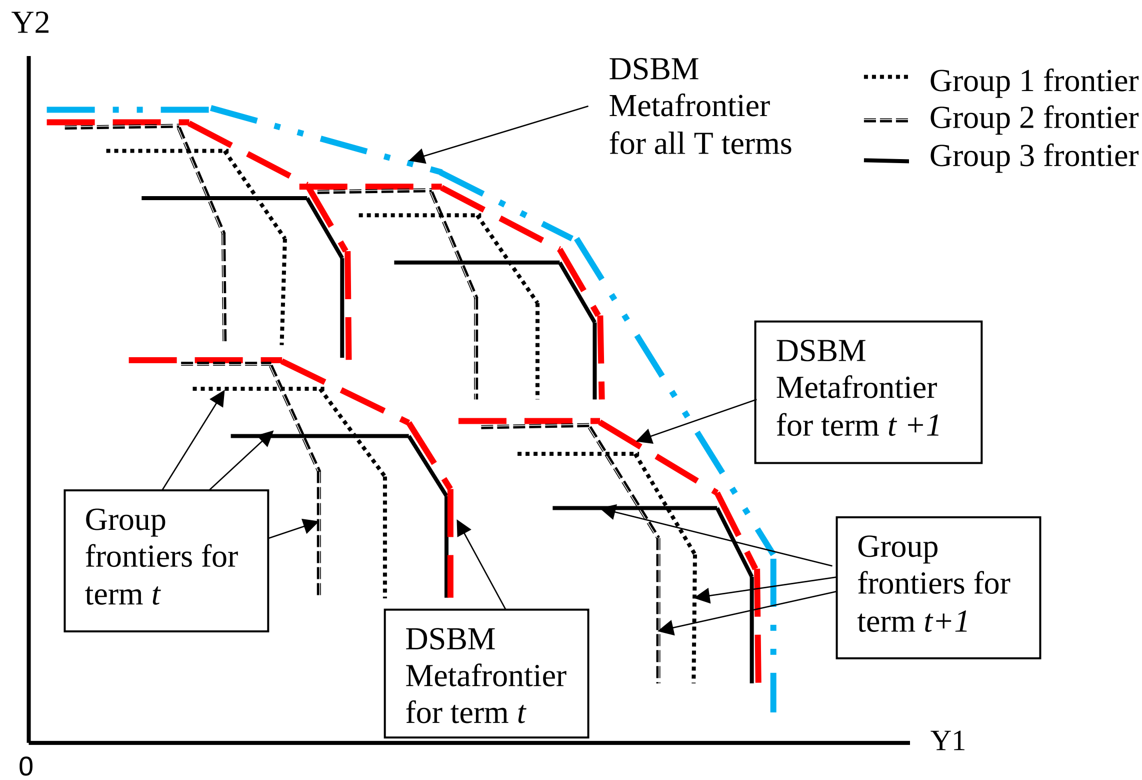

Figure 4.3: Graphical illustration of the DSBM Metafrontier

Supposing a DMU_o's dynamic efficiency as estimated by equation (12) was relative to one group's frontier (group k) within the meta technology, its DSBM efficiency score would be denoted by $\varnothing_o^k$ while equation (16) represents the dynamic efficiency $\left(\varnothing_o^M\right)$ of that same DMU_o relative to the pooled frontier (metafrontier). The scores from equations (12) and (16) can then be used to compute the Dynamic Technology Gap Ratio (DTGR) of the said DMU_o. The DTGR of DMU_o in group *k* is the ratio of the DSBM efficiency score relative to the metafrontier to the DSBM efficiency score relative to group *k's* frontier of that DMU_o.

Mathematically, $\mathrm{DTGR}_o^k = \dfrac{\varnothing_o^M}{\varnothing_o^k}$ (19)

4.7 Test of Return to Scale (RTS) or Scale Elasticity in DEA

In DEA, it is important to test for the returns to scale of the technology of the industry under consideration since the type of returns to scale could influence the conclusions drawn (Banker, 1996; Camanho & Dyson, 2005; Dyson et al., 2001; Ray & Desli, 1997; Simar & Wilson, 2002). This presupposes that failure to investigate the scale elasticity of the underlying technology could lead to misleading efficiency conclusions. Some studies select the type of scale based on the authors own belief about the technology type of the industry (Barros, Managi, & Matousek, 2012; Chen, Skully, & Brown, 2005; Lo & Lu, 2009) which could lead to erroneous conclusions. The scale elasticity could be Constant Returns to Scale (CRS) or Variable Returns to Scale (VRS). CRS assumes that the DMUs are of the same size and operating under optimal scale whereas VRS assumes differences in the sizes of DMUs which could result from factors such as imperfect competition and changes in regulations among others (Ohene-Asare & Asmild, 2012). To test the appropriate scale, this study adopts the Simar and Wilson (2002) and Simar and Wilson (2011) bootstrap based algorithms. The test is based on the following hypothesis:

$H_0 = \Psi$ *is globally CRS* (i.e., the production technology is globally CRS)

$H_a = \Psi$ *is VRS* (i.e., the production technology is globally VRS)

To test the hypotheses, mean of ratios or ratios of means can be used. Using mean of the ratios, the test statistic, $\hat{S}$ is defined as:

$$\hat{S} = n^{-1} \sum_{i=1}^{n} \left(\frac{D_n^{CRS}(x, y)}{D_n^{VRS}(x, y)} \right) \qquad (20)$$

Using the ratio of means we can define the test statistic $\hat{S}_1$ as:

$$\hat{S}_1 = \frac{\sum_{i=1}^{n} D_n^{CRS}(x, y)}{\sum_{i=1}^{n} D_n^{VRS}(x, y)} \tag{21}$$

In this study, the mean of ratios is employed to provide an intuitive geometric interpretation of the test score. The ratio measures the distance between the estimated VRS and CRS frontiers. The null hypothesis H_0 is rejected if $\hat{S}$ is significantly less than unity. However, if $\hat{S} = 1$, we fail to reject H_0, which means that the CRS efficiency scores for all observations is expected to be the same as the VRS scores $\left(D_n^{CRS}(x, y) = D_n^{VRS}(x, y)\right)$ for all firms. Since the distribution of the test statistic is unknown, bootstrapping methodology is employed to generate p-values and critical values. Hence H_0 *is* rejected if the p-value is less or equal to the chosen significance level or, if the test statistic is less than the critical value (Simar & Wilson, 2002).

4.8 Simar-Zelenyuk-adapted-Li Test (SZAL)

To explore the possible differences in dynamic efficiency scores under the extent of government ownership (fully, private, minority state-owned, majority state-owned and fully state-owned firms) and degree of vertical integration (least integrated, semi-integrated and highly integrated oil firms), the Simar-Zelenyuk-adapted-Li Test is employed. Although some DEA studies have used nonparametric tests such as Wilcoxon signed-rank test, Mann Whitney U-test, Kruskal-Wallis test and Friedman test for this purpose, SZAL is preferred because it is able to handle both dependent and independent samples and also able to deal with the unobserved nature of the true efficiency estimate which the other non-parametric tests face difficulty in dealing with (Kumar & Russell, 2002; Ohene-Asare et al., 2015) . SZAL is a statistical test, formerly Li test (Li, 1996) adapted and improved by Simar and Zelenyuk (2006) to suit the DEA framework. The test uses bootstrap procedures to compare the distributions of DEA efficiency scores of different groups based on kernel density estimations (Ohene-Asare et al., 2015). This test, unlike the aforementioned statistical tests which focus only on the means or medians of distributions, measures differences in the entire distribution of efficiency scores or productivity scores of different subgroups (Hadad, Hall, Kenjegalieva, Santoso, & Simper, 2012; Kenjegalieva, Simper, Weyman-Jones, & Zelenyuk, 2009).

To determine the potential differences in efficiency scores under different ownership types and under different levels of vertical integration (assuming we had two sub-groups), the following hypotheses are tested:

$H_0 : F_{G1}(\varphi^{G1}) = F_{G2}(\varphi^{G2})$ (The density of the efficiency estimates of the two groups is the same)

$H_a : F_{G1}(\varphi^{G1}) \neq F_{G2}(\varphi^{G2})$ (The density of the efficiency estimates of the two groups is different)

These hypotheses are tested using SZAL (Kenjegalieva et al., 2009; Simar & Zelenyuk, 2006):

$$\widehat{I}^{nd}_{n_{G1},n_{G2},h} = \begin{cases} \frac{1}{hn_{G1}(n_{G1}-1)} \sum_{j=1}^{n_{G2}} \sum_{k \neq j, k=1}^{n_{G1}} K\left(\frac{\hat{\rho}^{G1,j} - \hat{\rho}^{G1,k}}{h}\right) \\ + \frac{1}{hn_{G2}(n_{G2}-1)} \sum_{j=1}^{n_{G2}} \sum_{k \neq j, k=1}^{n_{G2}} K\left(\frac{\hat{\rho}^{G2,j} - \hat{\rho}^{G2,k}}{h}\right) \\ - \frac{1}{hn_{G1}(n_{G2}-1)} \sum_{j=1}^{n_{G2}} \sum_{k \neq j, k=1}^{n_{G1}} K\left(\frac{\hat{\rho}^{G2,j} - \hat{\rho}^{G1,j}}{h}\right) \\ - \frac{1}{hn_{G2}(n_{G1}-1)} \sum_{j=1}^{n_{G1}} \sum_{k \neq j, k=1}^{n_{G2}} K\left(\frac{\hat{\rho}^{G1,j} - \hat{\rho}^{G2,k}}{h}\right) \end{cases} \tag{22}$$

where K is a suitable kernel function, h is the bandwidth, window width or smoothing parameter which is computed using the plug-in method of (Sheather & Jones, 1991). If $\lambda_n = {n_{G1}}/{n_{G2}}$ and we assume $\lambda_n \rightarrow \lambda$ as $n_{G1} \rightarrow \infty$ where $(0,\infty)$ is a constant, the limiting distribution of equation (22) is normally distributed implying that the integrated squared error is the basis for building the statistic on which the test hinges (Kenjegalieva et al., 2009; Pagan & Ullah, 1999).

The Li (1996) test is based on the test statistic:

$$\hat{J}^{nd}_{n_{G1},n_{G2},h} \equiv \frac{n_{G1} h^{1/2} \hat{I}^{nd}_{n_{G1},n_{G2},h}}{\hat{\sigma}_{\lambda,h}} \xrightarrow{d} N(0,1) \tag{23}$$

Where

$$\hat{\sigma}^2_{\lambda' h} = 2\left\{ \frac{1}{hn^2_{G1}} \sum_{j=1}^{n_{G1}} \sum_{k=1}^{n_{G1}} K\left(\frac{\hat{\rho}^{G1,j} - \hat{\rho}^{G1,k}}{h} \right) + \frac{\lambda^2_n}{hn^2_{G2}} \sum_{j=1}^{n_{G2}} \sum_{k=1}^{n_{G2}} K\left(\frac{\hat{\rho}^{G2,j} - \hat{\rho}^{G2,k}}{h} \right) - \frac{\lambda_n}{hn_{G1}n_{G2}} \sum_{j=1}^{n_{G2}} \sum_{k=1}^{n_{G1}} K\left(\frac{\hat{\rho}^{G2,j} - \hat{\rho}^{G2,k}}{h} \right) - \frac{\lambda_n}{hn_{G1}n_{G2}} \sum_{j=1}^{n_{G1}} \sum_{k=1}^{n_{G2}} K\left(\frac{\hat{\rho}^{G2,J} - \hat{\rho}^{G1,k}}{h} \right) \right\} \left[\int K^2(\hat{\rho}) d\hat{\rho} \right]. \tag{24}$$

4.9 Model Inputs, Outputs Variables and Carry-overs

The appropriateness of variables used as inputs and outputs selected for DEA efficiency analysis affects the efficiency scores (Coelli, Rao, O'Donnell, & Battese, 2005). In the literature, the selection of inputs and outputs are usually based on experience, previous studies, researcher's judgment and data availability. Accurate selection of variables is crucial in any DEA study since wrong selection of variables could invalidate scores and decisions made thereof (Barros & Assaf, 2009).

4.9.1 Inputs (X)

In accordance with the "no free lunch axiom", no amount of output is possible unless a DMU (petroleum firm) uses some amount of input. Two inputs are used in this study; X_1: total assets and X_2: labor employed by oil and gas firms. Most oil efficiency studies ignore the use of total assets as variables of measurement based on the fact that most governmental oil and gas firms especially OPEC members fail to report on them (Eller et al., 2011; Ike & Lee, 2014). Hence, they used total reserves since it is perceived that these reserves remain a substantial part of the oil firm's total assets. However, although they may be affected by inflation, total assets denote the complete scope of the firm (Wolf, 2009) and could give a better representation of inputs employed by a firm. Total asset includes the tangible assets of a firm, financial assets, operating assets as well as investments into other segements.

Labor is a factor of production that encompasses manpower, knowledge and expertise exerted by people in order to achieve the goals of the firm. This study uses the number of employees as a proxy for labor as widely used in earlier oil and gas efficiency studies as presented in Table 4.5. It would have been more ideal to use wages and salaries to proxy labour, if certain shortcomings were absent, nevertheless, wages can be biased by wage differentials across countries. Also, there is a possibility that wages and salaries reported in a particular year could contain some amount carried forward from previous years (Coelli et al., 2005). That aside, most companies do not readily report on the wages and salaries.

4.9.2 Outputs (Y)

The outputs used are oil produced (Y_1) and gas produced (Y_2). Every firm aims at maximizing output and subsequently revenue in order to maximize shareholders' wealth. In the petroleum industry, output can be upstream crude oil or natural gas, refined oil and gas products and revenue from the sales of oil and gas products (Wolf, 2009). Some studies employ revenue and profitability as measures for output, however, the use of sales revenue is unconvincing and may lead to distorted results because some NOCs may be forced to sell products at subsidized prices and pursue other social objectives which might affect their revenue or profit (Ike & Lee, 2014; Wolf, 2009). Aside that, the tax regimes also differ across countries or locations and could put some companies at a disadvantage if revenue is used as a measure of output. Conversely, oil and gas produced have standardized units of measurement (they can easily be converted) and are likely to be recorded more accurately as compared to sales figures (Ike & Lee, 2014).

4.9.3 Carry-overs (Z)

Carry-overs are activities or variables that link two consecutive terms (Tone & Tsutsui, 2010). These variables could be inputs or outputs (Tone & Tsutsui, 2014) that are reported in the current period but used in the subsequent period(s). In this study, two desirable carry-overs are identified; oil reserves and gas reserves. Reserves represent quantities of liquids or hydrocarbons which have been proven, with reasonable certainty, as commercially recoverable from known reservoirs under certain economic conditions and regulations (OPEC, 2015). Current year's proved reserves are estimated as the (reserves carried forward from previous) + (extensions, discoveries and additions in current year) – (current year production levels and sales of properties) (Apache, 2013). A number of oil efficiency studies have used oil and gas reserves as inputs (Eller et al., 2011; Ike & Lee, 2014; Managi et al., 2006; Ohene-Asare et al., 2015; Sueyoshi & Goto, 2012, 2012a). However, Wolf (2009) argued that rather than being considered as a mere complementary input, reserves in the oil and gas industry can be considered as the result of capital spending. Since they do not pertain to one period nor affect only one period's activity (Thompson et al., 1996), oil and gas reserves are used as carry-over variables in this study. Therefore, one distinguishing reason why we choose to label oil and gas reserves as carryovers is that they are not entirely consumed or produced in one term or period (Wanke et al., 2015).

Table 4.5: Summary of Inputs and Outputs in Oil Efficiency Literature

	Variable	**Symbol**	**Unit of Measurement**	**Empirical Applications**
Inputs	Labour	X_1	Number of Employees	Al-Obaidan & Scully (1991, 1993,1995) ; Eller, Hartley & Medlock (2011); Ike & Lee (2014); Ohene-Asare, Turkson & Afful-Dadzie (2015); Sueyoshi & Goto (2012a, 2012b)
	Total Assets	X_2	US $ (millions)	Al-Obaidan & Scully (1991, 1993,1995); Ismail, Tai, Kong, Law, Shirazi & Karim (2013); Kim, Lee, Park & Kim (1999); Wolf (2009)
Outputs	Crude Oil Produced	Y_1	Barrels '000 b/c	Al-Obaidan & Scully (1991, 1993, 1995); Barros & Assaf (2009); Barros & Managi (2009); Ike & Lee (2014); Ohene-Asare, Turkson & Afful-Dadzie (2015); Sueyoshi & Goto (2012a, 2012b); Thompson, Dharmapala, Rothenberg & Thrall (1996)
	Gas Produced	Y_2	Cubic Metres MMcf/d	Barros & Assaf (2009); Barros & Managi (2009); Ike & Lee (2014); Ohene-Asare, Turkson & Afful-Dadzie (2015); Sueyoshi & Goto (2012a, 2012b); Thompson, Dharmapala, Rothenberg & Thrall (1996)
Carry-overs	Crude Oil Reserves	Z_1	Million Barrels (Bbl)	This study (2017)
	Gas Reserves	Z_2	Cubic Metres Bcf	This study (2017)

4.10 Variable Measurements

4.10.1 Degree of state ownership

The degree of state ownership measures the extent of state ownership and control of oil firms. This is determined by the percentage of shares owned by the state. Based on the percentage of shares held by the state, oil firms are then categorized into fully private, minority state-owned, majority state-owned and fully state-owned oil firms. The clusters provided in Wolf (2009) are adopted for this study. Table 4.6 summarizes these classifications, the basis of classifications and their application in previous studies.

4.10.2 Degree of vertical integration

Vertical integration measures the degree of self-sufficiency of a firm. The petroleum sector supply chain is basically made up of the upstream which deals with prospecting for reserves, oil and gas exploration and production and the downstream which deals in the refining of crude and gas into usable forms as well as making them available to end users. There is also the midstream sector which links the downstream and upstream by way of transportation and storage. Upstream companies are the target of the study and in this regard, vertical integration is defined by the ratio of crude oil refined to the amount of crude and gas produced by the firm. The greater the ratio of refined products to crude produced the less dependent the firm is on other external players in the industry and the more integrated the firm. Oil firms are categorized into three sub-groups (least integrated, semi integrated and highly integrated oil firms) (Al-Obaidan & Scully, 1993) based on the integration ratio scored by the firm. See Table 4.6

Table 4.6: Group Classifications

Umbrella group	Basis	Clusters	Application
Degree of State ownership	Percentage of shares owned by state	1. Fully Private [0%] 2. Minority state-owned [1%-49%] 3. Majority state-owned [50%-99%] 4. Fully state-owned [100%]	(Wolf, 2009)
Degree of vertical integration	Ratio of petroleum product sales (b/d) to crude and gas produced	1. Least integrated [0%-9%] 2. Semi-integrated [10%-20%] 3. Highly Integrated [>20%]	(Al-Obaidan & Scully, 1993; Eller et al., 2011)

4.11 DEA Estimation Considerations

DEA efficiency frontier is constructed based on either of three orientations; input orientation, output orientation or non-oriented/input-output orientation (Coelli et al., 2005). Input orientation seeks to minimize inputs without a reduction in outputs by reducing wastages in the production process; the output orientation on the other hand, seeks to maximize outputs without a change in inputs (Farrell, 1957). The non-oriented measure estimates efficiency by a simultaneous reduction in inputs and augmentation in outputs. In this study, the output orientation is used where the emphasis is on maximizing outputs (oil and gas produced) with a given set of inputs (labor and total assets). The output oriented efficiency measure is preferred when the objective of management is to produce as much output as possible (Coelli, Prasada Rao, & Battese, 1998). To this end, a firm is seen to be efficient if it produces the maximum possible output using the given levels of inputs. Other oil efficiency studies such as Barros and Managi (2009); Eller et al. (2011);

Ike and Lee (2014) have adopted an output orientation. Ike and Lee (2014) have noted that as cost of operations and expenditures in the industry vary across countries, an output orientation is most ideal.

A balanced panel data is a requirement for estimating efficiency using the DSBM. As a result, oil firms that may have been part of the technology but not in existence within the entire study period are removed. This has resulted in a reduction in the sample size to 32 from the top 50.

4.12 Instruments for Data Analysis

Descriptive and inferential statistics are used in the analysis of the data. Software packages such as R version 3.1.3 and MaxDEA Pro 6.93 are employed in the analysis. The R packages used include Frontier Efficiency Analysis with R (FEAR) version 2.0.1(Wilson, 2008) and Benchmarking Packages version 0.24 (Bogetoft & Otto, 2011).

4.13 Conclusion

This chapter has expatiated the methodologies used to analyze the impact of vertical integration and ownership on the performance of oil firms. The chapter explained the research design, sampling and data sources as well as the frontier methodologies applied in this study. Particular emphasis was placed on the DSBM and Metafrontier analysis and consequently a DSBM Metafrontier extension has been proposed for the dynamic assessment of heterogeneous groups. It has also described the inputs and outputs variables and carry-overs used in the dynamic efficiency assessment.

CHAPTER FIVE

DATA ANALYSIS AND DISCUSSION

5.0 Introduction

Chapter Five is dedicated to the analysis and discussion of the results in order to answer the research questions and achieve the objectives of the study. The chapter is made up of six sections. The first section presents descriptive statistics of the variables used in the study. It also provides a test of returns to scale results as it helps to determine the appropriate mode of analysis. Sections two, three, four and five are dedicated to answering research questions 1, 2, 3 and 4 respectively while the last section summarizes the chapter.

5.1 Summary Statistics of Variables and Groups (Pooled)

The data comprise a 10-year data covering the period 2001-2010 sourced from Energy Intelligence's Petroleum Intelligence Weekly and the annual reports of oil firms where available. In this study, oil firms are categorized into groups based on the extent of state-ownership as well as on the basis of the degree of vertical integration. To that end, an oil firm could be Fully Private (FP), Minority State-owned (MiSO), Majority State-owned (MaSO) or Fully State-owned (FSO). Following Wolf (2009), a fully private firm is a firm which is 100% owned by private individuals with no shares held by the state. A Minority State-Owned firm is a firm in which the state owns shares ranging from 1% to 49% whereas a firm is labelled Majority State-Owned if the state owns 50%-99% of its shares. Lastly, a fully State-Owned firm is one with 100% ownership and control by the state. Aside that, an oil firm could also be Least Integrated (LI), Semi Integrated (SI) or Highly Integrated (HI) depending on its level of integration in the industry. Vertical integration could be forward or backward, however, this study considers forward vertical integration of upstream oil firms. As per Al-Obaidan and Scully (1993), a firm is least integrated if it processes only up to 9% of its oil and gas produced, semi integrated if it processes up to 20% of oil and gas produced and highly integrated if it processes over 20% of its oil and gas extracted. The descriptive statistics of the variables- inputs, outputs and carry-over variables are presented below.

Table 5.1: Summary Statistics of Variables

	INPUTS (X)		OUTPUTS (Y)		LINKS (Z)	
Pooled	**Total Assets (US$ Million) X1**	**Labour (No. of employees) X2**	**Oil Produced (‘000b/d) Y1**	**Gas Produced (MMcf/d) Y2**	**Oil Reserves (MBBbls) Z1**	**Gas Reserves (Bcf) Z2**
Mean	78,860.41	83,706.89	1,112.87	4,720.37	9,147.34	58,103.69
Std. Dev.	70,833.83	112,924.41	904.85	8,702.98	23,773.79	159,730.22
Minimum	4,300.00	1,678.00	54.00	145.00	97.00	1,005.00
Maximum	322,560.00	552,698.00	3,754.00	53,772.00	296,501.00	1,320,000.00
Count	320.00	320.00	320.00	320.00	320.00	320.00
F Stat across time	**6.474*** **	**0.056**	**0.129**	**0.027**	**0.297**	**0.115**

**p* <0.05 ***p* <0.01 ****p* <0.001*

Table 5.1 shows the descriptive statistics of the dataset of 320 observations over the period 2000-2010. The range between the minimum and maximum values for all variables are quite high suggesting the possibility of significant differences in the sizes even among the top oil and gas firms under the study. This view is further supported by the magnitude of the standard deviations from the sample means. For instance the mean for labour employed is 83,707 employees with a higher standard deviation of 112,924.41. The same can be said of gas produced which has a mean of 4,720.37 million cubic feet per day and a higher standard deviation of 8,702.98 and of oil and gas reserves which have higher standard deviations than means. The test statistic of a one way ANOVA across the ten year period, however, reveals that apart from total assets with an F statistic of 6.474 which is significant at 0.001, there are no significant differences in all the other variables across the 10-year period. This indicates that the industry has been somewhat stable throughout the study period with insignificant variations in the inputs employed and outputs produced through the period.

A test of the differences in inputs across the varying degrees of state ownership as well as private ownership revealed significant differences in the inputs employed except total, outputs produced as well as oil and gas reserves held by oil firms with different types of ownership. In table 5.2 below summary statistics is presented on the data based on the ownership status of oil firms.

Table 5.2: Summary Statistics of Variables Based on Ownership

	Total Assets (US$ Million) X1	Labour (No. of employees) X2	Oil Produced ('000b/d) Y1	Gas Produced (MMcf/d) Y2	Oil Reserves (MMBbls) Z1	Gas Reserves (Bcf) Z2
Fully Private (FP) N = 170 (53.1%)						
Mean	81,645.69	49,162.18	992.46	3,493.93	4,680.73	19,113.04
Std. Dev.	76,884.68	45,814.09	833.13	2,915.39	4,367.38	17,375.03
Minimum	8,235.00	1,678.00	110.00	345.00	97.00	2,049.00
Maximum	322,560.00	152,500.00	2,681.00	12,148.00	17,360.00	78,815.00
Minority State-Owned (MiSO) N = 30 (9.4%)						
Mean	84,427.93	55,191.70	984.47	2,209.63	4,604.30	10,622.83
Std. Dev.	70,187.00	23,103.39	716.25	1,408.87	3,811.83	6,656.98
Minimum	11,544.00	5,659.00	54.00	145.00	173.00	1,005.00
Maximum	312,103.00	80,655.00	2,150.00	4,540.00	10,766.00	20,229.00
Majority State-Owned (MaSO) N= 60 (18.6%)						
Mean	85,482.70	228,157.02	1,068.08	10,303.45	7,295.78	170,353.55
Std. Dev.	74,076.24	185,947.82	687.34	18,396.64	5,107.92	337,558.39
Minimum	4,300.00	16,686.00	198.00	446.00	1,675.00	2,856.00
Maximum	302,620.00	552,698.00	2,386.00	53,772.00	18,110.00	1,320,000.00
Fully State-Owned (FSO) N= 60 (18.6%)						
Mean	61,562.72	51,391.05	1,563.03	3,867.57	25,925.83	80,067.78
Std. Dev.	43,592.03	44,297.84	1,206.52	2,404.92	51,090.61	65,452.71
Minimum	8,000.00	5,856.00	107.00	222.00	798.00	1,898.00
Maximum	168,480.00	147,368.00	3,754.00	8,152.00	296,501.00	195,095.00
F stat.	**1.524**	**64.3*****	**6.526*****	**11.39*****	**13.97*****	**16.65*****

$*p < 0.05$ $**p < 0.01$ $***p < 0.001$

A brief glance of the results indicates that FSO oil firms control the largest amount of oil reserves with a mean of 25,925.83 million barrels and standard deviation of 51,090.61, this is followed by the MaSO oil firms with a mean of 7,295.78 million barrels and standard deviation of 5,107.92 whereas fully private oil firms have an average oil reserves of 4,680.73 million barrels with a standard deviation of 4,367.38. This shows that generally, NOCs control more reserves than IOCs. Nearly the same can be said of gas reserves; MaSO firms control the highest amount of gas reserves (M= 170,353.55, SD= 5,107.92) followed by FSO firms (M= 80,067.78, SD= 80,067.78) and then FP (M= 19,113.04, SD= 17,375.03) and lastly the MiSO group which has the least control in both oil and gas reserves.

It can be observed that the level of control of reserves directly translates into the production levels. For oil production, FSO firms top the list (M=1,563.03, SD=1,206.52) followed by MaSO (M=1,068.08, SD=687.34), FP (M=992.46, SD=833.13) and then MiSO (M=984.47, SD=716.25). Gas production follows the same trend as the highest production comes from MaSO (M=10,303.45, SD=18,396.64), followed by the FSO, FP and MiSO in that order. In terms of the inputs, MaSO employs the highest amount of total assets (M=85,482.70, SD=85,482.70) and labour (M=228,157.02, SD=185,947.82) and interestingly, FSO firms seems to employ the least amount of total assets (M=61,562.72, SD=43,592.03) and labour (M=51,391.05, SD=44,297.84). this could be due to locational effect of the oil and gas wells of FSO firms. Mostly, the oil and gas wells of FSO firms are located Consequently, the F-statistic of a one way ANOVA test conducted to investigate the differences of variables across ownership types showed significant differences in input usage and output generation.

Another test of differences was also conducted to test differences across least integrated, semi integrated and highly integrated oil firms. The test revealed that significant differences exist in the resource usage, output generation and control of reserves across the groups. Table 5.3 displays the summary statistics and test of differences across oil firms on the basis of their degree of forward vertical integration.

Table 5.3: Summary Statistics of Variables based on Vertical Integration

	Total Assets (US$ Million) X1	Labour (No. of employees) X2	Oil Produced ('000b/d) Y1	Gas Produced (MMcf/d) Y2	Oil Reserves (MBBbls) Z1	Gas Reserves (Bcf) Z2
Least Integrated N = 80 (25%)						
Mean	46743.22	54365.08	337.06	8158.90	2753.54	117261.11
Std. Dev	60793.14	120850.30	218.46	16311.49	3583.15	303489.66
Semi Integrated N = 30 (9.4%)						
Mean	51526.77	56206.23	1220.7	3965.07	6698.73	60946.07
Std. Dev	35953.31	31692.57	394.56	2800.79	3753.71	66463.59
Highly Integrated N = 210 (65.6%)						
Mean	95000.33	98813.40	1393.01	3518.35	11932.88	35161.48
Std. Dev	72924.75	114613.32	948.22	2808.59	28836.60	40550.35
F stat.	**17.56*** **	**5.628** **	**52.49*** **	**8.767*** **	**4.595***	**7.993*** **

**p <0.05 **p <0.01 ***p <0.001*

Table 5.3, shows that majority of the oil and gas firms are highly integrated, refining and processing over 20% of their extracted oil and gas. Manifestly, 65.6% of the firms are highly integrated, 9.4% are semi integrated whilst 25% are least integrated firms. This evidence clearly supports the view that vertical integration is an important concept in the oil industry. In terms of input usage, least integrated firms use the least amount of assets (M=46743.22, SD=60793.14) and labour (M=54365.08, SD= 120850.30) whereas, highly integrated firms use the highest amount of assets (M=95000.33, SD=72924.75) and labour (M=98813.40, SD=114613.32). This could be as a result of the high capital base needed to venture into an additional segment in the industry (Szilas, 1985). Interestingly, when it comes to output generation, although highly integrated firms top the list oil in production (M=1393.01, SD=948.22), least integrated firms produce the largest amount of gas (M=8158.90, SD=16311.49) with highly integrated firms producing the least quantity of gas (M=3518.35, SD=2808.59). However, the large magnitude of the standard deviation indicates that the gas production levels vary greatly among the least integrated firms. A glimpse at the control of reserves shows that highly integrated firms control the largest amount of oil reserves (M=11932.88, SD= 28836.60) whereas least integrated firms control the smallest (M=2753.54, SD=3583.15). On the other hand, least integrated firms control the largest amount of gas reserves (M=117261.11, SD=303489.66) whereas highly integrated firms control the least (M=35161.48, SD=40550.35). A subsequent test of differences across the varying levels of vertical integration discloses that significant differences exist across the groups in their inputs, outputs and reserves levels.

One important prerequisite for the estimation of efficiency or productivity scores using the DEA technique is that input variables should be positively correlated with output variables (Avkiran, 2006; Wanke et al., 2015). This requirement is to satisfy the isotonicity assumption of DEA which requires that an increase in input should not result in a decrease in output (Dyson et al., 2001). The input and output variables are said to have passed the isotonicity test if this condition is fulfilled (Avkiran, 2006; Cooper et al., 2011; Thanassoulis, 2001). Table 5.4 presents the correlation matrix of all inputs, outputs and link variables used in this study.

Table 5.4: Correlation Matrix of Inputs, Outputs and Link Variables

	Total Assets	Labour	Oil Produced	Gas Produced	Crude Reserves	Gas Reserves
Total Assets	1.00					
Labour	0.40***	1.00				
Crude Produced	0.59***	0.33***	1.00			
Gas Produced	0.45***	0.45***	0.08	1.00		
Crude Reserves	0.15**	0.07	0.44***	0.05	1.00	
Gas Reserves	0.24***	0.41***	0.00	0.91***	0.17**	1.00

**p <0.05 **p <0.01 ***p <0.001*

From Table 5.4, it can be observed that there is a significant positive relationship between input variables (total assets and labor) and output variables (oil produced and gas produced). This proves that the isotonicity property of DEA, which requires all inputs to have a positive relationship with outputs has been duly met (Lu et al., 2014). It therefore, means that the input and output variables in this study have passed the isotonicity test.

5.2 Test of Returns to Scale

As discussed in chapter four, it is essential to determine scale elasticity of the underlying technology of the oil industry in order to ensure the appropriate estimation and analysis of efficiency scores under the right technology. As earlier stated the technology of the industry could exhibit constant returns to scale or variable returns to scale. Using the Mean of Ratios, we test the data to determine whether the petroleum industry exhibits VRS or CRS. Table 5.5 below shows the results of the type of returns to scale technology exhibited by global oil firms.

Table 5.5: Results of Scale Elasticity Test (Simar & Wilson 2002, 2011)

	Test Statistic	**Critical Value**	**P-Value**	**RTS**
Pooled	-0.6695	-0.1460	0.0005	VRS

From Table 5.5, since the test statistic of -0.6695 is less than the critical value of -0.1460 we reject the null hypothesis that the production technology is globally CRS at 5% significance and conclude that the underlying technology of the oil industry exhibits VRS (Simar & Wilson, 2011). This conclusion implies that the international oil and gas firms vary in sizes, therefore in the efficiency estimation, size is of essence. This provides a statistical justification for the adoption of VRS in all DEA efficiency estimations in this study.

5.3 Dynamic Efficiency in the Global Petroleum Industry

The first objective of this study seeks to assess the dynamic efficiency of oil firms while taking into consideration interconnecting activities between various operational periods using the dynamic slack-based measure of Tone and Tsutsui (2010). The DSBM measure is a long term assessment technique that evaluates the efficiency of firms over time, taking into account activities that link successive operational periods. The aim here is to learn whether the petroleum industry is advancing, stagnating or regressing. This section assesses the industry performance as a whole over the ten year period as well as the overall dynamic efficiency scores of the individual oil firms over the period. Table 5.6 presents the yearly average dynamic efficiency scores whereas Table 5.7 shows the overall dynamic efficiency scores for each firm. Geometric means are used instead of arithmetic means since DEA efficiency estimates are ratios and could be skewed.

The trend analysis presented in Table 5.6 depicts that efficiency in the global petroleum industry has been increasing steadily over the period under consideration.

Table 5.6: Year on Year Dynamic Efficiency Trend in the Petroleum Industry

Year	Dynamic Efficiency (Geomean)	% Change	Std. Dev.	No. of firms efficient
2001	0.5057	-	0.3777	17
2002	0.5242	3.66	0.3728	17
2003	0.5404	3.10	0.3679	16
2004	0.5476	1.33	0.3736	17
2005	0.5737	4.78	0.3601	18
2006	0.5724	-0.23	0.3622	18
2007	0.5813	1.56	0.3633	18
2008	0.5834	0.35	0.3570	18
2009	0.5518	-5.41	0.3617	17
2010	0.6964	26.22	0.2736	16
AVERAGE	**0.5677**	**3.93**		

The results in Table 5.6 show that efficiency in the industry has generally been progressing through the years. The year 2001 recorded the lowest dynamic efficiency score of 0.5057 whereas year 2010 recorded the highest dynamic efficiency score of 0.6964. The mild recession in America coupled with failure by some OPEC firms to adhere to production fall-offs could be the possible reasons for the abysmal performance of oil industry in 2001. Despite the general progress from 2001, the industry recorded negative growth in 2006 (-0.23%) and 2009 (-5.41%). The significant dip in efficiency in 2009 could possibly be attributed to the global economic recession of 2008 which continued into 2009 (OPEC, 2009). The fall in prices rendered some exploration programmes unviable, hence their cancellation. Contraction in credit also resulted in difficulty access to funding causing delays and cancellations of productive activities of petroleum firms (Watt, 2009).

The effect of the recession is also evident in 2008's performance as that year recorded the least level of progress (0.35%) compared to all other years under study. Contrariwise, the efficiency of the industry surged again in 2010 by the highest percentage of growth ever experienced in the industry throughout the period. This could be as a result of the gradual recovery from the depression where businesses began to get back on their feet. The industry was characterized by growth in oil demand driven by unparalleled government support to revive the economy after the 2009 recession (EIA, 2011). The oil market experienced relative stability during this period, it is therefore not surprising that the industry experienced such a high level of progress. The standard deviations also indicate that generally, efficiency in the industry has been relatively stable through the period.

A pictorial view of the efficiency trend presented in Figure 5.1 below shows that indeed there has been an increasing trend in the efficiency of oil firms in the oil industry as a whole through the study period.

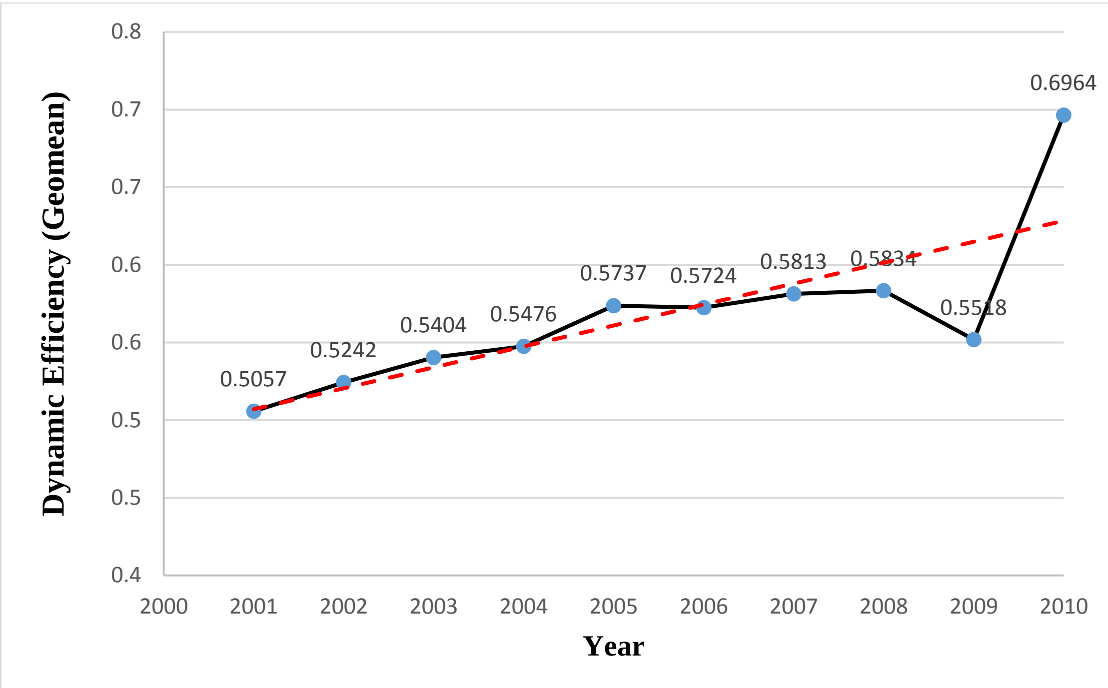

Figure 5.1: Year-on-Year DSBM Efficiency Trend from 2001-2010

A glimpse at the trend line from figure 5.1 shows that there is a consistent upward movement of efficiency in the industry through the period except for 2009 where the industry experienced a decline by 5.4%. The efficiency however, rose sharply in 2010 by 26.22% representing the highest improvement in dynamic efficiency in the oil industry throughout the period under consideration.

Narrowing down to oil companies, the output oriented DSBM scores measured under the VRS assumption for the 10-year period are presented in Table 5.7. The overall efficiency scores, maximum and minimum scores, and number of times each firm has been efficient through the period are provided. Even though output orientation is employed, the inverse of all scores are reported for this and subsequent sections, hence, restricting the scores between 0 and 1. A firm is said to be efficient if it has an efficiency score of unity and in the same vein, a firm with a score closer to one is seen as more efficient than one with a lower score. For a particular firm to attain an efficiency score of unity, it must have been efficient throughout all the 10 years. Consequently, a firm like BG which is efficient for 9 years and inefficient for 1 year would attain an overall score of less than one.

Table 5.7: DSBM Efficiency Scores of Petroleum Firms for the Period 2001-2010

S/N	DMU	Overall Score	Times efficient	Min.	Max.	Ownership	VI
1	Anadarko	0.923	6	0.5519	1	FP	LI
2	Apache	1	10	1	1	FP	LI
3	BG	0.9696	9	0.7613	1	FP	LI
4	BP	0.9444	6	0.7443	1	FP	HI
5	Chevron	0.6956	0	0.2614	0.8013	FP	HI
6	ConocoPhillips	0.9328	7	0.6772	1	FP	HI
7	Devon Energy	1	10	1	1	FP	LI
8	Ecopetrol	1	10	1	1	FSO	HI
9	EnCana	1	10	1	1	FP	LI
10	Eni	0.4356	0	0.2035	0.4758	MiSO	HI
11	Exxon Mobil	1	10	1	1	FP	HI
12	Gazprom	1	10	1	1	MaSO	LI
13	Hess	0.4891	0	0.3377	0.8583	FP	HI
14	Lukoil	0.785	6	0.5527	1	FP	HI
15	Marathon	0.2459	0	0.0862	0.2529	FP	HI
16	Occidental	0.5388	0	0.2389	0.7626	FP	LI
17	OMV	0.1961	0	0.0752	0.3529	MiSO	LI
18	ONGC	1	10	1	1	MaSO	HI
19	PDV	1	10	1	1	FSO	HI
20	Pemex	1	10	1	1	FSO	HI
21	Pertamina	1	10	1	1	FSO	HI
22	Petrobras	0.4632	0	0.1732	0.4371	MiSO	HI
23	PetroChina	0.3117	0	0.1616	0.5331	MaSO	HI
24	Petronas	0.7092	0	0.5449	0.9027	FSO	HI
25	Repsol YPF	0.4619	0	0.1524	0.4014	FP	HI
26	Rosneft	0.8366	8	0.5012	1	MaSO	HI
27	Royal Dutch Shell	0.7746	0	0.4832	0.7236	FP	HI
28	Sinopec	0.0624	0	0.0199	0.1159	MaSO	HI
29	Sonatrach	1	10	1	1	FSO	SI
30	Statoil	1	10	1	1	MaSO	SI
31	Surgutneftegas	1	10	1	1	FP	SI
32	Total	0.471	0	0.1835	0.5967	FP	HI
	Average	**0.6651**	**5**				

From Table 5.7, 13 (Apache, Devon Energy, Ecopetrol, EnCana, Exxon Mobil, Gazprom, ONGC, PDV, Pemex, Pertamina, Sonatrach, Statoil, Surgutneftegas) out of the 32 oil firms were efficient while 13 (Chevron, Eni, Hess, Marathon, Occidental, OMV, Petrobras, PetroChina, Petronas, Repsol YPF, Royal Dutch, Shell, Sinopec, Total) were inefficient throughout the 10-year period. The remaining 6 firms were efficient for some of the years and inefficient for other years, hence, they had an overall efficiency score of less than unity. Of the overall efficient firms, 6 are private NIOCs (Apache, Devon Energy, EnCana, Exxon Mobil, Gazprom, Surgutneftegas) whilst 7 are state-owned NOCs (Ecopetrol, ONGC, PDV, Pemex, Pertamina, Sonatrach, Statoil). Ten of the firms that were not efficient in at least one year throughout the period are private firms (Chevron, Eni, Hess, Marathon, Occidental, OMV, Petrobras, Repsol YPF, Royal Dutch, Shell, Total) whilst the remaining three are state-owned. It is not surprising that Exxon Mobil, Gazprom and PDV, major IOCs which have been consistently part of the top ten oil firms for a number years are among the best performers as Ike and Lee (2014) and Eller et al. (2011) have previously recognized their high performance.

Conversely, it is quite unanticipated that Chevron, Royal Dutch, Shell and Total which have been part of the top ten have not been efficient in a single year throughout the period. This observation indicates that although these firms might control more assets and reserves and produce more than most oil companies in the industry, they are not operating at their optimal level in converting inputs to outputs. A superficial glance at this trend gives an indication that state-owned oil firms count among the dominating firms whereas majority of the firms lagging behind are private oil firms. This observation however, is quite contrary to most oil efficiency studies. Aside, Sueyoshi and Goto (2012), all oil efficiency studies reviewed in this study observed otherwise. Further analysis is done in the subsequent sections to ascertain the dynamic efficiency differences among private and differing degrees of state-owned firms.

Assessing the firms' efficiencies by their level of integration shows that all semi integrated firms (Surgutneftegas, Sonatrach, Statoil) were efficient, 50% of the least integrated firms (Apache, Devon Energy, EnCana, Exxon Mobil, Gazprom) were efficient whilst 28.6% of the highly integrated firms (Ecopetrol, Exxon Mobil, PDV, Pemex, Pertamina) were efficient. This seems to suggest that vertical integration has a positive relationship with dynamic efficiency only to some extent. The subsequent sections investigate in-depth, the dynamic efficiency differences among these groups taking into consideration their technology heterogeneity.

On the whole, the average DSBM efficiency score of all oil firms understudy over the period was about 66.51% which means that on the average, all the firms under the study over the period, were 66.51% efficient in generating outputs from the given inputs.

5.4 Ownership and Dynamic Efficiency of Petroleum Firms

This section, in line with the second objective, non-parametrically assesses the impact of ownership on the dynamic performance of oil firms. The aim here is to determine which category of the different ownership groups are the best and worst performers respectively. This is achieved with the use of dynamic DEA coupled with metafrontier analysis. The metafrontier approach which is used to assess groups usually pools the data, thereby acting as a static measure. However as extension, the DSBM of Tone and Tsutsui (2010) is combined with the Metafrontier approach to ascertain which group is better overtime instead of using just the pooled data. The first subsection of this section presents the within group analysis where the dynamic group scores, meta scores and Technology Gap Ratios of each firm in each group is discussed. This assessment provides the basis to understand which firms drive the performance of each group. The inter group comparison is then done in the second subsection using the Geometric means of the various groups while subsection three presents pairwise comparisons to determine if differences are significant.

A firm with a group or meta efficiency score of one must have been efficient relative to the group or metafrontier for all the periods under consideration. The meta efficiency score represents a firm's efficiency relative to the metafrontier which is the overarching technology, knowledge and resources available to the industry as a whole irrespective of the type of ownership of the firm. The group efficiency score is the efficiency of an oil firm relative to its own group's frontier, which is, the knowledge, physical, social and economic environment that characterizes a particular group while the TGR provides a measure of how close the group frontier is to the metafrontier (O'Donnell et al., 2008). The value of the TGR explains the technological improvement or retrogression between the group and the industry as a whole (Battese & Rao, 2002). Its value ranges from zero to one, therefore, a score closer to 1 denotes lesser divergence between the group frontier and the meta frontier (Ahmed & Krishnasamy, 2013; Wang, Zhang, & Zhang, 2013). The TGRs of the differing groups of ownership are subsequently ranked in order of importance.

5.4.1 Intra-group analysis

In this section, the results are clustered and presented by groups to discusses the performance of oil firms within the various groups. Tables 5.8, 5.9, 5.10, and 5.11 present the results for each Fully Private (FP), Minority State-Owned (MiSO), Majority State-Owned (MaSO) and Fully State-Owned (FSO) firms respectively.

In Table 5.8, both group and meta efficiency scores for fully private oil firms are presented. Fully Private (FP) oil firms are those firms fully owned by private individuals without any amount of state ownership (Wolf, 2009)

Table 5.8: Dynamic Efficiency of Fully Private Oil Firms

S/N	Oil Firm	Ownership	Meta Efficiency	Group Efficiency	DTGR
1	Anadarko	FP	0.923	1	0.923
2	Apache	FP	1	1	1
3	BG	FP	0.9696	0.9725	0.997
4	BP	FP	0.9444	0.9599	0.9839
5	Chevron	FP	0.6956	1	0.6956
6	ConocoPhillips	FP	0.9328	1	0.9328
7	Devon Energy	FP	1	1	1
8	EnCana	FP	1	1	1
9	Exxon Mobil	FP	1	1	1
10	Hess	FP	0.4891	1	0.4891
11	Lukoil	FP	0.785	1	0.785
12	Marathon	FP	0.2459	0.4261	0.5771
13	Occidental	FP	0.5388	1	0.5388
14	Repsol YPF	FP	0.4619	0.6771	0.6822
15	Royal Dutch Shell	FP	0.7746	1	0.7746
16	Surgutneftegas	FP	1	1	1
17	Total	FP	0.471	0.7688	0.6126
	Geomean		**0.7296**	**0.9115**	**0.8004**

The intra group analysis presented in Table 5.8 shows the meta efficiency score, group efficiency score and the technology gap ratio of each FP oil firm. An observation of the group efficiency scores shows that only 5 of the 17 FP oil firms including BG (0.9725), BP (0.9599), Marathon (0.4261), Repsol YPF (0.6771) and Total (0.7688) are inefficient with respect to their group frontier, that is, having a group efficiency score of less than one as in the parenthesis. Even the efficiency scores of the firms that are inefficient are quite close to one which means their level of inefficiency is relatively low. This gives an indication that with the given technology, knowledge and other resources and infrastructure available to fully private firms, most of them are efficient in their output augmentation. However, the meta efficiency scores show that only 5 FP oil firms comprising Apache, Devon Energy, EnCana, Exxon Mobil and Surgutneftegas are efficient with respect to the metafrontier. This implies that given the technology available to petroleum companies in the industry as a whole, irrespective of their ownership status, these 5 firms are part of the best performers.

Although most of the firms do not have a meta efficiency score of one, most of these firms have scores which are nearly unity indicating that they are almost catching up with the best performers in the industry as a whole. The Dynamic Technology Gap Ratios also show that these five firms which are efficient relative to the metafrontier are the firms tapping fully into the knowledge, technology, economic infrastructure and the environmental and institutional opportunities available to the industry since they have DTGRs of 100%. The only firm with a DTGR less than 50% is the Hess with a DTGR of 48.9% indicating that on the average Hess produces using only 48% of the technological spill over in the industry. This could be as a result of differences in technology across countries where these firms operate as posited by Taylor, d'Ortigue, Francoeur, and Trudeau (2010). On a whole, FP oil firms have an average group efficiency of 0.9115, an average meta efficiency score of 0.7296 and a DTGR of 0.8004, signifying that on the average, FP firms produced using about 80% of the existing technology in the oil industry.

Table 5.9 below presents the dynamic meta efficiency, dynamic group efficiency and DTGR for petroleum companies with minority state ownership, that is, oil companies with state ownership between 1% and 49%.

Table 5.9: Dynamic Efficiency of Minority State-Owned Oil Firms

S/N	Oil Firm	Ownership	Meta Efficiency	Group Efficiency	DTGR
1	Eni	MiSO	0.4356	1	0.4356
2	OMV	MiSO	0.1961	1	0.1961
3	Petrobras	MiSO	0.4632	1	0.4632
	Geomean		**0.3408**	**1**	**0.3408**

The results presented in Table 5.9 are quite different from those presented in Table 5.8. It can be observed that every oil firm in this cluster is efficient with respect to their group frontier signifying that with the given technology, know how, resources and institutions available to this group, all MiSO firms are efficient in their production levels. This indicates that for all the 10 years under consideration, all the MiSO have been consistently efficient within the technology available to the group. This could be as a result of their low representation in the sample. However, their efficiency with regard to the metafrontier is fairly appalling. None of the firms in this cluster has attained a score up to 50% relative to the metafrontier. This implies that MiSO firms produce about 34.08% of their potential output given the technology available to the industry as a whole (Battese et al., 2004). MiSO Firms are therefore not taking full advantage of the technology available to the industry and should put in place measures to allow it tap fully into the industry technology.

This could possibly be as a result of conflicting goals pursued by firms with some amount of state ownership (Al-Obaidan & Scully, 1991). Moving to the DTGR, the MiSO firms as a whole attained an average DTGR of 34.08% suggesting that MiSO could at best produce 34.08% of the output that could be produced using the unrestricted technology available to the whole industry. A detailed look at the results shows that OMV is the worst firm (DTGR=0.1961) with regards to taking advantage of the industry-wide know how in production whereas Petrobras is the best with a DTGR of 0.4632. As posited by Taylor et al. (2010) the relatively poor performance of OMV could be as a result of the differences in production infrastructure across countries or even across firms.

The next group under consideration is Majority State-Owned (MaSO) oil firms. Of the 32 firms considered in this study, only 6 firms representing 18.6% of the sample size are majority state-owned firms. Presented in Table 5.10 are the dynamic meta efficiency, group efficiency and

DTGRs of firms with majority state ownership, that is, firms with state ownership of shares ranging between 50% and 99%.

Table 5.10: Dynamic Efficiency of Majority State-Owned Oil Firms

S/N	Oil Firm	Ownership	Meta Efficiency	Group Efficiency	DTGR
1	Gazprom	MaSO	1	1	1
2	ONGC	MaSO	1	1	1
3	PetroChina	MaSO	0.3117	1	0.3117
4	Rosneft	MaSO	0.8366	1	0.8366
5	Sinopec	MaSO	0.0624	0.0772	0.8083
6	Statoil	MaSO	1	1	1
	Geomean		**0.5034**	**0.6525**	**0.7714**

It is evident from Table 5.10 that out of the 6 majority state-owned firms, 5 were able to optimize their production levels for the entire period with the given resources, technology, regulations, and economic and institutional arrangements available to the group. However, Sinopec (0.0772) seems to be substantially underperforming the rest of the firms in this category as its group efficiency score is below 10%. This gross inefficiency could probably be attributed to firm specific differences and differences in managerial competences. There could also be other country specific factors that have affected oil firms where Sinopec operates (Taylor et al., 2010). A look at the DTGR of Sinopec (0.8083) indicates that it can at its best, produce about 80.83% of the output that could be produced using the technology available to the industry which suggests that majority of the inefficiency of this firm is more from its internal management rather than its membership to this group. Collectively, MaSO oil firms attained an average meta efficiency score of 0.5034, average group efficiency score of 0.6525 and an average DTGR of 0.7714. This indicates that using technology available to industry as a whole, MaSO firms could at their best produce 77.14% of the output that it could have produced. Despite having a group score of 1, PetroChina had a meta efficiency score of 0.3117 and subsequently, a DTGR of 0.3117 signifying that it produces only 31.17% of its potential output using the technological spillover in the industry.

With respect to Fully State-Owned (FSO) firms, results are presented in table 5.11. Six out of the 32 firms, representing 18.6% of the sample are 100% owned by the state. Table 5.11 shows the dynamic group efficiency, meta efficiency and DTGRs for fully state-owned firms.

Table 5.11: Dynamic Efficiency of Fully State-Owned Oil Firms

S/N	Oil Firm	Ownership	Meta Efficiency	Group Efficiency	DTGR
1	Ecopetrol	FSO	1	1	1
2	PDV	FSO	1	1	1
3	Pemex	FSO	1	1	1
4	Pertamina	FSO	1	1	1
5	Petronas	FSO	0.7092	1	0.7092
6	Sonatrach	FSO	1	1	1
	Geomean		**0.9443**	**1**	**0.9443**

Interestingly, the results on FSO firms presented in Table 5.11 suggest that all FSO oil firms were efficient throughout the 10-year period as they all scored an overall group efficiency score of unity (Tone & Tsutsui, 2010). Also, when it comes to the meta efficiency, all firms except Petronas (0.7092) attained a score of one. Consequently, Petronas attained a DTGR of 0.7092 which means that using the technology available to the industry Petronas could produce 70.92% of the output that it could have produced. The group on a whole attained a DTGR of 0.9443 indicating that on the average, FSO firms could at their best produce about 94.43% of the output that they could produce with their current level of input using the skills, knowledge, resources, and technological spillover available to the industry as a whole.

5.4.2 Inter-group performance assessment

Based on the intra group analysis presented in section 5.4.1 above, the inter group comparison of the four groups is shown in Table 5.12 below. The average dynamic meta efficiency, group efficiency and DTGR for each of the groups are presented and subsequently, ranks are assigned to these groups in descending order from the best performing to the worst performing group. The scores from the Table are then presented graphically in Figure 5.2 for better conceptualization of inferences.

Table 5.12: DSBM Metafrontier Results based on Ownership Status

S/N	Ownership	Meta Efficiency	Group Efficiency	DTGR	Rank
1	FP	0.7296	0.9115	0.8004	2
2	MiSO	0.3408	1	0.3408	4
3	MaSO	0.5034	0.6525	0.7714	3
4	FSO	0.9443	1	0.9443	1
ANOVA (F)		**40.89*** **		**65.64*** **	
K-Wallis (H)		**83.19*** **		**109.71*** **	

**p <0.05 **p <0.01 ***p <0.001*

As detailed in Table 5.12 above, the group efficiency scores of each group are quite high indicating that these firms within their local environments are performing well. It is evident that on the average, minority state-owned (MiSO) and Fully State-Owned (FSO) firms are producing the optimum amount of output given the resources and the technology available to each of these groups. Nonetheless, Fully Private (FP) and Majority State-Owned (MaSO) oil firms are producing 91.15% and 65.25% of their potential capacities respectively given their group specific technologies. However, since the group efficiencies are computed relative to different production frontiers, it is inappropriate to compare the group specific efficiency scores of these different groups (Assaf et al., 2010; Oh & Lee, 2010). Therefore, the Dynamic metafrontier results are used to compare the performance of these groups over time based on a common overarching frontier

(O'Donnell et al., 2008). The average meta efficiency scores of FSO (0.9443) and FP (0.7296) are quite close to unity indicating that these firms are close to being efficient when measured against the industry-wide frontier. Followed by these are the MaSO and MiSO firms with meta scores of 0.5034 and 0.3408 respectively. This indicates that when measured against the metafrontier, MaSO firms are 50.34% efficient while MiSO firms are only 34.08% efficient. A careful observation of the results shows that FSO (0.9443) and FP (0.8004) firms have DTGRs very close to one indicating that FSO firms are producing at 94.43% of their potential output whereas FP firms are producing at 80.04% of their potential output given the technology available to the industry. MaSO firms have an average DTGR of 0.7714, quite close to the best performers, while MiSO firms attained the least average DTGR of 0.3408 demonstrating that MiSO firms are producing about 34.08% of their potential output given the know-how, resources, infrastructure and institutions available to the industry as a whole. The ANOVA and Kruska-Wallis tests both indicate significant differences in the meta efficiency scores (F= 40.89, H= 83.19, $p < 0.001$) and DTGRs (F= 65.64, H= 109.71, $p < 0.001$) among the four groups.

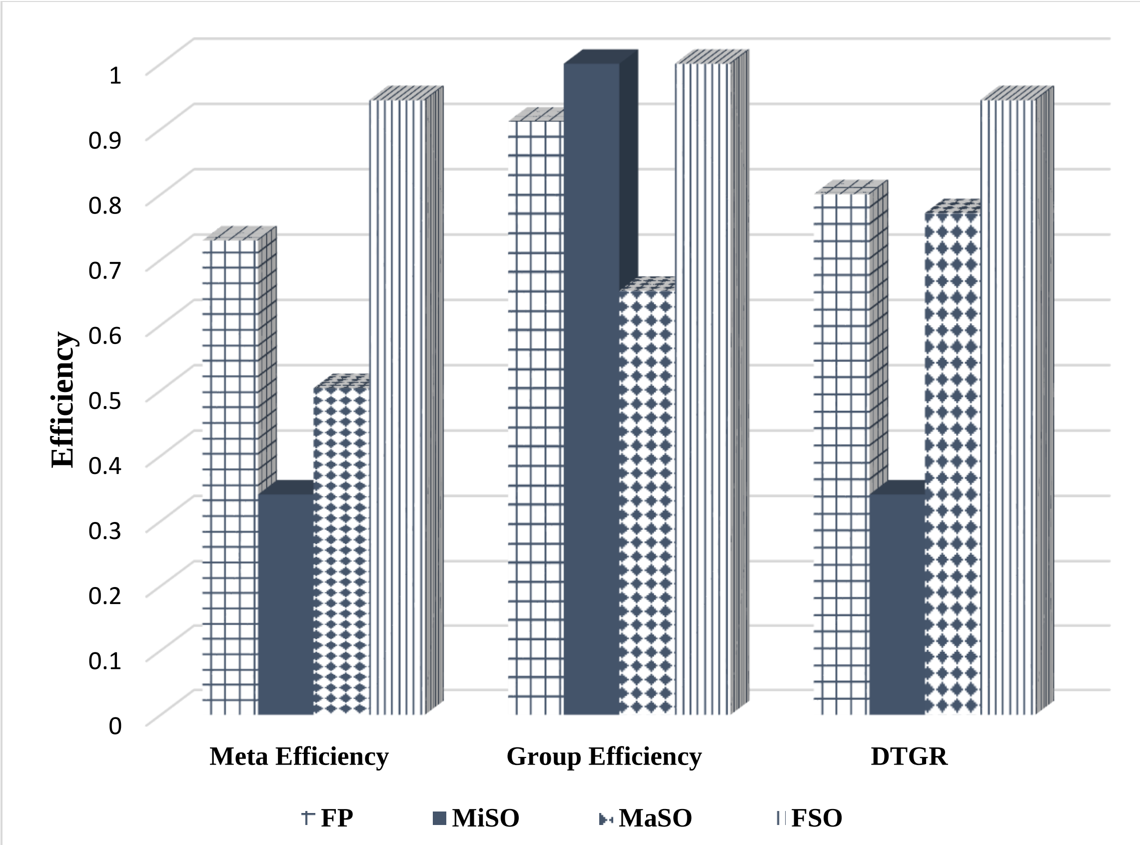

Figure 5.2: Distribution of Dynamic Meta, Group Scores and DTGRs

Figure 5.2 presents a graphical illustration of the distribution of the average dynamic meta efficiency, group efficiency and DTGR of the various groups of oil firms. The graphical assessment enables easy understanding of how different the scores of specific groups are from others. It is clear that on the average, FSO firms have the highest meta efficiency score, signifying the highest level of efficiency followed by FP, MaSO and lastly, MiSO. The group efficiency shows that each of the groups is performing considerably well within their territories. Whereas FSO and MiSO firms are operating on an optimal level, FSO firms have a score quite close to unity and MaSO firms too on average are producing over 50% of their optimum output level. The DTGRs show clearly that FSO firms are the leaders in the industry, closely followed by FP and then MaSO and lastly, MiSO. MiSO's DTGR shows that the category is lagging far behind its peers in the industry. However, it is not obvious whether differences in dynamic efficiencies and

DTGRs observed in the inter-group comparison are statistically significant. This is the basis for the pairwise comparisons presented in the next section.

5.4.3 Differences in distribution of efficiencies among groups

In order to determine whether the differences established in the intergroup comparison above are significant, Simar-Zelenyuk-adapted-Li Test (Li, 1996; Simar & Zelenyuk, 2006), (SZAL) is employed. The SZAL test uses kernel density estimators to compare the distribution of the entire dataset unlike other tests of differences such as Independent t-test and Mann Whitney U tests which only compare point estimates and neglect the distribution of the entire dataset, SZAL test considers the distribution of the entire dataset (Li, 1996; Simar & Zelenyuk, 2006). To ensure robustness, the pairwise comparison of the means and ranks of the various groups is first done using traditional statistical techniques such as Tuckey's HSD and Mann Whitney U tests and subsequently, the SZAL is employed to test the differences in the entire dataset. The test statistics are presented in Table 5.9 together with p-values in parenthesis. Note that group efficiencies are not compared in this table since the group efficiency scores of the various groups are based on distinct production frontiers.

Table 5.13: Pairwise Comparisons of Dynamic Efficiency

Ownership Type	Efficiency	Tuckey HSD	Mann Whitney	SZAL
FP – MiSO	Meta Eff.	0.253 (0.000)***	4586 (0.000)***	21.950 (0.000)***
	DTGR	0.533 (0.000)***	4974 (0.000)***	23.71 (0.000)***
FP – MaSO	Meta Eff.	0.006 (0.999)	6341 (0.003)**	1.859 (0.032)*
	DTGR	0.097 (0.042)*	4238.5 (0.035)*	1.411 (0.071)
FP – FSO	Meta Eff.	-0.253 (0.000)***	3053 (0.000)***	7.198 (0.000)***
	DTGR	0.214 (0.042)*	3081 (0.000)***	6.658 (0.000)***
MiSO – MaSO	Meta Eff.	-0.500 (0.000)***	352 (0.000)***	24.791 (0.000)***
	DTGR	-0.630 (0.000)***	55 (0.000)***	24.990 (0.000)***
MiSO – FSO	Meta Eff.	-0.746 (0.000)***	0 (0.000)***	34.750 (0.000)***
	DTGR	-0.747 (0.000)***	0 (0.000)***	35.535 (0.000)***
MaSO – FSO	Meta Eff.	-0.246 (0.000)***	700 (0.000)***	8.751 (0.000)**
	TGR	-0.116 (0.046)*	1390 (0.006)**	1.331 (0.092)

****p <0.001. **p<0.01. *p<0.05; p-values in parenthesis*

As expected, the first comparison between FP and MiSO firms indicates that FP firms significantly outperform MiSO firms using all three tests. At 0.1% level of significance, FP firms significantly outperform MiSO firms in both meta efficiency and DTGR. Comparison between FP and MaSO shows similar results as FP firms significantly outperform MaSO firms in both meta efficiency and DTGR at 1% and 5% levels of significance by the various tests. Comparison of FP and FSO however, reveal incongruent results with empirical and theoretical literature. It is revealed that FSO firms significantly outperform their FP counterparts in both meta efficiency and DTGR at 0.1% significance using all the three tests of differences. Focus on the MiSO firms indicate that all the other groups, FP, MaSO and FSO firms significantly perform better than MiSO firms at 0.1% level of significance. This places the group at the bottom as the least performing group in terms of the degree of state ownership. A consideration of MaSO firms shows that while MaSO firms outperforms MiSO firms in both meta efficiency and DTGR at 0.1% level of significance using all the estimators, it is significantly outperformed by FSO and FP firms at 0.1% level of significance and 5% level of significance respectively. When it comes to FSO firms, Table 5.9 shows that this group is the best performing group as it significantly outperforms all other groups under consideration. Overall, it can be suggested that FSO firms are the best performers in terms of dynamic performance, followed by FP firms, MaSO firms and lastly, MiSO firms. Kernel Density plot of the distribution of the DTGRs of the various groups are presented in Figure 5.3 for better visualization of the distribution of the technology gap ratios.

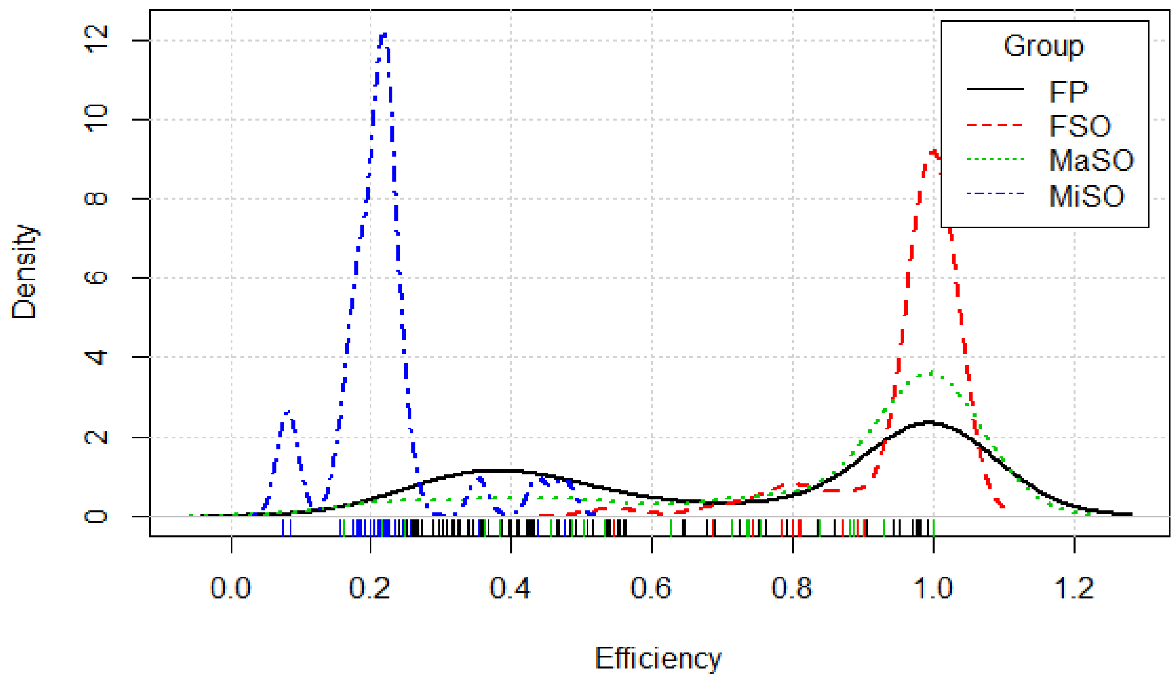

Figure 5.3: Kernel Density Plot of Dynamic Technology Gap Ratios

An observation of Figure 5.3 shows two groups at the opposite extremes. Whereas FSO firms gather greater probability mass on the right tail, MiSO firms gather greater probability mass on the left tail suggesting that a greater number of the FSO oil firms are located close to the efficiency boundary whilst a greater number of the MiSO oil firms are located further away from the efficiency frontier. FP and MaSO firms seem to be peaking around the same range, that is, from 0.9 to 1.0.

It is interesting that in both group and meta efficiency as well as DTGR, FSO firms significantly outperform all the other groups emerging as the best group. This revelation is quite incongruent with empirical literature. Empirically, it is quite contrary with previous studies, as notable oil efficiency studies such as Al-Obaidan and Scully (1991), Wolf (2009), Eller et al. (2011), and Ike and Lee (2014) have all found state-owned oil firms to be among the least performing firms in the industry as compared to private firms. This observation however, could be a further endorsement of the claim that NOCs are retaining a dominant position in the international petroleum industry (Energy Intelligence, 2015). For example, Energy Intelligence's Top 50 annual ranking for 2015 revealed that the top three spots are being held by national oil companies and over 60% of the top 25 firms are majority government-owned. There is the possibility of strong sovereign backing and more favourable operating environment for FSOs that give them a higher comparative advantage over the other groups. On the other hand, the results support the observation of Chen et al. (2009) that private firms are superior to some categories of state-owned firms but not superior to other categories of state-owned firms.

The divergence of the results from previous studies could also probably be attributed to the differences in methodologies employed. Previous literature employed efficiency measures or methodologies that could not account for carry-over activities or incorporate group heterogeneity in their assessment as catered for in this study. Oil and gas reserves for instance, which are interconnecting variables between consecutive periods, have not been accounted for as such in all the previous literature reviewed. Instead, oil and gas reserves have been considered as inputs, although, justifiable, this might lead to inappropriate conclusions as the amount of oil and gas reserves usually reported are not exhausted in a single period but carried forward from one period to another as explained by Thompson et al. (1994) and Thompson et al. (1996). The treatment of oil and gas reserves as inputs consumed in a particular period instead of desirable carryovers could be the reason why state firms appear inefficient in previous studies. Also, the metafrontier approach applied in this study accounts for the different environments within which firms operate. Comparing them on the same level might not be truly representative of their performance since the structures, resources and institutions within which these firms operate could differ (Oh & Lee, 2010). Therefore, the DSBM-Metafrontier approach applied in this study for the first time in the oil industry could also contribute to the inconsistency of the results with previous studies.

Theoretically, it is possible that with the prevalence of more media interventions and more awareness drawn by previous studies, state firms have begun putting in place strict measures and policies to mitigate the relatively higher agency problems asserted by the agency theory. On this basis, the findings of earlier studies that the level of inefficiency is expected to increase with increasing state ownership and control due to an increase in agency problems (Eller et al., 2011) has not been supported by the study. This could probably be an indication that state-owned firms are indeed working hard to retain a dominant position in the oil industry (Energy Intelligence, 2015). Additionally, there is no enough evidence to suggest in accordance with the property rights theory that resources in state-owned oil firms are not being allocated according to the highest valued use. Possibly, state-owned oil firms have been awakened by the call to properly define the property rights to their resources to ensure their efficient allocation as postulated by and Demsetz (1967) and Alchian and Demsetz (1973). This could be an indication that in their quest to retain dominant positions in the industry, FSO firms are gradually reducing the level of political interference to ensure efficient allocation of resources.

Although quite unexpected, this revelation buttresses the claim that though private firms might be among the best performers in the industry, it is not all groups of state-owned firms that are out-performed by private firms (Chen et al., 2009). The results also seem to suggest that full private ownership or full state ownership of oil firms is healthier for their performance as compared to shared ownership between state and private entities. Indeed, Ding et al. (2007) noted that aside the existing owner-manager conflicts in the agency relationship, there exists some other conflicts among the controlling (majority) shareholders and the minority shareholders since the majority shareholders might have some dominating interests which might not be in the interest of the other shareholders.

5.5 Vertical Integration and Dynamic Efficiency of Petroleum Firms

The third objective of the study seeks to ascertain the impact of vertical integration on the dynamic efficiency of oil firms. The intent here is to determine the level of vertical integration that is suitable for optimal performance of oil firms and to help those firms suffering adversely as a result of improper levels of vertical integration to improve. To accomplish this objective, dynamic DEA is employed concurrently with Metafrontier analysis. The Metafrontier approach which is used to assess groups usually pools the data, thereby acting as a static measure. However, as a novelty, the DSBM of Tone and Tsutsui (2010) is combined with the Metafrontier approach to discover which group is better over time instead of using just the pooled data. Subsection 5.5.1 discusses the dynamic group efficiency score, dynamic meta efficiency score and dynamic technology gap ratio for each firm in each group. This assessment enables us to understand which firms control the performance of each group. The inter-group comparison is then done in subsection 5.5.2 using the geometric means of the various groups whereas the last subsection tests for pairwise differences.

A firm with a group efficiency or meta efficiency score of 1 must have been efficient relative to the group or metafrontier for all the periods under consideration. The meta efficiency score represents a firm's efficiency relative to the metafrontier whereas the group efficiency score is the efficiency of an oil firm relative to its own group's frontier which is the knowledge, physical, social and economic environment that characterize a particular group. The DTGR helps to measure how close a group frontier is to the metafrontier (O'Donnell et al., 2008). Its value explains the technological progress or decline between the group and the industry as a whole (Battese & Rao, 2002). Consequently, a score closer to 1 denotes lesser deviation of the group frontier from the meta frontier (Ahmed & Krishnasamy, 2013). The DTGRs of the different groups of integration levels are then ranked from highest to lowest to ascertain which group outperform the others.

5.5.1 Intra-group analysis

Tables 5.14, 5.15 and 5.16 present the dynamic group efficiency scores, dynamic meta efficiency scores and dynamic technology gap ratios for each firm in each group.

Table 5.8 presents, both group and meta efficiency for Least Integrated (LI) oil firms. Following Al-Obaidan and Scully (1993), a Least Integrated firm is one that processes less than 10% of its crude and gas produced.

Table 5.14: Dynamic Efficiency of Least Integrated Oil Firms

S/N	Oil Firm	Degree of VI	Meta Efficiency	Group Efficiency	DTGR
1	Anadarko	LI	0.923	1	0.923
2	Apache	LI	1	1	1
3	BG	LI	0.9696	0.9726	0.9969
4	Devon Energy	LI	1	1	1
5	EnCana	LI	1	1	1
6	Gazprom	LI	1	1	1
7	Occidental	LI	0.5388	1	0.5388
8	ONGC	LI	1	1	1
	Geomean		**0.9129**	**0.9965**	**0.9160**

As shown in Table 5.14, all least integrated oil firms are efficient with respect to their group frontier with the exception of BG (0.9726). Although not efficient, BG has a score (0.9726) quite close to one indicating that its distance from the frontier is minute. This is evidenced by the average group efficiency score of 0.9965, showing that on the average, over the period, LI firms produce 99.65% of their potential output given their inputs and group-specific technology. With respect to the metafrontier, three of the firms are inefficient including Anadarko (0.923), BG (0.9696) and Occidental (0.5388). This clearly shows that much of the inefficiency relative to the metafrontier, is driven by Occidental which produces about 50% of its potential output given the technological spillover of the industry. The group has an average DTGR of 0.91603 signifying that on the average, LI firms can at best produce about 92.60% of their optimum output using the knowledge, resources, infrastructure and the social and economic environment available to the entire industry. This is quite good as it is very close to unity, indicating that distance between the group's frontier to that of the industry frontier is not much (Assaf et al., 2010).

The next group for consideration is the Semi Integrated (SI) firms. The meta efficiency, group efficiency and DTGRs of firms in this group are presented in Table 5.15.

Table 5.15: Dynamic Efficiency of Semi Integrated Oil Firms

S/N	Oil Firm	Degree of VI	Meta Efficiency	Group Efficiency	DTGR
1	Sonatrach	SI	1	1	1
2	Statoil	SI	1	1	1
3	Surgutneftegas	SI	1	1	1
	Geomean		**1**	**1**	**1**

Semi Integrated firms are the least represented when it comes to degree of vertical integration. Only 3 out of the 32 firms under study are semi integrated. A look at the results in Table 5.15 however, suggests that all of these SI firms are efficient relative to their group frontier and metafrontier as they attain average meta efficiency and group efficiency scores of unity. Also, the group has an average DTGR of 1, demonstrating that using the industry-wide technology, SI firms can produce 100% of their potential output. This means that there is zero distance between the group's frontier and the pooled frontier which is quite remarkable.

Lastly, we consider the intra-group analysis of Highly Integrated (HI) firms. Presented in Table 5.16 are the dynamic meta efficiency, group efficiency and DTGRs of HI oil firms.

Table 5.16: Dynamic Efficiency of Highly Integrated Oil Firms

S/N	Oil Firm	Degree of VI	Meta Efficiency	Group Efficiency	DTGR
1	BP	HI	0.9444	0.9448	0.9996
2	Chevron	HI	0.6956	0.8016	0.8678
3	ConocoPhillips	HI	0.9328	0.9622	0.9694
4	Ecopetrol	HI	1	1	1
5	Eni	HI	0.4356	0.5048	0.8629
6	Exxon Mobil	HI	1	1	1
7	Hess	HI	0.4891	1	0.4891
8	Lukoil	HI	0.785	0.8284	0.9476
9	Marathon	HI	0.2459	0.3249	0.7568
10	OMV	HI	0.1961	1	0.1961
11	PDV	HI	1	1	1
12	Pemex	HI	1	1	1
13	Pertamina	HI	1	1	1
14	Petrobras	HI	0.4632	0.5565	0.8323
15	PetroChina	HI	0.3117	0.6653	0.4685
16	Petronas	HI	0.7092	1	0.7092
17	Repsol YPF	HI	0.4619	0.6069	0.7611
18	Rosneft	HI	0.8366	1	0.8366
19	Royal Dutch Shell	HI	0.7746	1	0.7746
20	Sinopec	HI	0.0624	0.1903	0.3279
21	Total	HI	0.471	0.6409	0.7349
	Geomean		**0.5561**	**0.7547**	**0.7369**

Out of the 32 oil firms used in the study, 21 are highly integrated, signifying that vertical integration is one of the major phenomena in the oil and gas industry. Interestingly, 10 out of these 21 firms (Ecopetrol, Exxon Mobil, Hess, OMV, PDV, Pemex, Pertamina, Petrobras, Petronas, Rosneft and Royal Dutch Shell) are efficient relative to their group frontier while 11 of the firms in this category are inefficient. When it comes to group efficiency, the worst performer is Sinopec with a score of 0.1903 meaning that the firm is producing 19.03% of its potential output. Closely followed by Sinopec is Marathon producing 32.49% of its potential output. Aside these two, all other firms are producing over 50% of their potential output. These difference could be as a result of firm specific or country specific differences within the group (Taylor et al., 2010). The group scores and average group efficiency score of 75.47%, meta efficiency score of 55.61% and DTGR of 73.69%.

5.5.2 Inter-group performance assessment

Following the within group analysis presented in the previous section, this section discusses the inter group dynamic efficiency differences among the 3 groups. Based on the dynamic meta efficiency, group efficiency and DTGRs presented in Table 5.17, ranks are assigned to each group from 1 to 3 indicating the best to worst performing groups respectively. Consequently, the various efficiency scores are graphically presented in Figure 5.9 for easy visualization of the performance of groups.

Table 5.17: DSBM Metafrontier Results based on Degree of VI

S/N	Vertical Integration	Meta Efficiency	Group Efficiency	DTGR	Rank
1	LI	0.9129	0.9965	0.9160	2
2	SI	1	1	1	1
3	HI	0.5561	0.7547	0.7369	3
ANOVA (F)		**42.01*** **		**16.45*** **	
K-Wallis H		**73.83*** **		**61.547*** **	

*p <0.05 **p <0.01 ***p <0.001

As shown it Table 5.17, all the groups are performing relatively well with respect to their group frontiers. Semi Integrated (SI) firms scored 100% with Highly Integrated (LI) firms too almost scoring 100% whereas Highly Integrated (HI) firms attained an average score of 75.47%. Also, with the meta efficiency, all groups performed relatively well where SI firms scored 1, followed by LI firms with a score of 0.9129 and lastly HI firms with a score 0.5561. In the same vein, the DTGR shows that with the industry technology and structures, SI firms can best produce at 100% of their potential output placing them at the top position, LI firms can best produce at 91.60% of their optimum output, making them the second best whereas HI firms can best produce at 73.69% making them the worst performing group. ANOVA and Kruska-Wallis tests both emphasize the existence of significant differences in the dynamic meta efficiency scores (F= 42.01, H= 73.83, $p < 0.001$) and DTGRs (F= 16.45, H= 61.547, $p < 0.001$) among the three groups.

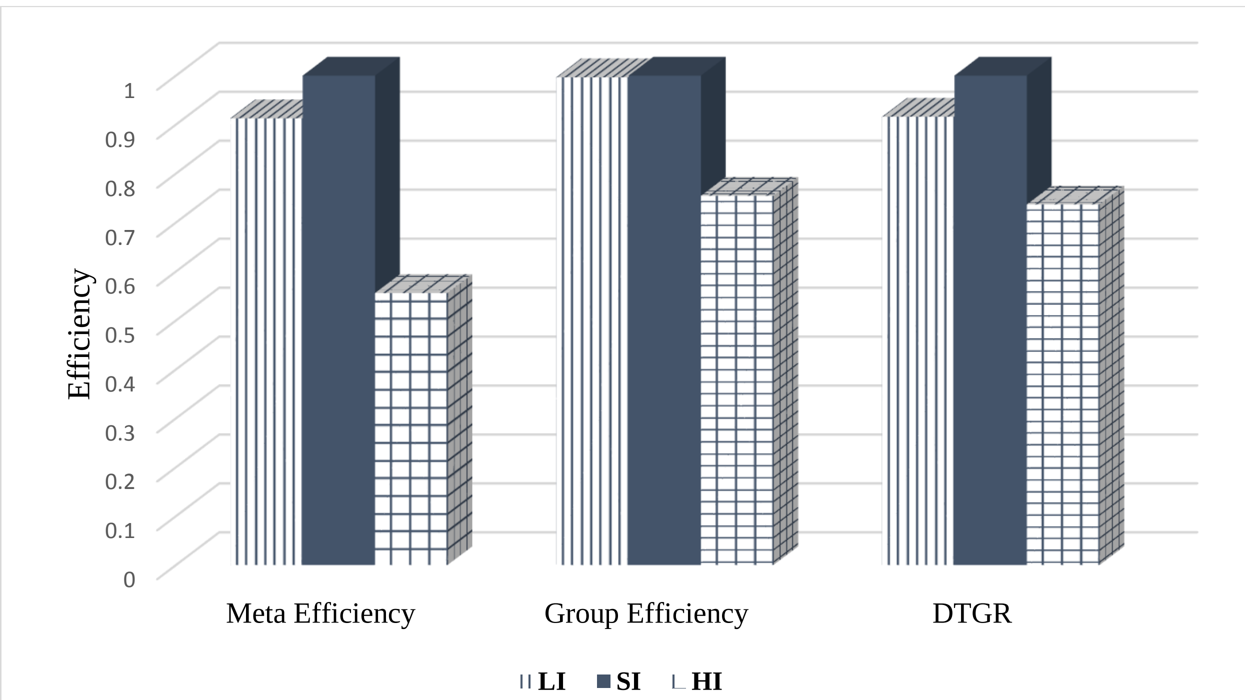

Figure 5.4: Distribution of Dynamic Efficiency by Degree of VI

Figure 5.3 presents a graphical illustration of the distribution of the average dynamic meta efficiency, group efficiency and DTGR of the different levels of integration of oil firms. The graphical representation allows for easy understanding of how scores of particular groups differ from others. A glance at the diagram shows that on the average, SI firms have the highest meta efficiency score, signifying the highest level of efficiency followed by LI firms and lastly, HI firms. The group efficiency indicates that each of the groups is performing substantially well within their terrains. While SI firms are operating on an optimal level and LI firms are almost on efficient frontier, HI firms seem to be inefficient although they produce over 50% of their optimum output level. The DTGRs show evidently that SI firms top in performance in the industry, closely followed by LI and lastly, HI firms. To determine the particular pairs causing differences in dynamic efficiencies and DTGRs observed in the inter-group comparison, pairwise comparisons are presented in the next section to test the significance of the differences.

5.5.3 Differences in distribution of efficiencies among groups

The Simar-Zelenyuk-adapted-Li Test (Li, 1996; Simar & Zelenyuk, 2006), (SZAL) is employed to determine whether the differences established in the intergroup comparison above are significant and which pairs are driving the differences. The SZAL test uses kernel density estimators to compare the distribution of the entire dataset unlike other tests of differences such as Independent t-test and Mann Whitney U test which only compare point estimates and neglect the distribution of the entire dataset. Test statistics of Tuckey's HSD, Mann-Whitney U test and SZAL test are presented in table 5.18 with their corresponding p-values in parenthesis. The SZAL which is a non-parametric measure is the most suitable test since efficiency scores are mostly not normally distributed. It also measures the distribution of the entire dataset unlike Mann Whitney U test which is also a non-parametric test.

Table 5.18: Pairwise Comparisons of Dynamic Efficiency Between Groups

VI	Efficiency	Tuckey HSD	Mann Whitney	SZAL
LI – SI	Meta Eff.	-0.09 (0.379)	975 (0.012)*	0.327 (0.372)
	DTGR	-0.087 (0.224)	975 (0.012)*	0.245 (0.403)
LI – HI	Meta Eff.	0.312 (0.000)***	12532 (0.000)***	16.783 (0.000)***
	DTGR	0.135 (0.000)***	10420 (0.001)**	11.218 (0.000)***
SI – HI	Meta Eff.	0.402 (0.000)***	5145 (0.000)***	10.798 (0.000)***
	DTGR	0.222 (0.004)**	449 (0.000)***	7.672 (0.000)***

****p <0.001. **p<0.01. *p<0.05 p-values in parenthesis*

The pairwise comparison between LI and SI firms reveals that although the Tuckey's HSD and U-test indicate significant difference between the groups, the SZAL test shows otherwise. Using the SZAL test we conclude that there are no significant differences between the performance of LI and SI firms. However, the differences in meta efficiency and DTGRs between LI and HI are significant at 0.1% and 1% levels of significance accordingly signifying that Least Integrated firms significantly outperform Highly Integrated firms in meta efficiency (l=16.783, p<0.001) and DTGR (l=11.218, p<0.001). Also, between SI and HI, all three tests observed a significant difference in meta efficiency and DTGR at 0.1% level of significance. This is an indication that Semi Integrated firms perform better than Highly Integrated firms. On a whole, it can be inferred that Semi Integrated oil firms are the industry pioneers, followed by Least Integrated oil firms while Highly Integrated firms are the least performers. For better conceptualization, the distribution of the DTGRs ratios of the various groups are presented in a Kernel density plot in Figure 5.5 below.

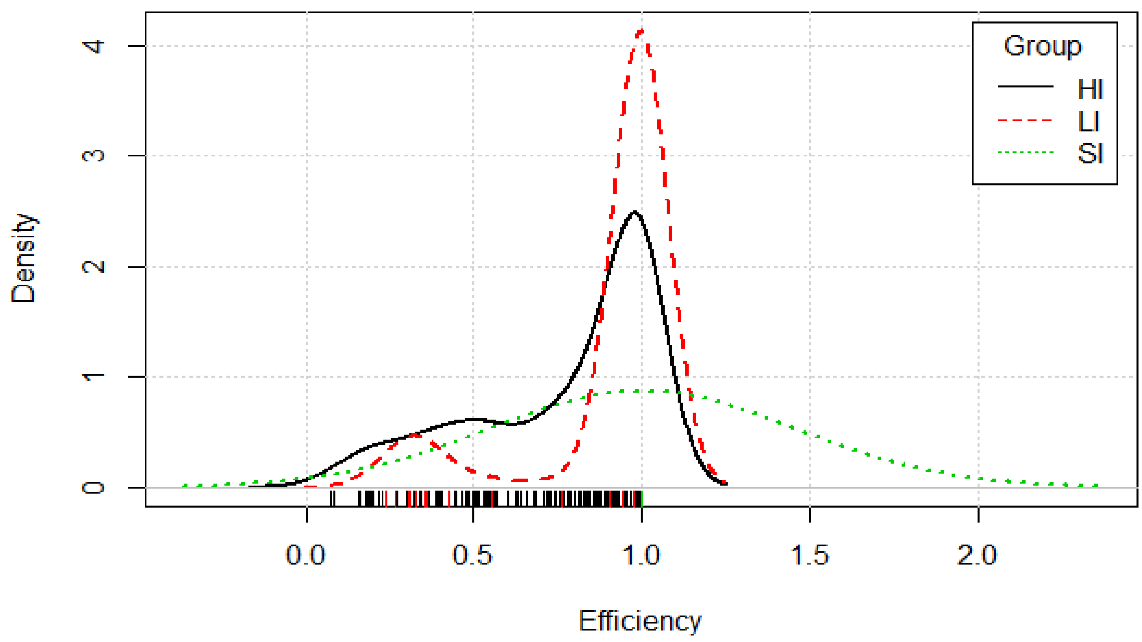

Figure 5.5: Kernel Density Plots of Dynamic Technology Gap Ratios

From the analysis above, it is clear that though insignificant, Semi Integrated firms outperform Least Integrated firms who in turn significantly perform better than Highly Integrated firms. Empirically, the observations here seem to support the claims of earlier studies that VI presents mixed effects on the efficiency of petroleum firms. Earlier studies in the industry have not reached an agreement on the impact of VI on efficiency. Previously, Al-Obaidan and Scully (1993) cited VI as a strategy for significant reduction of business risk as well as a strategy that improves scale efficiency probably as a result of spreading investments across broader operations. However, the same study found similar to the present study that vertical integration reduced the technical and economic efficiency of firms. Ike and Lee (2014) had found similar results and cited the pursuance of too many objectives as the possible reason for the negative relationship between VI and technical efficiency. Nonetheless, Eller et al. (2011) found the degree of vertical integration to have a positive relationship with the revenue efficiency of a firm probably because these companies are able to sell higher valued products at higher prices. It must be noted however that the study did not account for the higher capital inputs such as refineries, transport infrastructure, retail outlets, and so on that may be needed to support the activities of vertically integrated firms which could be the reason why they appeared more efficient.

Theoretically, the assertion by the transactional framework that an integrated firm is expected to do better than its non-integrated competitors (Guan & Rehme, 2012), cannot be entirely supported in the current study. Future studies could explore further using profit or revenue efficiency to test whether high profits can be found in the supply chain with the ability of firms to sell higher valued products for higher prices. Afuah (2001) earlier argued that in the face of rapid technological change which renders upstream capabilities obsolete, the benefits of integration are considerably reduced hence, integration might not be the solution to the problem of high transaction costs. Although the resource based view provides a sound argument that it is prudent for firms with wide range of resources to explore these resources fully in order to attain a competitive advantage over their competitors via VI, (Teece, 1982), the results show that this expansion must be done in moderation. The results could further buttress the claim of the industrial organization perspective that as the size of a firm increases the internal cost of operation of the firm increases as well hence, making vertical integration a costly strategy (Al-Obaidan & Scully, 1993).

From the foregoing, it is obvious that whilst other studies have identified vertical integration as an apparent strategy to circumvent high transaction costs and take advantage of technology spill over and economies of scale (Al-Obaidan & Scully, 1993; Eisenhardt, 1989; Hennessy, 1996), it could also be a costly strategy which has a negative effect on technical efficiency and result in diseconomies of scale (Al-Obaidan & Scully, 1993). Kerkvliet (1991) even noted earlier that in spite of its other notable advantages, VI could bring about coordination problems and other managerial diseconomies. It is thus not surprising that it has a somewhat negative impact on dynamic efficiency in the current study.

5.6 Proposed DSBM-Metafrontier Model

The last objective of the study seeks to propose an extension to the DSBM and Metafrontier approaches for the assessment of group dynamic efficiency. As discussed in section 4.6 of chapter four, this study proposes for adoption, a DSBM-Metafrontier model which is based on the DSBM of Tone and Tsutsui (2010) and Metafrontier framework of Battese and Rao (2002); Battese et al. (2004); O'Donnell et al. (2008). The DSBM-Metafrontier model is ideal for assessing the efficiency of DMUs categorized into different groups (for example: fully private, minority state-owned, majority state-owned and fully state-owned oil firms) due to technological heterogeneity while accounting for interconnecting activities that link successive periods (for instance: oil reserves and gas reserves). Although the DSBM of Tone and Tsutsui (2010) is able to incorporate interconnecting variables in assessing efficiency overtime, it is not able to consider group dynamics in its assessment. Meanwhile, the meta-frontier approach of Battese and Rao (2002); Battese et al. (2004); O'Donnell et al. (2008), which is able to assess efficiency differences among groups whilst accounting for the differences in their technology sets, does not account for carry-over activities. The model extension is necessary in order to achieve objectives 2 and 3 of this study. Objectives 2 and 3 of the current study which assessed group dynamic efficiency of petroleum firms on the basis of ownership and vertical integration respectively, were achieved by the application of the proposed DSBM-Metafrontier model.

The model specification and detailed explanation have been presented in section 4.6 of chapter four of the current study.

5.7 Conclusion

The Chapter has provided enough results and discussions to answer the research questions of the study. Prior to answering the research objectives, the scale elasticity test was conducted and the results indicate that the petroleum industry operates under variable returns to scale. The first objective was achieved by assessing dynamic efficiency of the petroleum industry for the period under study. Dynamic efficiency in the industry has been rising sturdily although with some dips possibly due to major economic events, although other factors could affect efficiency. Objectives 2 and 3 were achieved by applying the Dynamic Metafrontier model proposed in the methodology. The results showed that Fully State-Owned (FSO) firms are the best performers in the oil industry followed by Fully Private, Majority State-Owned and lastly by Minority State-Owned firms respectively. With vertical integration, the results implied that Highly Integrated firms are the worst performers in the oil industry followed by Least Integrated firms whereas Semi Integrated firms emerged as best performers. The last objective was achieved by extending the DSBM and the metafrontier approach into a DSBM-Metafrontier model for adoption by future studies.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.0 Introduction

This chapter, which is devoted to the summary, conclusions and recommendations from the study, is divided into three sections. The aims and objectives of the study as well as the key findings are presented in the first section, the second section draws conclusions from the findings whereas recommendations for policy and practice and directions for further research are provided in the final section.

6.1 Summary of the Study

The purpose of this study is to assess the impact of different typologies of ownership and vertical integration on the dynamic efficiency of petroleum firms and to subsequently combine the DSBM of Tone and Tsutsui (2010) and Metafrontier of Battese and Rao (2002); Battese et al. (2004); O'Donnell et al. (2008) into a DSBM-Metafrontier measure for the assessment of dynamic efficiency of firms in different groups. Although there are a number of studies on ownership, this study was unique in many ways: the study investigated the varying degrees of state ownership by segregating state ownership into Minority State-Owned (MiSO), Majority State-Owned (MaSO) and Fully State-Owned (FSO) based on the amount of shares held by the state. This segregation helps to ascertain the specific type(s) of state ownership that is (are) beneficial or detrimental to the performance of global petroleum firms. Also, unlike other studies, the study accounted for carryover activities such as oil and gas reserves that connect successive periods, a phenomenon that cannot be ignored especially in the operations of the oil industry. Oil and gas reserves have been accounted for in previous studies as inputs, implying that they are used up in a single period, however, this is not the case because reserves are held by oil firms and transferred from one period to another. Treating reserves as inputs that are used up in a single period might make firms with higher reserves appear inefficient since they would be seen to be using too much inputs relative to their outputs. Oil firms are categorized into fully state-owned, majority state-owned, minority state-owned and fully private as well as into least integrated, semi integrated and highly integrated. It must be noted that firms in different groups might be faced with different production capabilities resulting from differences in resource endowment, levels of state support and subvention and other group specific differences. To enable a fair comparison, the metafrontier methodology was applied to incorporate these group heterogeneities in the assessment. Lastly, a model extension, DSBM-Metafrontier model has been proposed to assess group dynamic efficiency of firms. The model is presented and discussed in chapter four of the study.

Data of 32 petroleum firms for the period 2001-2010 was sourced from the annual rankings of Energy Intelligence's Petroleum Intelligence Weekly (PIW). The sample is part of the top 50 oil companies globally selected annually by Energy Intelligence, a widely acclaimed source of petroleum sector data and ranked on the basis of oil reserves; gas reserves; oil production; gas production; product sales; and refining capacity. Due to model requirements of a balanced panel, 32 of the 50 firms could be used for the study. Nevertheless, firms in the top 50 are globally known companies with international presence and many years of active involvement in the industry the 32 firms used comprise a good representation of the 50 firms. In all 32 firms for 10 years gave 320 individual observations for the study.

The data were first analyzed by presenting the summary statistics and returns to scale test and subsequently the research objectives. For the first objective, the dynamic efficiency trends of the oil industry were analyzed by years and by firms. This was followed by the assessment of the impact of ownership and vertical integration on dynamic efficiency of oil firms. The firms were grouped into Fully Private (FP), Minority State-Owned (MiSO), Majority State-Owned (MaSO) and Fully State-Owned (FSO) for the ownership assessment. They were again categorized into Least Integrated (LI), Semi Integrated (SI) and Highly Integrated (HI) for assessment on vertical integration. The major findings identified in the study are as follows:

a. The sizes of firms in the global petroleum industry vary, implying that size is of essence in any efficiency or performance assessment that is to be carried out in the industry.
b. Annual dynamic efficiency growth for the period averaged about 3.93%. Growth has been steady from 2001 although the industry experienced a substantial decline in efficiency in 2009 and immediately shot up again in 2010.
c. Major changes in the global markets such as economic booms and shocks appear to have a link with the performance of the industry.
d. The average dynamic efficiency of all oil firms under study over the period was about 66.51%.
e. Of the 32 firms under study, 13 were efficient throughout the period, 13 were inefficient throughout the period while 6 were efficient for some years and inefficient for others.
f. Majority of the firms under study were fully private oil firms as data on most of the state-owned firms were unavailable for some of the variables under study. Minority state-owned firms were the least group in the sample.
g. Majority state-owned firms use the highest amount of labour and total assets followed by minority state-owned firms, fully private firms and lastly, fully state-owned firms respectively.
h. NOCs control more reserves than IOCs; fully state-owned firms control the largest amount of oil and gas reserves followed by majority state-owned firms, fully private firms and lastly minority state-owned firms.

i. Fully State-Owned (FSO) and Majority State-Owned (MaSO) firms produce the largest amount of oil and gas followed by Fully Private (FP) firms and lastly, Minority State-Owned (MiSO) firms.

j. Fully State-Owned firms had the highest dynamic efficiency followed by Fully Private, Majority State-Owned and Minority State-Owned firms accordingly.

k. Most of the firms in the petroleum industry are highly vertically integrated. About 66% of the firms under study process over 20% of their oil and gas extracted.

l. Highly Integrated (HI) firms use the highest amounts of labor and total assets and control the largest amount of oil reserves whereas the majority of gas reserves is controlled by Least Integrated (LI) firms.

m. Semi integrated (SI) firms are more efficient than Least Integrated and Highly Integrated firms.

6.2 Conclusions of the Study

The findings of the study have revealed some thought-provoking issues for consideration in efficiency assessments in the petroleum industry. First is on the scale of operation and its implications on productive capabilities of oil firms. The test of returns to scale conducted showed the industry operates on a variable returns to scale implying that size matters. This is an indication that not all firms in the international oil industry are operating on an optimal production scale. Impliedly, some of the firms could improve their efficiency by either increasing or reducing their scale of operation. Firms should, therefore, evaluate their operations and either increase or reduce their scale of operation in order to enjoy economies of scale.

This study covers a period which was marked by a sequence of events such as the September 11 terrorist attacks, USA invasion of Iraq, the global economic recession in 2008 and 2009 which may have affected the performance of the industry. With governments working to avoid a further occurrence of such events, the growth in the industry expected to average higher than the 3.93% observed in this study.

Another issue worth considering is the participation of states in the international oil industry. It appears from the findings that governments have deemed the petroleum industry too important an industry to be left in the hands of private entities. Not only are they merely participating in the industry but they are striving hard to retain a dominant position in the industry. This appears to be explained by the huge amounts of oil and gas reserves held by state firms relative to their private counterparts. There is the avenue for private firms to work at increasing their reserve levels to better match their state counterparts.

One finding which cannot go unnoticed is the fact that fully state-owned firms outperformed fully private firms. All previous studies had found the otherwise. This observation is probably because of the distinctness of this study from all other studies because oil and gas reserves which are considered in previous studies as inputs were considered in this study as desirable carryovers. Considering reserves as inputs that are used up in a single period makes fully state-owned firms with higher reserves appear inefficient since they would be seen to be using too many inputs relative to their outputs. Their heavy control of reserves allows fully state-owned firms to produce in higher quantities compared to private counterparts. Private firms could take a cue and put in place the necessary strategies and actions to increase their reserves levels as well as cut down on their inputs to allow them to produce at maximum capacities.

It is also noticeable that fully state-owned and fully private firms outperform the groups with shared ownership (majority and minority state-owned firms). This could be a probable reflection of more complex agency problems in organizations with joint ownership as argued by Ding et al.

(2007). Ding et al. (2007) asserts that aside the existing owner-manager conflicts there exists some other conflicts among the controlling (majority) shareholders and the minority shareholders since the majority shareholders might have some dominating interests which might not be in the interest of the other shareholders (Ding et al., 2007) and might lead to more inefficiencies. It is further revealed that the labor and asset levels of jointly owned firms far outweigh that used by fully state-owned and fully private firms. The over-employment of resources in these groups could be a sign of the struggle between the two groups as each group might be interested in getting their own manpower into the firms which could be a major cause of their inefficiencies. Management of these firm must put in place more efforts in reducing any conflicts that may be compelling these firms to hire such higher levels of employees which hampers their efficiency.

On the issue of integration, semi integrated firms have been found to outperform highly integrated and least integrated firms, a finding which suggests that although vertical integration could be a good move, it has to be done in moderation for firms are to reap its benefits. It should be noted that the dynamic efficiency difference is not statistically significant between semi integrated firms and least integrated firms. Inference can be made therefore, that although vertical integration might have some advantages, it generally has a negative impact on the efficiency of petroleum firms. Firms can enjoy a bit of economies of scale or suffer diseconomies of scale as a result of their expansion into other aspects of their supply chain.

Lastly, the study has proposed a DSBM-Metafrontier model based on the DSBM and Metafrontier approaches for the assessment of group dynamic efficiency. This model is able to consider carryover activities as well as cater for group differences exhibited by oil firms found in different categories such as fully state-owned firms against fully private firms.

6.3 Recommendations

Based on the findings and conclusions of the study, essential recommendations have been made for policy, practice and for future research. These are detailed below:

For policy:

a. There may be conflicts of interest between majority and minority shareholders in firms with share ownership by state and private individuals. Clear and strict rules must be laid to separate the activities of shareholders from management and minimize the possible conflicts. Clear policies must also be enacted in these firms to regulate the employment levels and reduce inefficiency.

b. Also, it has been seen that whereas vertical integration can be beneficial for performance, there is the need for moderation in the level of integration. Policy makers on vertical integration could adopt the semi integrated firms as models to determine integration levels prudent for oil firms' performance.

For Practice:

a. Managers of private oil firms should put in place more strategies and efforts to increase their long term prospect since their long held advantage is seen to be gradually taken over by state owned oil firms.

b. The study indicates that supply chain management is very essential in the oil and gas industry. Petroleum firms should rather concentrate on managing the oil and gas industry supply chain instead of attempting to assume control of other segments of the industry. This will ensure that they do not lose focus on their core businesses as per the industrial organization perspective. For firms that still wish to undertake vertical integration for its other perceived benefits, managers ought to constantly perform cost and benefit analysis to ensure they integrate only up to a point where the cost of integration does not surpass its benefits. Coordination should also be strengthened to keep firms in focus towards their objectives and evade internal diseconomies of scale.

c. Some of the firms are not operating on an optimal scale, it is up to managers to evaluate their operations and either scale up or down their capacity in order to be efficient.

d. In the face of uncertainties and constant global technological changes, firms can still optimize their performance by making the appropriate diversity of ownership as well as the appropriate integration levels.

For future research:

a. Further efficiency and productivity studies aiming at assessing in the oil industry with similar data and period could adopt variable returns to scale as the tests show that the size of operation in the international oil and gas industry matters for their performance.

b. There is a possibility that major economic changes such as global recessions and booms, economic shocks and other environmental factors affect the dynamic efficiency of oil firms, however, since this study did not clearly explore how specific major happenings influence performance, further research could investigate the impact of these factors efficiency and productivity of petroleum firms.

c. Although this study has provided important insights on upstream sector of the petroleum industry, future research can consider efficiency and productivity of firms in both the upstream and downstream segments of oil the industry using either revenue or profit efficiency in order to provide a more comprehensive picture of the industry. This is because most of the firms sampled have business units in both segments of the industry, in order to holistically assess the impact of vertical integration, the higher capital inputs such as refineries, transport infrastructure, retail outlets, and so on that may be needed to support the activities of vertically integrated firms as well as the output from these inputs must be adequately accounted for.

d. To substantiate the findings in this study, further studies could increase sample size and period to make all groups or clusters more representative as well as include up-to-date data to align findings with current technological, economic and political developments in the industry. There has been a sequence a sequence of events such as mergers and acquisitions, the upsurge of ISIS, splits within the European Union among others which might have affected the performance of the industry.

e. The DSBM used in this study does not have a bootstrap component, future studies could consider developing bootstrap algorithms for the dynamic DEA measure.

f. Future studies could consider decomposing dynamic efficiency into pure technical and scale efficiency to assess if vertical integration is associated to or brings about scale efficiency for integrated firms in order to better inform management on the sources of inefficiency.

g. The DSBM-Metafrontier model proposed in this study can be applied by future studies for the assessment of group dynamic efficiency.

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APPENDICES

APPENDIX A: Taxonomy of Efficiency Studies in the Petroleum Industry

NO.	AUTHOR	RESEARCH ISSUES	METHOD	INPUTS	OUTPUTS	SAMPLE/STUDY PERIOD	SECTOR	JOURNAL
1	Al-Obaidan and Scully (1991)	Ownership and efficiency	SFA Aigner-Chu deterministi c frontier	• Total assets	• Total revenue • Barrels of crude oil produced + barrels of crude oil refined	44 oil companies (1979-1983)	Downstream	Applied Economics
2	Al-Obaidan and Scully (1993)	Backward Vertical Integration	Aigner-Chu deterministi c frontier SFA	• Total assets	• Total revenue	55 oil companies (1979-1982)	Downstream	Applied Economics
3	Al-Obaidan and Scully, (1995)	Multinationalit y	SFA Aigner-Chu deterministi c frontier	• Total assets	• Total revenue Barrels crude oil produced + barrels crude oil refined	44 oil companies (1976-1982)	Downstream	Applied Economics
4	Barros and Antunes (2014)	Productivity Change. Malmquist vs Luenberger	DEA Luenberger Productivity Indicator	• Operational cost • Taxes	• Production of oil • Investment premium	9 Angolan oil Blocks (2002-2008)	Upstream	Economics, Planning, and Policy
5	Barros and Assaf (2009)	Bootstrapping	DEA Bootstrappi ng Bootstrappe d truncated regression	• Operational cost • Investment premium • Taxes	• Gross production	9 Angolan oil Blocks (2002-2007)	Upstream	Energy Policy

NO.	AUTHOR (S)	RESEARCH ISSUES	METHOD	INPUTS	OUTPUTS	SAMPLE/STUDY PERIOD	SECTOR	JOURNAL
6	Barros and Managi (2009)	Growth Accounting vs Productivity Method	DEA	•Operational cost • Investment premium• Taxes	• Gross production	9 Angolan oil blocks (2002-2007)	Upstream	Energy
7	Eller, Hartley and Medlock (2011).	Ownership	DEA SFA	• Oil reserves • Number of employees • Natural gas reserves	• Revenues	78 oil firms (2002-2004)	Upstream	Empirical Economics
8	Francisco ,de Almeida and de Silva (2012)	Environmental Efficiency	DEA	• Amount of water consumed • Percentage of Idleness	• Processed oil • Effluents (Undesirable) • Age of Refinery (Uncontrollable)	10 Brazilian Refineries (2004)	Downstream	International Journal of Engineering Business Managemen t
9	Hartley and Medlock (2013)	Ownership	DEA SFA	• Oil reserves • Gas reserves • Distilling capacity • Employees	•Revenue	61 oil companies (2001-2009)	Upstream	The Energy Journal
10	Hawdon (2003)	Regulation	DEA Bootstrappi ng	• Employment • Length of Pipelines	• Gas Consumption • Number of Customers	Country-level Data of 33 countries (1998, 1999) Gas Industry	Downstream	Energy Policy
11	Ike and Lee, H. (2014)	Ownership	DEA Slack Based MPI Regression	• Oil reserves • Gas reserves • Number of employees	• Oil production • Gas Production	38 oil companies (2003-2010)	Upstream	Geosystem Engineering

NO.	AUTHOR (Kim et al.)S)	RESEARCH ISSUES	METHOD	INPUTS	OUTPUTS	SAMPLE/STUDY PERIOD	SECTOR	JOURNAL
12	Ismail, Tai, Kong, Law, Shirazi and Karim (2003)	Environmental Efficiency	DEA	• Assets • Employee Numbers	• Revenue	17 Oil Companies (2008)	Upstream	Measureme nt
13	Kashani (2005)	Regulation	DEA SFA Regression	• Construction Cost • Variable Cost • Water depth • Revenue depth • Number of partners	• Oil Production • Gas Production	66 oil and gas fields, 67 oil fields. United Kingdom. (1974-1991)	Upstream	Energy Policy
14	Kashani (2005)	State Intervention	DEA SFA Regression	• Construction Cost • Variable Cost • Water depth • Revenue depth • Number of partners	• Oil Production • Gas Production	37 Gas Fields in Norway. (1972-2000)	Upstream	Energy Policy
15	Kim, Lee, Park and Kim, (1999)	International Comparison, Determinants of Productivity	Multilateral Tornqvist Managerial Index System Analysis Non-parametric Efficiency Analysis	• Labour • Capital (Assets) • Administration	• Total volume of gas supplied • Revenue from gas transportation	28 Natural Gas transmission and distribution companies in 8 countries (1987-1995)	Downstrea m	Energy Economics
16	Lee, Park and Kim. (1996)	International Comparison	Edgeworth Index	• Capital • Labour •Administration	• Gas deliveries	28 natural gas transportation utilities in 8 countries (1987-1995)	Downstrea m	Energy Economics

NO.	AUTHOR (S)	RESEARCH ISSUES	METHOD	INPUTS	OUTPUTS	SAMPLE/STUDY PERIOD	SECTOR	JOURNAL
17	Managi, Opaluch, Jin and Grigalunas, (2005)	Technology Change	Regression	• Drilling distance per exploratory well • Drilling distance per development well • Total number of exploratory and development wells • Price of oil & gas • Water depth	• Quantity of oil and gas reserves discovered in barrels of oil equivalent	370 Drilling wells in gulf of Mexico-US (1947-1998)	Upstream	Energy Policy
18	Managi, Opaluch, Jin and Grigalunas (2006)	Technology Change	SFA	• Oil reserves • Water depth • 5 yrs. ex drill mills ratio • Gas reserves	• Porosity	370 Drilling wells in gulf of Mexico-US (1947-1998)	Upstream	Ecological Economics
19	Price and Weyman-Jones (1996)	Privatization	DEA SFA	• Number of employees • Length of gas Mains Transmission and distribution system	• Domestic gas sales • Industrial gas sales • Commercial gas sales • Number of Customers • Gas using appliances sold	12 distribution regions in UK (1977-78 to 1990-91)	Downstream	Applied Economics
20	Sueyoshi and Goto (2012)	Conceptual Paper: Environmental Efficiency and Ownership	DEA	• Oil Reserves • Gas Reserves • Total cost • Number of employees	• Oil Production • Gas Production • CO_2 emission (Undesirable)	19 oil firms. (2005-2009)	Upstream	European Journal of Operational Research
21	Sueyoshi and Goto (2012)	Conceptual Paper: Environmental	DEA	• Oil Reserves • Gas Reserves • Total cost	• Oil Production • Gas Production	19 oil firms. (2005-2009)	Upstream	Energy Economics

NO.	AUTHOR (S)	RESEARCH ISSUES	METHOD	INPUTS	OUTPUTS	SAMPLE/STUDY PERIOD	SECTOR	JOURNAL
		Efficiency and Ownership		• Number of employees	• CO_2 emission (Undesirable)			
22	Thompson Dharmapala, Rothenberg and Thrall (1994)	DEA/ AR and Profitability	DEA	• Total Cost • Proved reserves	• Additions to reserves (combined) • Sales of production from reserves	14 integrated oil companies in US (1980-1987)	Upstream	Journal of Productivity Analysis
23	Thompson, Dharmapala, Diaz, Gonzalez-Lima and Thrall(1996)	Conceptual Paper	DEA	• Total production costs • Total proven crude reserves • Total exploratory and development wells drilled • Total proven natural gas reserves	• Oil Production • Gas Production	30 oil companies (1983-1985)	Upstream	Computers & Operations Research
24	Thompson, Dharmapala, Rothenberg and Thrall (1996)	Application of DEA AR and CR	DEA	• Expenditure in exploration • Crude oil reserves • Natural gas reserves	• Crude oil discovered proved reserves • Natural gas discovered proved reserves	14 integrated oil companies in US (1980-1991)	Upstream	Annals of Operations Research
25	Wolf (2009)	Ownership and efficiency	Regression	• Oil and gas reserves • OPEC membership • Total assets • State ownership Percentage • Ratio of oil and gas reserves • Number of employees	• Annual oil and gas production • Revenue • Net income	87 oil firms (1987-2006)	Upstream	Energy Policy

APPENDIX B: Annual Summary Statistics

	Total Assets (US$ Mil) X1	*Labour (No. of employees) X2*	*Crude Produced ('000b/d) Y1*	*Gas Produced (MMcf/d) Y2*	*Crude Reserves (MMBbls) Z1*	*Gas Reserves (Bcf) Z2*
2001						
Mean	39851.66	82191.22	1001.31	4348.22	8696.91	69517.50
Std. Dev.	36877.81	118276.70	918.69	8654.59	14945.85	227679.14
Minimum	4300	1915	79	145	341	1005
Maximum	143174	510000	3560	49500	77783	1300000
2002						
Mean	45952.72	81330.53	1031.47	4359.28	8049.28	73825.78
Std. Dev.	43280.36	109589.96	910.84	8406.48	13669.52	231428.15
Minimum	5193	1958	54	182	173	1019
Maximum	159125	419598	3529	48000	77900	1320000
2003						
Mean	52057.38	75924.19	1079.34	4546.41	7854.91	63839.56
Std. Dev.	47784.38	107030.10	919.82	9077.42	13632.14	174159.61
Minimum	6797	2353	79	253	237	1039
Maximum	174278	417229	3723	52244	77800	988400
2004						
Mean	60599.63	79890.66	1100.69	4719.03	7782.72	68680.72
Std. Dev.	53604.96	107266.37	943.68	9106.00	13493.53	200156.11
Minimum	9426	2642	76	299	560	2400
Maximum	195256	424175	3754	52574	77140	1140000
2005						
Mean	70145.06	82290.28	1151.34	4611.38	7772.47	51384.63
Std. Dev.	60263.08	111780.61	945.12	9196.54	13880.05	130331.26
Minimum	14300	2806	134	222	572	2406
Maximum	219516	439220	3710	53135	79700	732806
2006						
Mean	82428.66	81772.56	1150.88	4810.53	7863.22	48959.69
Std. Dev.	66040.72	111567.97	935.64	9268.62	13889.37	115004.07
Minimum	16235	1678	107	612	552	2466
Maximum	235276	452861	3649	53772	79700	642460

APPENDIX B: ***Continued***

	Total Assets (US$ Mil) X1	*Labour (No. of employees) X2*	*Crude Produced ('000b/d) Y1*	*Gas Produced (MMcf/d) Y2*	*Crude Reserves (MMBbls) Z1*	*Gas Reserves (Bcf) Z2*
2007						
Mean	99456.63	84355.50	1164.19	4879.53	8451.19	49989.00
Std. Dev.	76637.32	115665.27	918.23	9121.76	17233.79	116041.03
Minimum	18500	3521	134	613	506	2439
Maximum	277123	466502	3474	53056	99377	645583
2008						
Mean	102290.56	87895.78	1131.63	5004.06	8372.81	50472.59
Std. Dev.	74585.08	113663.77	872.83	9104.81	17242.81	115732.96
Minimum	20000	3639	134	486	688	1898
Maximum	282401	477780	3101	53018	99377	642460
2009						
Mean	109388.59	90448.69	1158.66	4804.59	11927.19	51407.13
Std. Dev.	81011.06	123119.27	905.19	7684.47	36623.59	118549.76
Minimum	22450	3452	137	578	97	2310
Maximum	292181	539168	3170	44633	211000	656580
2010						
Mean	126433.22	90969.53	1159.22	5120.66	14702.75	52960.34
Std. Dev.	95290.22	125101.36	889.06	8501.08	51642.90	121467.33
Minimum	26651	4400	143	569	109	2598
Maximum	322560	552698	2970	49188	296501	670700

APPENDIX C: Yearly DSBM Efficiency Scores of Firms

S/N	Oil Firm	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Over all	Times eff.
1	Anadarko	1	1	0.55	0.98	0.91	0.94	1	1	1	1	**0.92**	6
2	Apache	1	1	1	1	1	1	1	1	1	1	**1**	10
3	BG	1	1	1	1	1	1	1	1	1	0.76	**0.97**	9
4	BP	0.74	0.84	0.91	0.99	1	1	1	1	1	1	**0.94**	6
5	Chevron	0.32	0.32	0.33	0.32	0.34	0.35	0.32	0.32	0.26	0.80	**0.70**	0
6	ConocoPhillips	0.68	0.75	0.95	1	1	1	1	1	1	1	**0.93**	7
7	Devon Energy	1	1	1	1	1	1	1	1	1	1	**1**	10
8	Ecopetrol	1	1	1	1	1	1	1	1	1	1	**1**	10
9	EnCana	1	1	1	1	1	1	1	1	1	1	**1**	10
10	Eni	0.20	0.21	0.23	0.22	0.23	0.23	0.24	0.26	0.23	0.48	**0.44**	0
11	Exxon Mobil	1	1	1	1	1	1	1	1	1	1	**1**	10
12	Gazprom	1	1	1	1	1	1	1	1	1	1	**1**	10
13	Hess	0.40	0.47	0.86	0.36	0.34	0.36	0.40	0.38	0.37	0.54	**0.49**	0
14	Lukoil	1	1	1	1	1	1	0.98	0.64	0.55	0.69	**0.79**	6
15	Marathon	0.11	0.11	0.09	0.10	0.13	0.13	0.14	0.16	0.13	0.25	**0.25**	0
16	Occidental	0.24	0.27	0.31	0.33	0.42	0.36	0.32	0.36	0.30	0.76	**0.54**	0
17	OMV	0.09	0.08	0.09	0.15	0.22	0.20	0.19	0.18	0.18	0.35	**0.20**	0
18	ONGC	1	1	1	1	1	1	1	1	1	1	**1**	10
19	PDV	1	1	1	1	1	1	1	1	1	1	**1**	10
20	Pemex	1	1	1	1	1	1	1	1	1	1	**1**	10
21	Pertamina	1	1	1	1	1	1	1	1	1	1	**1**	10
22	Petrobras	0.17	0.18	0.21	0.21	0.22	0.22	0.22	0.22	0.17	0.44	**0.46**	0
23	PetroChina	0.16	0.21	0.25	0.26	0.36	0.38	0.35	0.46	0.49	0.53	**0.31**	0
24	Petronas	0.69	0.81	0.89	0.87	0.80	0.78	0.81	0.90	0.74	0.54	**0.71**	0
25	Repsol YPF	0.32	0.31	0.32	0.32	0.23	0.19	0.18	0.18	0.15	0.40	**0.46**	0
26	Rosneft	1	1	1	1	1	1	1	1	0.63	0.50	**0.84**	8
27	Royal Dutch Shell	0.54	0.64	0.56	0.48	0.52	0.54	0.51	0.50	0.56	0.72	**0.77**	0
28	Sinopec	0.02	0.02	0.02	0.02	0.03	0.04	0.07	0.07	0.07	0.12	**0.06**	0
29	Sonatrach	1	1	1	1	1	1	1	1	1	1	**1**	10
30	Statoil	1	1	1	1	1	1	1	1	1	1	**1**	10
31	Surgutneftegas	1	1	1	1	1	1	1	1	1	1	**1**	10
32	Total	0.18	0.19	0.22	0.21	0.26	0.28	0.28	0.28	0.27	0.60	**0.47**	0
	Geomean	**0.51**	**0.52**	**0.54**	**0.55**	**0.57**	**0.57**	**0.58**	**0.58**	**0.55**	**0.70**		
	No. of firms eff	17	17	16	17	18	18	18	18	17	16		