

**UNIVERSITY OF GHANA**

**COLLEGE OF HUMANITIES**

**DYNAMIC PRODUCTIVITY DIFFERENCES BETWEEN STATE AND PRIVATE  
OWNERSHIP IN THE INTERNATIONAL OIL INDUSTRY**



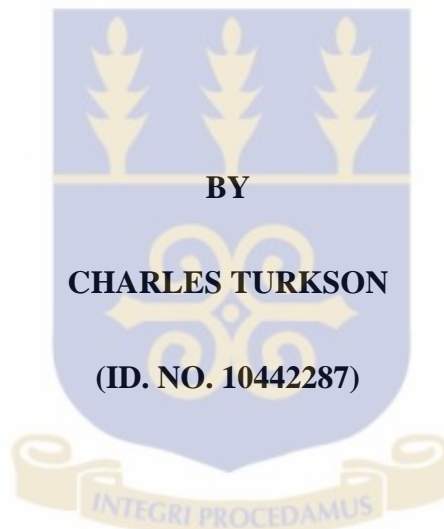
**DEPARTMENT OF OPERATIONS AND MANAGEMENT INFORMATION  
SYSTEMS**

**JULY 2015**

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**COLLEGE OF HUMANITIES**

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**THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN  
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**DEPARTMENT OF OPERATIONS AND MANAGEMENT INFORMATION  
SYSTEMS**

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## DECLARATION

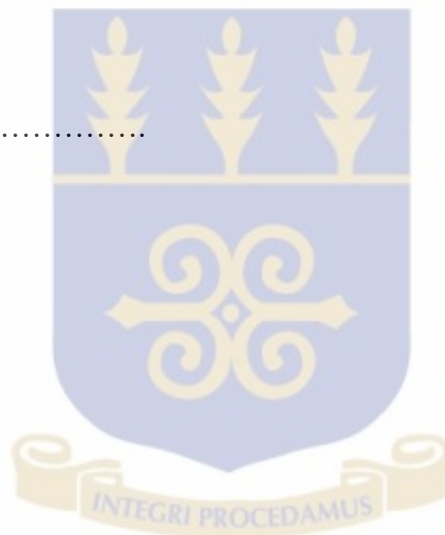
I do hereby declare that this work is the result of my own research and has not been presented by anyone for any academic award in this or any other university. All references used in the work have been fully acknowledged.

I bear sole responsibility for any shortcomings.

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CHARLES TURKSON

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DATE

**CERTIFICATION**

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

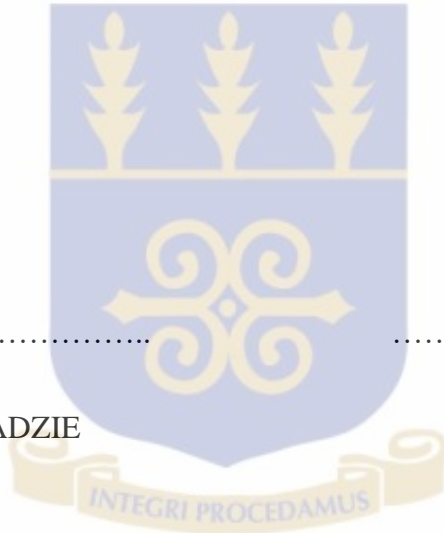
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## **DEDICATION**

To LyZAndra Nambu.



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**LIST OF ACRONYMS**

BMPI	Biennial Malmquist Productivity Index
BP	British Petroleum
BPEC	Biennial Pure Efficiency Change
BPTC	Biennial Pure Technical Change
BSEC	Biennial Scale Change
BTC	Biennial Technical Change
CRS	Constant Returns to Scale
DEA	Data Envelopment Analysis
DGP	Data Generation Process
DMU	Decision Making Unit
E&P	Exploration and Production
EC	Efficiency Change
FDI	Foreign Direct Investment
FPSO	Floating Production, Storage and Offloading
GDP	Gross Domestic Product
IEA	International Energy Agency
IGO	Intergovernmental Organisations
IOC	International Oil Company
L	Local Oil Company
LIOC	Local International Oil Company
LNOC	Local National Oil Company
LP	Linear Programming
M	Multinational Oil Company
MIOC	Multinational International Oil Company

MNOC	Multinational National Oil Company
MPI	Malmquist Productivity Index
NIOC	National International Oil Company
NOC	National Oil Company
OAPEC	Organisation of Arab Petroleum Exporting Countries
OECD	Organisation for Economic Cooperation and Development
OPEC	Organisation of the Petroleum Exporting Countries
PEC	Pure Efficiency Change
PIW	Petroleum Intelligence Weekly
PRT	Property Rights Theory
SCH	Scale Change
SEC	Scale Efficiency Change
SFA	Stochastic Frontier Analysis
TC	Technological/Technical Change
US	United States of America
VRS	Variable Returns to Scale

## ABSTRACT

The participation of countries in the international oil industry in the form of national oil companies started in 1914 and has continued to this date. Although their role in market systems has been seen in literature to be a major cause of inefficiency, active state participation does not seem to be waning. This is primarily because of state dependence on oil products, growth of major state-owned oil companies and the belief that state control over its resources is a major sign of national sovereignty. This study provides insights on decisions operations managers of such state firms can adopt to make their operations more efficient. This was achieved by assessing whether multinational operations can offset the inefficiencies state-owned oil firms face due to home-country political influences. This was done by comparing efficiency and productivity differences between state and private oil companies as well as state multinationals and private multinationals globally. It also compares various efficiency and productivity measurement techniques in performance measurement in the industry with the aim of providing operations managers with the appropriate techniques for performance benchmarking.

An unbalanced panel of 66 unique oil firms from the Petroleum Intelligence Weekly Database of Energy Intelligence was used for this study. Data on the 10 year period from 2001 to 2010 was assessed using relevant productivity measurement techniques in operations management and management science. From the findings, private firms are seen to out-perform state firms. Similarly, multinationals are seen to out-perform local firms. Multinational operation was also found to be a useful and relevant policy direction towards reducing productive inefficiencies of state-owned oil firms. However, multinational operations could not offset scale inefficiencies of state firms. Therefore, whereas state firms should be advised to incorporate multinational operations into future policies in order to reduce home-country inefficiencies, further efforts need to be directed towards reducing the size of operations since size is a major source of inefficiency.

## CHAPTER ONE

### INTRODUCTION

#### 1.0 Background of the study

One of the most remarkable industries in international trade is the oil industry. About two billion dollars of petroleum are traded daily worldwide, making petroleum the largest single item in the balance of payment and exchange between countries (Tordo, Tracy, & Arfaa, 2011). There is a rapid increment in the oil trade and this trend is predicted to grow even more largely due to strong growth of emerging economies such as China and India (Barros & Assaf, 2009). Coupled with this, petroleum firms are among the largest firms in the world, dominating the top ten (10) of the Fortune 500 company rankings (Fortune Magazine, 2014). The susceptibility of global economies to oil supply and price volatility is as a result of their dependence on oil-based products (Cunado & Gracia, 2003; Jiménez-Rodríguez & Sánchez, 2005). This dependence is seen in all other industries, including transportation, agriculture and power, as well as for domestic consumption. These are probably the reasons for state interventions, in the form of National Oil Companies (NOC) in the oil industry.

State ownership of oil companies started in 1914 when the British government acquired a controlling stake in the Anglo-Persian Oil Company, now British Petroleum (BP), setting a precedent for the many state-owned oil companies to follow in other countries (Wolf, 2009). Since 1991, countries that possess NOCs have held nearly 90% of global crude oil reserves (Eller, Hartley, & Medlock, 2011). Various governments have therefore seen the oil industry as too important to be left in the hands of private international oil companies (IOCs) as direct state control over its resources is a strong indicator of national sovereignty (Mommer, 2002). This notwithstanding, to some researchers direct state intervention is seen as a major cause of inefficiency in this industry (Kashani, 2005a).

Another important characteristic of the oil industry is the multinational nature of most oil companies. In operations management, multinational operation is part of a broader subject area pertaining to facility location decisions. Petroleum firms are among the largest multinational firms globally (Al-Obaidan & Scully, 1995). Royal Dutch Shell, Sinopec Group, China National Petroleum and Exxon Mobil are among the top five global firms on Fortune Magazine's 2014 company ranking (Fortune Magazine, 2014). Royal Dutch Shell, for example, reported revenues of more than \$459 billion and an asset value of more than \$357 billion (Fortune Magazine, 2014). Even some of the NOCs, who would be expected to only operate in their home countries, have multinational operations. For example, China National Petroleum Corporation (CNPC), a company with 100% state ownership (Energy Intelligence, 2013), has oil and gas operations in 29 countries around the world (CNPC, 2014). As a result of the participation of NOCs in international oil operations, private oil companies have found it increasingly difficult to gain access to large oil prospects, which could further increase NOCs dominance of the global crude oil market (Eller et al., 2011). From the theoretical arguments of both Dunning's (1977) eclectic paradigm and Markowitz's (1952) portfolio diversification theory, multinational operations bring some gains to a firm's operation in the form of efficiency (Al-Obaidan & Scully, 1995).

The oil industry is a highly competitive industry, dominated by entities with both political and resource endowment. There is intense competition in the industry caused by globalization, technological innovation, increased regulatory stringency (Barros & Managi, 2009), and the importance of future availability and viability of oil operations to public resource and international relations policy of countries (Managi, Opaluch, Jin, & Grigalunas, 2005). Consequently, there is the need for continual academic interrogation of the dynamic performance of firms in the industry to guide operations managers improve performance. Indeed, the need to maintain consistent performance in this industry is challenged by several

uncontrollable phenomena like price change, oil exhaustion and political upheavals (Barros & Assaf, 2009). It is therefore important that operations managers of these oil firms are guided through robust academic research to ensure continual and efficient management of their highly demanded outputs. This study is therefore expected to contribute to the existing debate on the role of state influence in the operation of NOCs by examining the possibility of off-setting inefficiencies of these NOCs through multinational operations.

### **1.1 Problem statement**

The efficiency of various aspects of the oil industry is an important concern of operations managers that has attracted a number of academic research over the years. This has arguably been fuelled by the dependence of states on oil-based products (Cunado & Gracia, 2003) and the value of transactions in oil trade. It is quite evident that the overarching theme of most of these studies has been the issue of state ownership versus private ownership of oil companies. Indeed, Al-Obaidan and Scully (1991), Eller et al. (2011), Ike and Lee (2014), Wolf (2009), and Sueyoshi and Goto (2012a, 2012b) have provided empirical evidence on the differences in the efficiency of state controlled oil companies and privately controlled ones. Eller et al. (2011), for example, using a panel of 78 firms, presented empirical evidence that NOCs are less efficient than IOCs due to differences in the structural and institutional features of the firms. Similarly, Al-Obaidan and Scully (1991) saw that state oil firms could satisfy demand for the outputs with less than half of their current inputs, simply by privatizing. On the contrary, Sueyoshi and Goto (2012a) saw that public ownership out-performs private ownership when the focus is on reducing both inputs and undesirable outputs, a result which seems to belie the previously mentioned studies.

Although, these studies mostly favour private ownership of oil companies, the debate does not seem to be dwindling since high energy prices, asset nationalization and economic success of some NOCs have re-ignited calls for more state involvement (Wolf, 2009). There is, therefore, the need to reconsider how state firms can be more productive compared to their private counterparts. Empirical evidence show that one way firms can improve efficiency, be it state-owned firms or privately-owned firms, is through multinationality (Greene, Hornstein, & White, 2009; Li, 2008). A multinational firm is one that owns and operates income generating assets in more than one country. Although the view that multinational operation improves firm performance is quiet predominant in theory, more empirical testing of it in the petroleum industry is needed. From the evidence gathered, only Al-Obaidan and Scully (1995) have explored performance differences between multinationals and local oil firms in efficiency assessment in the oil industry. However, they failed to consider efficiency and productivity differences between state-owned multinational companies and privately-owned multinational companies. They also failed to assess if multinational operation can make a state firm more efficient in its operations. As more and more NOCs become multinational in their operations, it is important to consider whether such international operations are off-setting the inefficiencies of state controlled operations.

On the effect of multinationality on efficiency of oil companies, Al-Obaidan and Scully (1995) have espoused empirical arguments to support the view that going multinational brings some gains to firms. They did this by employing Aigner and Chu's (1968) deterministic frontier function and stochastic frontier analysis (SFA) on 44 oil firms from 1976 to 1982. These are parametric frontier techniques that are advantageous in better separating noise from inefficiency (Bogetoft & Otto, 2011; Jacobs, 2001). However, these models require extensive model specifications and assumptions for estimation (Jacobs, 2001). SFA, for example, demands parametric restrictions on not only the shape of the frontier, but the Data Generating

Process (DGP) in order to allow the identification of noise from inefficiency and the estimation of the frontier (Daraio & Simar, 2007). In addition, SFA usually requires a single dependent variable representing an output or input (Jacobs, 2001; Odeck, 2007) which could be impractical as many firms engage in multidimensional inputs and outputs in real market systems. On the other hand, Data Envelopment Analysis (DEA), a nonparametric frontier approach, is able to estimate efficiency of firms with very few assumptions (Daraio & Simar, 2007). DEA has a more flexible production structure (Bogetoft & Otto, 2011). DEA can handle multiple inputs and outputs (Jacobs, 2001) and can decompose efficiency into several factors thereby tracking the sources of inefficiencies. Indeed, introduction of bootstrapping techniques into DEA by Simar and Wilson (1998, 1999, 2000), has unified the results of DEA and SFA thereby addressing the flaws of the DEA technique, including outlying observations, its inability to adequately handle statistical noise and its general deterministic nature. It is therefore important to test the efficiency differences between multinationals and local companies using DEA models. This is crucial as it appears that no paper, assessing multinationality of oil firms found so far has employed DEA.

Another seemingly important observation in the review of oil industry efficiency literature is the inadequacy of more robust DEA estimation techniques. There have been a wide acceptance of DEA in the oil industry, as Barros and Assaf (2009), Barros and Managi (2009), Eller et al. (2011), and Sueyoshi and Goto (2012b) and a host of other researchers have applied DEA in oil industry assessments. Coupled with this, the use of other frontier-based parametric techniques has been quite profound. Al-Obaidan and Scully (1991, 1993, 1995), Eller et al. (2011), Managi, Opaluch, Jin and Grigalunas (2006) and Price and Weyman-Jones (1996) have used SFA solely or jointly with other DEA techniques in the oil industry. For Wolf (2009), ordinary least square based panel regression was the most preferred technique for assessing efficiency. Although these techniques have provided important insights into the efficiency and

productivity change of the international oil industry, there is the need for more robust assessments (Barros & Managi, 2009). The application of bootstrapping techniques in estimating DEA scores seems to be lacking. From review, only Barros and Assaf (2009) and Hawdon (2003) have applied such bootstrapping techniques on traditional DEA techniques. This notwithstanding, no paper reviewed so far applied the bootstrapping technique on productivity change indices, although these models have the ability of measuring productivity stagnation, progress or regress in the industry. Bootstrapping allows for the construction of confidence intervals that provide statistical basis for judging if a productivity change is significant (Simar & Wilson, 1999).

Finally, there is an ongoing debate regarding the appropriateness of the Malmquist productivity change index for capturing scale changes of a set of decision making units (DMUs). Since its introduction, the Malmquist productivity change index has been widely accepted and applied for productivity change analysis (Pastor, Asmild, & Lovell, 2011). In the oil industry, Price and Weyman-Jones (1996) as well as Barros and Managi (2009) have used the Malmquist index. This index was first decomposed into efficiency change and technical change based on the constant returns to scale assumption, but subsequently, the efficiency change component was further decomposed into pure efficiency change and scale change (Fare, Grosskopf, Lindgren, & Roos, 1992; Fare, Grosskopf, Norris, & Zhang, 1994).

The problem, however, is that estimating the scale efficiency requires the use of the variable returns to scale (VRS) assumption by Banker, Charnes and Cooper (1984). However, computing cross-period efficiencies may result in infeasibilities in the linear programming for some DMUs. Pastor et al. (2011) have thereby proposed the biennial Malmquist productivity change index that avoids the linear programming infeasibilities under VRS assumption. The biennial Malmquist index has no known empirical weaknesses, and its empirical advantages,

which is shared by no other Malmquist index, warrants careful consideration through empirical analysis (Pastor et al., 2011). As yet, only Vidal, Pastor, Borrás and Pastor (2013) have applied the biennial Malmquist index in the Spanish wine sector. In addition, there has been some methodological extensions by Tohidi and Tohidinia (2014) and Mohammadi and Yousefpour (2014). This index, however, lacks empirical application in the oil industry. In an industry where multinational operations may yield some scale efficiencies (Al-Obaidan & Scully, 1995), the biennial Malmquist will therefore provide the necessary insights on the scale changes of oil companies. It is therefore crucial that the biennial Malmquist is not only empirically tested, but compared with the traditional Malmquist index and all disparities addressed. This will provide operations managers with the necessary tools to determine the impact of operation size on efficiency over time.

## **1.2 Gaps and contributions**

From the previous section, four main gaps have been identified. The first is a conceptual gap, where it is evident from studies gathered, that there is the need to consider multinationality in the NOC and IOC debate. Evidently, most of the studies reviewed have failed to consider the issue of multinationality completely (Eller et al., 2011; Sueyoshi & Goto, 2012a) except for Al-Obaidan and Scully (1995) who did not, however, link multinationality directly with ownership. For the second gap, there is a need for empirical testing of multinationality using DEA models since the previous study, by Al-Obaidan and Scully (1995), used parametric techniques. Also, from evidence gathered, there has been no use of the bootstrapped Malmquist index in the oil industry. Finally, although the biennial Malmquist index, proposed by Pastor et al. (2011), has the ability to correct linear programming infeasibilities in the traditional Malmquist, its empirical application and comparison with the traditional Malmquist is lacking especially in the international oil industry.

This study therefore makes four key contributions to literature and policy. First, it contributes to the existing body of knowledge on the efficiency differentials between state and privately-owned oil companies. The unique characteristic of this study is that, it introduces the multinationality dimension to the ownership debate which, from review of related literature, has not been assessed by previous researchers. It will also assess the effects of multinationality in the oil industry using nonparametric techniques, a model that previous researchers have not used. The contributions of this study towards method include; a first time application of bootstrap Malmquist index in the oil industry; and the premier application of biennial Malmquist index in the oil industry.

### **1.3 Research objectives**

This study examines the efficiency and productivity changes of oil companies over the ten-year period from 2001 to 2010. The goal is to identify the effect of multinationality on firm efficiency and productivity change. It therefore assesses the possibility of off-setting inefficiencies due to state ownership through multinational operation. The specific objectives of this study are:

1. To examine the dynamic productivities of the oil firms and the source of the change thereof using a bootstrapped Malmquist index;
2. To evaluate the changes in the productivity of multinational and local, state and privately-owned oil firms; and
3. To compare scale efficiency changes of oil firms estimated using the traditional Malmquist and the biennial Malmquist indices.

#### **1.4 Research questions**

1. Has there been a significant change in overall productivity over the study period?
2. What drives productivity change in the international oil industry?
3. Are there significant differences in the productivities of multinational and local, state and privately-owned oil firms?
4. Are there significant differences between the results of the traditional Malmquist and the biennial Malmquist indices in estimating scale efficiency change?

#### **1.5 Significance of the study**

The outcome of this study has policy, practice and research benefits. This study has a strong policy-oriented benefit, since it provides empirical evidence on whether multinationality is a viable option in improving efficiency of oil firms. It should guide oil firms, both in Ghana and internationally, in their internationalization policies. For practice, the study measures productivity changes in the international oil industry and provides empirical insights into the trends in industry productivity over a ten year period. The study also provides a decomposition of the Malmquist index that clearly shows operations managers the drivers of productivity change within the industry by employing robust measurement techniques.

Its contributions to research are four fold. First, it contributes to the existing body of knowledge on ownership and efficiency in the oil industry. Second, it provides further testing of multinationality theories, contributing to the understanding of the nature of the relationship between international operation and performance. Furthermore, it introduces the multinationality dimension in the ownership and efficiency debate in the oil industry. Finally, this study provides statistical evidence on whether the results of the traditional Malmquist

significantly differ from that of the biennial Malmquist. This is aimed at providing operations managers with appropriate techniques for efficiency and productivity assessments.

## **1.6 Limitations of the study**

Notwithstanding the anticipated benefits of the study, there are a few limitations. First, not all oil companies can be incorporated in the study. The exact number of oil companies worldwide is not clearly known. The study relies on the list of 50 firms, each year, by Energy Intelligence, which documents the top 50 oil firms globally. This sample provides a more holistic picture than that used in other researches in the industry. Second, the study employs DEA, a nonparametric technique. Since it is nonparametric, it has quite limited statistical robustness and is subject to biases, such as the presence of outliers. To a large extent, this limitation is handled by bootstrapping. However, bootstrapping approximates the true frontier and is not a complete solution to the problem.

This work is also limited to the ten year period from 2001 to 2010. This is primarily because of data availability. However, this study period provides more contemporary assessment of the oil industry as compared to that of previous studies like Al-Obaidan and Scully (1991, 1993, 1995), Eller et al. (2011) and Ike and Lee (2014). Finally, in this study, the traditional Malmquist index is compared with the biennial Malmquist. Although there is an established framework for bootstrapping the traditional Malmquist index, no such framework exists for the biennial Malmquist. Therefore, comparisons of the two models has been done using the original estimates. It will be interesting to compare the bootstrapped Malmquist index with a bootstrapped biennial index.

## **1.7 Thesis structure**

The thesis is structured in six chapters. Chapter One provides the necessary background based upon which the research problems were conceptualized. It then clearly shows the problems in literature that this study seeks to answer. Therefore, research objectives and questions are developed here, as well as providing the significance of this study.

Chapter Two is used to highlight important theoretical and conceptual arguments based upon which this study was conducted. This chapter is divided into three main sections, the first of which is used to clearly elaborate ownership and international trade theories that would guide the thought process. The second section of this chapter is used to clearly show empirical works conducted in the subject area and it lays a solid foundation to conduct this study. Finally, based on ideas in the theoretical and empirical reviews, the third section provides a conceptual framework that should guide the analysis of the study.

Whiles Chapter Three is used primarily to present the context of the study, Chapter Four shows the research methodology. All model specifications are discussed in this chapter. The findings of the study are presented and discussed in Chapter Five, based on which, conclusions and policy directions are made in Chapter Six.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.0 Introduction**

This chapter reviews the theoretical and empirical literature related to ownership, multinationality, and the efficiency and productivity changes within the international oil industry. It is divided into three main sections - a theoretical review, an empirical review and a conceptual framework. Whereas the theoretical review presents the theoretical grounding for the study, the empirical review presents the current state of research relating to efficiency and productivity differences between state and privately-owned oil companies. The conceptual framework brings the theoretical and empirical knowledge gained into an ambience that will guide the research.

#### **2.1 Theoretical review**

##### **2.1.1 Ownership and firm performance**

Performance differences debate between state and privately-owned enterprises have interested academics for some time now. Theoretical underpinnings of the ownership debate in the international oil industry have been grounded on mainstream economics theories including property rights theory, agency theory and other regulation theories (Al-Obaidan & Scully, 1991; Eller et al., 2011; Wolf, 2009). These theories explain the role of ownership of firms in motivating organisational efficiency and productivity. The definition of what exactly constitutes ownership of an enterprise is a function of the controlling rights the party has in the decisions of the enterprise. Like most corporations, ownership may be shared by several parties or possessed by a few. In this study, a distinction is drawn between private and state-owned enterprises based on a majority share ownership.

State ownership of enterprises is mainly driven by two motives- market imperfections and political ideologies and strategies (Cuervo-Cazurra, Inkpen, Musacchio, & Ramaswamy, 2014). This means that state ownership may be justified to better allocate resources when the market is unable to efficiently allocate such resources, or to promulgate the political ideologies of government (Cuervo-Cazurra et al., 2014). There has been interest in separating state-owned enterprises in the literature into fully state-owned NOCs majority state-owned NOCs and minority state-owned NOCs; or state agency and state minority owned (Chen, Firth, & Xu, 2009; Cuervo-Cazurra et al., 2014; Li, Cui, & Lu, 2014; Wolf, 2009). Chen et al. (2009), for example, observed that privately-owned enterprises are superior to some categories of state-owned firms but not superior to other state-owned firms. By implication, there are differences between the performances of various types of state enterprises. This study will use the traditional majority ownership definition used by Al-Obaidan and Scully (1991), Eller et al. (2011) and Sueyoshi and Goto (2012a, 2012b), instead of that used by Chen et al. (2014). This is primarily because the majority ownership definition allows for a clear distinction between state and private ownership. However, further research can explore how the degree of government ownership affects performance by assessing performance differences between the various typologies of state ownership, such as central government-owned state enterprises, local government-owned, state asset management bureaus among others (Chen et al., 2014). Two theories - property rights and agency theories - will be used to elucidate the relationship between ownership and firm performance. It is important at this stage to detail these theories.

#### ***2.1.1.1 Property rights theory***

The classical property or ownership rights theory (PRT) is attributable to the early works of Coase (1960), Alchian (1965), Demsetz (1964, 1966, 1967) and Alchian and Demsetz (1973). Studies on the theory of property rights and asset ownership have gained a wider intellectual interest in economics and other disciplines in recent years (Kim & Mahoney, 2005). Based on

this, a “modern property rights theory” has been proposed following the works of Grossman and Hart (1986) and Hart and Moore (1990) (Kim & Mahoney, 2010). Property rights can be seen as the rights of individuals to use some resources supported by the force of etiquette and formal legally enacted laws supported by state powers of violence and punishment (Alchian, 1965). This definition of property rights underscores three key elements of property rights that are worth elaborating upon: rights to use resources; etiquette and formal nature; and state powers of punishment.

First, the mere possession of a resource is not seen as ownership, but rather the right to use the resource (Alchian & Demsetz, 1973). This theory views economic transactions as bundles of property rights (Coase, 1960). For example, whereas someone has the right to drink from a river, another has the right to go fishing in the same river, and yet, another person still has the right to enjoy recreational swimming or boat-riding. These partitioned uses of resources among different persons can be aggregated as bundles of property rights. However, it is the economic rights in such resources that are of concern to property rights theorists (Alchian & Demsetz, 1972; Kim & Mahoney, 2010). These rights may include: the right to earn appropriate economic rent from the resource; the right to change the nature of the resource; and the right to transfer ownership of such resources (Libecap, 1989). According to the PRT, if two or more parties possess the rights to a property, but fail to co-exist smoothly, property rights must be allocated to the party who can produce more benefits from this resource (Coase, 1960; Demsetz, 1967). For example, if two oil firms have the right to extract oil resources from a 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 concentration of such property rights is believed to create incentive to utilize resources more efficiently (Demsetz, 1967).

The next important element in Alchian’s definition of property rights is the legal and formal nature of such rights. It is important to understand that property rights cannot be absolute as

complete control over resources can harm social or individual interests (Kotz, 2006). Such effects of the activities of a decision maker on others is referred to as externalities, specifically, negative externalities (Besanko & Braeutigam, 2010; Varian, 2010). Property rights define only sanctioned human behaviour, that is not legally prohibited (Alchian, 1965). For example, although an individual has the rights to fish in the river, that individual does not have the rights to use prohibited chemicals or equipment in this regard. Legality or legal rules matter for efficient outcomes (Coase, 1960; Kim & Mahoney, 2005). Such legal rights bring to the fore the last element of the Alchian's definition - power of the state. This implies that the state is expected to use its police power and the courts to assist private individuals in enforcing legal contracts on property rights. This state role in the contractual relations of private parties is expected to lower exchange costs especially if the state uses its power in a systematic and predictable manner (Mahoney, 2005).

Property rights theory distinguishes communal ownership from private and state ownerships. If resources are available to all persons in the state without any demarcation of boundaries, this resource is communal in nature. This kind of property is governed on a first-come first-serve basis (Alchian & Demsetz, 1973), and can be exercised by all members of the community (Demsetz, 1967). For example, a river can be used by any member of the community for fishing on a first-come first-serve basis without exclusion. However, if a private party has the right to prohibit other persons from using a particular portion of the river, or for a particular use, it becomes private property. Private property rights, therefore, exist when the right of an owner to exclude others from exercising the owner's private rights are recognized by the community (Demsetz, 1967). For state ownership, it implies that the state uses its powers to decide who can and cannot have rights to a property, as long as this power is used in a legally acceptable manner (Demsetz, 1967). It is important to note, that, communal ownership is technically

associated with state ownership (Alchian & Demsetz, 1973); therefore, distinction is not made between state and communal ownership for the purpose of this study.

Arguably, public property rights can lead to inefficiencies and externalities since it is difficult to accurately account for the costs of such rights (Alchian & Demsetz, 1973; Demsetz, 1967). Communal rights fail to consider the impact of a decision maker's action on others. For example, if strict drilling demarcations are non-existent on an oil well, the only way an oil company can maximize its productivity is to extract as much oil as possible, neglecting the social costs of such activities or the depletion of the future value of the asset. On the contrary, private ownership is seen to be more efficient at internalizing (reducing) all externalities associated with the property right (Davies, 1971). If the rights to the oil well are owned by one party, that party will try to maximize its present value by taking into account the alternative future streams of benefits and costs by selecting the best decision that will maximize overall efficiency (Demsetz, 1967). In effect, the more of a person's own wealth an individual uses in an economic activity, the more care that individual will dedicate in making decisions that will affect the sustainability of the size of the wealth (Davies, 1971).

To put simply, whereas the effects of a person's activities on neighbours and subsequent generations is not fully accounted for in public property rights, private ownership can be used for a much more efficient internalization of such externalities caused by communal ownership. The state should therefore attempt to reduce the external costs resulting from public ownership by allowing private ownership by a small number of private groups (Demsetz, 1967). This is since an increase in the number of owners drives ownership towards communal ownership and also increases the costs of internalizing. Property rights theory, therefore, suggests that state ownership involves inferior governance quality compared to private ownership (Alchian, 1977; Shleifer, 1998), and hence, public enterprises should perform less efficiently and less profitably compared to private enterprises (Boardman & Vining, 1989), for property rights are less

optimistic at the national level (Kim & Mahoney, 2005). These views seem to suggest that the more state controlled an organisation is, the higher the tendency that organisational objectives would not be towards achieving a Pareto-efficient level.

### ***2.1.1.2 Agency theory***

Since Jensen and Mecklings' (1976) theory of the firm, the theoretical arguments of the agency theory has found conceptual and empirical acceptance in a wide spectrum of disciplines, such as accounting, finance, economics, organisational behaviour and sociology (Ang, Cole, & Lin, 2000; Eisenhardt, 1989; Miles, 2012). It is regarded as the most appropriate theory in describing the agency or owner-manager relationship and the managerial decision making process (Liang, Ren, & Sun, 2014) and the dominant perspective on which corporate governance research relies (Dalton, Hitt, Certo, & Dalton, 2008). An agency relationship arises between two or more parties when one party (the agent) acts for or on behalf of another party (the principal), in a domain of decision problems (Eisenhardt, 1988; Miles, 2012; Ross, 1973). It therefore examines the relationship between a principal and another party who has been given the authority and incentives to carry out some specific tasks on behalf of the principal. Examples of such agency relationships are between shareholders and board of directors; shareholders and auditors; citizens and government; fans and a team coach; and a creditor and a debtor.

Although most of these agency relationships are governed by contracts, externalities associated with agency relationships may arise in cooperative efforts by two or more persons even when there is no clear principal-agent relationship (Jensen & Meckling, 1976). The agency theory recognizes that, when both parties to an agency relationship are utility maximizers, there is bound to be a conflict of interest between the objectives of the principal and the agent because of an improper alignment of the agent's and the principal's interests (Ang et al., 2000; Jensen, 1986; Jensen & Meckling, 1976; Wiseman, Cuevas-Rodriguez, & Gomez-Mejia, 2012). In the

corporate context, for example, shareholders (owners of the firm) hold diversified portfolios and therefore delegate financial and other decision making to corporate managers who are expected to act in the best interest of such shareholders (Crutchley & Hansen, 1989). However, the agency problem exists, 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, like pursuing their own risk averse interests.

The agency theory recognizes that there exist an imperfect contract position between management and shareholders. This is fuelled by information asymmetry, bounded rationality, imperfect information and opportunism assumptions that govern such relationships (Cuervo-Cazzura et al., 2014). The central tenet of the theory is, therefore, that there is potential for mischief when the interest of owners and managers diverge (Dalton et al., 2008). Shareholders are to put in measures to reduce these equity agency costs as a result of loss in revenues attributable to inefficient asset utilization by management (Ang et al., 2000). This will be achieved by determining the most efficient contract governing the principal-agent relationship (Eisenhardt, 1989). Note that these measures also come at a cost. Three main approaches have been proposed in dealing with such agency problems: the equity approach; the independence approach; and the market for corporate control or control hypothesis. For more information on this, please refer to Dalton et al. (2008), Jensen (1986), Crutchley and Hansen (1989) and Jensen and Meckling (1976) for more discussion.

Proponents of the agency theory believe that it is more difficult to address the agency problem in state-owned companies as compared to privately controlled ones because there is an extra agency relationship in state-owned companies compared to privately-owned companies, as the controlling owners are themselves agents of the true owners: the state (Ding, Zhang, & Zhang, 2007). Although the citizenry are the true owners of the state-owned enterprise, they do not possess the direct control right or ability to incentivize management to undertake their specific

interests. Citizens delegate such controlling powers to politicians through elections. Their control over such politicians are limited to elections and a few consumer protection agencies. Whereas citizens' interest may be towards long-term sustainability of the venture, the interests of politicians may be towards ensuring short-term gains in order to secure the political office in the next election. Coupled with this, there is an extra agency relationship between the politicians and the management of such state-owned enterprises. First, the appointment of the board of such corporate organisations may be influenced by political affiliations and interests. This means that, management may tend to have more allegiance to the appointing authority than the true owners (Cuervo-Cazurra et al., 2014). Second, some of the remedies to the agency problem are rendered ineffective, especially when the state enterprise is wholly owned by the state. For example, management cannot be incentivized through shareholding as the shares are state-owned. In addition, because state-owned enterprises belong to the state, dividends paid will go to the state providing little or no benefit for private interests thereby attracting no interest from stock market regulations (Dalton et al., 2008; Jensen, 1986).

Consequently, companies with more private ownership are more likely to have less serious agency problems as compared to state firms (Ding, Zhang, & Zhang, 2007). Indeed, Ang et al. (2000) believe that agency problems are higher among firms that are not 100% owned by management. This is true since ownership associated agency problems are smaller when a private investor is the dominant shareholder of the firm (Chen et al., 2009). Therefore, government intervention is seen as the key reason for the inefficiency of state-owned enterprises.

Although theoretically, private ownership may seem to be preferred over state ownership, empirically, this theoretical stance may not be justified. Several studies, especially in the banking industry, have seen considerable efficiency gains by state-owned enterprises (Bhattacharyya, Lovell, & Sahay, 1997; Ray & Das, 2010; Staub, Souza, & Tabak, 2010).

Staub et al. (2010), for example, identify that state-owned banks were able to manage cost of production more efficiently than their foreign and private domestic counterparts. This state advantage may be due to improved performance standards as a result of competition. State enterprises can better harness their resource endowment in a way that makes them more efficient than their private counterparts.

### **2.1.2 Multinationality and firm performance**

The effects of multinationality on firm performance is one area that has seen a number of theoretical and empirical interests in literature (Hennart, 2007; Morck & Yeung, 1991; Thomas & Eden, 2004). This concept in the efficiency and productivity change assessment of oil firms has been based on two main theoretical arguments- Markowitz's (1952) portfolio diversification theory and Dunning's (1977) eclectic theory of international production (Al-Obaidan & Scully, 1995). These are the theoretical basis for the existence of positive net economic benefits attributable to international diversification of business operations.

International diversification or multinationality is, therefore, supposed to increase firm efficiency and profitability because it can result in economies of scale, provide better and flexible access to resources and allow for more learning (Hennart, 2007). Multinationality also allows firms to exploit competitive advantages that are not available to domestic firms (Thomas & Eden, 2004). It should be noted that, empirical results, because they are mixed, do not support the one-sided theoretical argument that multinational firms out-perform their local counterparts. (Hennart, 2007; Morck & Yeung, 1991; Thomas & Eden, 2004). Its application in the oil industry has however seen strong indications to support the view that multinational oil companies perform better than localized firms (Al-Obaidan & Scully, 1995). Al-Obaidan and Scully (1995), the only paper to assess the impact of multinationality on firm performance in the oil industry, observed that multinationals have higher scale efficiencies than local firms

probably due to their ability to spread costs across other business units. However, this paper failed to consider possible performance differences in multinational-state firms and multinational-private firms.

### ***2.1.2.1 Portfolio diversification theory***

The finance theory of portfolio diversification, propounded by Markowitz (1952), is the initial impetus for the multinationality and productivity change arguments (Hennart, 2007). This theory assumes that an investor aims to hold a collection of risky (stocks and bonds) and risk-free (treasury bills) assets in a way to achieve an optimal risk-return trade-off (Harlow, 1991; Cesari & Cremonini, 2003; Adachi & Gupta, 2005). Diversification is central here, since as the number of securities in a portfolio approaches that of the market, it is expected that the risks in the portfolio return approaches the level of systematic variation and thereby reducing the impact of firm-specific risks (Detemple, Garcia, & Rindisbacher, 2005; Evans & Archer, 1968). Investors can, by this, reduce the overall risk of their investments by forming well diversified portfolios (Harlow, 1991). Although any rule which does not imply the superiority of diversification as a hypothesis must be rejected, it is worth acknowledging that diversification cannot eliminate all risk (Markowitz, 1952).

Although traditionally, the theory deals with financial instruments, it can be extended to explain why firms decide to hold a portfolio of income generating assets both domestically and internationally. A portfolio is said to be internationally diversified if the assets in this portfolio are constructed from more than one economy (Driessen & Laeven, 2007). This means that a multinational portfolio choice is internationally diversified. Global asset allocation is the largest source of differences in portfolio performance since global asset markets provide significant opportunities to improve investment returns (Coval & Moskowitz, 1999; Gratcheva & Falk, 2003). There are significant regional and global diversification benefits for investors

in both developed and developing countries, although investors from developing countries stand to benefit more (Driessen & Laeven, 2007). This perspective to multinationality views product and process diversification across boundaries as having the potential to improve the risks and return performance of investors by investing in assets whose returns are uncorrelated (Annavarjuka & Beldona, 2000; Hennart, 2007). This is so because economic activities of different countries are less than perfectly correlated (Annavarjuka & Beldona, 2000). Harvey (1995), for example, has seen that, there is low correlation between the economies of emerging and developed countries, thereby providing lower portfolio risks. Therefore, it is expected that firms that have operations in several countries that are not economically integrated, would enjoy higher productivity change as compared to firms with less geographically diversified portfolios. Consequently, multinational oil companies should out-perform localized oil firms. This is because, such diversified oil companies are expected to better diversify their country-specific market risks by operating in uncorrelated foreign markets.

#### ***2.1.2.2 Eclectic paradigm of international production***

Another basis for the multinationality arguments is the eclectic paradigm by Dunning (1977). The eclectic paradigm still remains a powerful and robust framework for evaluating context-specific theories of foreign direct investment (FDI) and international production (Cantwell & Narula, 2001; Dunning, 2001; Stoian & Filippaios, 2008). It is still the dominant paradigm in international business studies (Eden & Dai, 2010; Rugman, 2010). This paradigm is context-specific, and varies across firms, industries, regions, countries or value addition processes (Stoian & Filippaios, 2008). It is best to regard the eclectic paradigm as a framework for analysing the determinants of international production rather than as a predictive theory of the activities of multinational enterprises (Dunning, 2001). The paradigm sets out conceptual

arguments to answer the questions- why do firms invest overseas, or what determines the amount and composition of international production? (Eden & Dai, 2010).

The eclectic paradigm, also known as the OLI-Model, seeks to explain the reason why firms go multinational from 3 main angles- Ownership advantages (O); Location advantages (L); and Internalization advantages (I) (Dunning, 1980). In other words, the extent to which a firm engages in FDI rests on the interaction of these three interdependent determinants (Arnett & Madhavaram, 2012; Dunning, 2000). Ownership advantage refers to the extent to which a foreign firm possesses or gains access to resources or assets that rivals lack (Arnett & Madhavaram, 2012). These are firm-specific competitive advantages that are created through the firm's international experience, size and ability to differentiate its products from competitors (Brouthers, Brouthers, & Werner, 1996). In the oil industry, advantages may emanate from possession of rich oil fields, access to markets, transportation and distribution advantages (Al-Obaidan & Scully, 1995).

The locational advantages, explain the country-specific factors relating to the potential market or simply where to produce (Brouthers et al., 1996). It assesses market potential and risks available to all firms in a particular market including the economic, political, legal and other trade policies pervasive in a particular market under consideration (Dunning, 1980). Although, locational advantages are available to all firms, different firms can take better advantage of these. Therefore, it is expected that a firm will be more profitable if it is able to utilize, not only its ownership advantages, but also some factor inputs outside its home-country (Itaki, 1991). Finally, internationalization advantages are mostly concerned with the cost of directly producing in the host-country, as compared to licensing of other parties in such host countries (Arnett & Madhavaram, 2012; Rugman, 2010). Internalization comes at a transaction cost which must be compared to costs associated with finding and maintaining an external partner to perform similar functions in the international market (Brouthers et al., 1996). These

advantages are inter-dependent and must be seen as complementary (Stoian & Filippaous, 2008). For example, if an oil company possesses the necessary technological expertise or staff (ownership advantages) superior to competitors, and is able to better pursue the locational advantages, such as resource endowment, in another country; that firm is expected to adopt a strategy of FDI. Their complementary nature ensures better efficiency throughout the value chain (Dunning, 1998).

The eclectic theory merges several isolated theories in international economics to explain the propensity for firms to engage in international production financed by FDI and other foreign activities of multinational enterprises, instead of export or other licensing agreements (Dunning, 2000). Four main foreign-based multinational activities have been suggested by scholars of this paradigm (Dunning, 2000; Rugman, 2010): market-seeking (demand oriented FDI); resource-seeking (supply oriented FDI); efficiency-seeking activities; and asset-seeking activities. This can be better summarised in Figure 1 which shows the strategic orientation of firms given a high and low firm-specific and country-specific advantages.

		Firm-Specific Advantages	
		Low	High
Country-Specific Advantages	High	<b>1</b> <ul style="list-style-type: none"> <li>• Resource-seeking</li> <li>• Market-seeking</li> <li>• Efficiency-seeking</li> </ul>	<b>3</b> <ul style="list-style-type: none"> <li>• Asset-seeking</li> </ul>
	Low	<b>2</b> <ul style="list-style-type: none"> <li>• No FDI</li> </ul>	<b>4</b> <ul style="list-style-type: none"> <li>• No FDI</li> </ul>

Figure 1: The Eclectic Paradigm's Motives for FDI

**Source:** Rugman (2010)

According to Dunning (2000), market-seeking activities are designed to satisfy the demands of a particular market. This means that a firm will go international in order to meet the specific demands of people in a particular market. Conversely, resource-seeking activities have a supply orientation. They are designed to gain access to some natural resources available in another country. The FDI activities aimed at promoting an efficient labour specialization of an existing portfolio of assets by a multinational is viewed as a rationalized or efficiency-seeking motive. Finally, activities designed to protect or augment existing ownership advantages or to reduce competitive forces are the strategic asset-seeking motive. In cell 1, home-country firm-specific advantages do not matter; rather the country-specific advantages of the host-country are important to such firms. Home-country firms will therefore want access to such cheap labour, resources or favourable trade terms (resource-seeking) (Rugman, 2010).

Market-seeking motives may also be identified in such a configuration. Similarly, because of the favourable operational context in the host-country, a firm may go international for cost efficiencies, such as cheap labour. Indeed, strong country-specific advantages in the host-country are the most important determinants of FDI motive (Dunning, 2000). This is since cell 3 is regarded as a weak form of FDI, because although home-country firms may be interested in acquiring knowledge-related assets in order to augment their own competitive advantages, there is no guarantee that host-country firms will sell them this working knowledge (Rugman, 2010). In short, the eclectic paradigm suggests that firms go international to efficiently allocate their economic activities through resource savings and to take advantage of country-specific advantages in host countries rather than operating in one country. It stands to reason that if a firm possesses the ownership advantages, and there are locational advantages in the host-country of choice, then by better internalizing these advantages, international production would be of benefit to this firm. On the contrary, where these advantages do not exist, if a firm goes international, it may not bring enough benefits to the firm's operations.

### **2.1.3 Ownership and multinationality**

It is evident from the theories reviewed thus far that, whereas ownership theories support private ownership over public or state ownership, multinationality theories seem to mainly favour multinationals as against locals, irrespective of ownership status. However, is it true that private firms are always better than state? Do private multinationals out-perform state multinationals? Do state multinationals out-perform local state firms? And do state multinationals out-perform local private firms? Recently, Bass and Chakrabarty (2014), Choudhury and Khanna (2014), Cuervo-Cazzura et al. (2014), Li, Cui and Lu (2014), Meyer, Ding, Li and Zhang (2014), Pan et al. (2014) and Liang et al. (2014), have sought to fill this gap in research by providing new theoretical arguments for statistical testing. These studies have provided theoretical extensions on established theories, like agency theory, transaction cost economics, resource-based view, resource dependence theory and institutional theory, in order to explain why state firms go multinational. These will be the lens within which the relationship between ownership and multinationality is seen.

The role of state-owned enterprises as multinationals seem to contradict the very reasons for their establishment (Cuervo-Cazzura et al., 2014). This is because, instead of creating employment for citizens, they rather create income generating welfare for foreign citizens. However, a critical look at it reveals that the home-country stands to benefit immensely from such international production (Bass & Chakrabarty, 2014). International activities of state-owned firms may be necessary in ensuring that home-country continually have a stable supply of some critical resources. Bass and Chakrabarty (2014), for example, have identified that state-owned firms invest abroad to safe-guard home-country's future through long-term investments, compared with more short-term investment perspective of private multinationals. Therefore, the short-term losses in the initial investments, would be duly redeemed in the long-run. This

shows that, in their view, state-owned multinationals, may stand to have a more efficiency and dynamic productivity gains as compared to private multinationals. State enterprises may also go international in order to seek global cash-flows to achieve resource independence from state actors (Choudhury & Khanna, 2014). This shows that a state enterprise stands to benefit from internationalization because, the international returns would move such enterprises from total dependence on government resources. Inefficient influences of political actors would therefore be adequately mitigated. Government support may even provide such state enterprises with the necessary financial advantages and a higher risk tolerance capacity over private counterparts (Cuervo-Cazzura et al., 2014) in foreign investment decisions. Coupled with this, state firms may be an appropriate public relations tool for home-country governments to spread their political ideologies internationally (Duanmu, 2014).

On the other hand, this state backing may result in an adverse effect on state enterprise performance, because of a combination of ideological conflicts, perceived threats to national security and unfair competitive advantages due to support by home-governments (Meyer et al., 2014). State-owned multinationals are, in effect, likely to face more hostility in foreign investments as compared to private multinationals (Cuervo-Cazzura et al., 2014). Therefore, such state enterprises must be careful in selecting the appropriate investment destination that would result in less friction between them and their hosts. Such firms can leverage home-state power and diplomacy to counter monopoly powers of host-country producers (Duanmu, 2014). The problem, however, is that the appropriate destination in this context, may not necessarily be the best destination for optimal productivity and locational advantages. It is evident that the role of a state enterprise as a multinational can bring benefits to such enterprises, or may result in a very difficult operational environment for such enterprises if conflicts exists between home and host countries.

## **2.2 Empirical review**

### **2.2.1 Frontier efficiency and productivity change in the oil industry**

The efficiency of the energy industry has been of interest in research since the 1973/1974 world oil crisis that spurred researchers' enthusiasm in formulating and applying analytical/modelling techniques in energy studies (Loken, 2007; Zhou, Ang, & Poh, 2008). These studies span various sub-sectors of the industry such as district heating plants, oil and gas producing firms and countries, electricity plants and coal mines (Zhou et al., 2008). In the oil and gas industry, studies have assessed the efficiency of countries (Hawdon, 2003); refineries (Francisco, de Almeida, & da Silva, 2012); oil exploration companies (Eller et al., 2011; Wolf, 2009); and drilling wells, oil blocks and fields (Barros & Managi, 2009; Kashani, 2005a; Managi, Opaluch, Jin, & Grigalunas, 2005). Although most of these studies have assessed oil and gas together, few find it necessary to focus on one of these subdivisions (Barros & Antunes, 2014; Barros & Assaf, 2009; Kashani, 2005b). A tabular taxonomy of the relevant literature on efficiency and productivity change studies in the oil industry can be found in Appendix B.

The main research issues underlining these studies include ownership, environmental efficiency and the effects of government regulation and other interventions on performance. Since ownership is one of the key issues of this study, an in-depth review of empirical works in this regard is provided in subsequent sections. A closely related research issue is the role of government on efficiency in the industry. Researches on privatization (Price & Weyman-Jones, 1996), regulation (Hawdon, 2003; Kashani, 2005a) and state interventions (Kashani, 2005b) have built our understanding of the efficiency in the oil industry. By employing DEA, SFA and regression analysis on oil and gas fields in the UK between 1974 and 1991, Kashani (2005a), for example, has empirically identified that by removing governmental restrictions, large efficiency improvements would be possible in the oil and gas industry. This is since inefficiencies were lower during periods of no state intervention in the UK oil and gas industry.

A similar study by the same author on Norway also revealed that reduced interventions promotes efficiency (Kashani, 2005b). This was since gas fields operated by independent companies exhibited higher than average efficiencies.

Just like Kashani (2005a), Price and Weyman-Jones (1996) earlier used DEA and SFA in the UK oil and gas industry, except that this study focussed on the downstream sector. They wanted to understand the effects of privatization of distribution regions on performance. The efficiency frontier was composed of the post privatization gas industry, signifying that periods where government was in operational control of gas distribution was markedly inefficient. Although these studies have provided valuable insights on governments role in the industry, there is a critical question of whether their findings are still of relevance in the industry. Whereas the study period of Kashani (2005a) and (2005b) are 1974-1991 and 1972-2000 respectively, that of Price and Weyman-Jones (1996) was 1977 to 1991. Similarly, Hawdon (2003) sampled a cross-sectional data on the gas industry in 1998 and 1999. It is possible that, over time, changes in technology and other industry dynamics have affected the validity of findings of these studies. A much more current understanding of the oil and gas industry is warranted; an exercise undertaken in the current study.

Another theoretical perspective of efficiency studies in the industry is with environmental efficiency, which takes into consideration some unfavourable by-products, such as pollution in efficiency benchmarking. Although oil and gas exploration, extraction, refining, distribution and use may have harming consequences on the environment, unfortunately unlike other research issues in the industry, this has not been of much interest to researchers. Only four studies, from the studies reviewed, have examined this issue (Francisco et al., 2012; Sueyoshi & Goto, 2012a, 2012b; Ismail et al., 2013) of which only two are actual empirical works. Francisco et al. (2012) empirically assessed environmental efficiency of public-sector refineries in Brazil using DEA models for undesirable outputs. In their view, technical

efficiency scores without considering undesirable outputs is misleading. For Sueyoshi and Goto (2012a, 2012b), although they eventually used some actual data, this can be seen as a more conceptual paper as the sample of only 19 firms is not large enough for generalization. The focus of their studies were rather on developing important models for environmental efficiency assessment. Whereas environmental assessment is a major policy issue in the world (Sueyoshi & Goto, 2012a), its assessment in the oil and gas industry is still lacking. More empirical work is warranted to develop environmental efficiency assessment models or to apply them to inform policy.

Other notable efficiency-related studies in the oil and gas industry tend to provide a context-specific view of efficiency. Whereas Barros and Managi (2009), Barros and Assaf (2009) and Barros and Antunes (2014) assess efficiency of Angolan oil blocks, Managi et al. (2005) and Managi et al. (2006) both provide insights into drilling wells in the Gulf of Mexico. In effect, these studies have provided rich insights about the Angolan and American oil industry. Angolan oil blocks have been seen to be experiencing a consistent productivity growth since 2002 attributable to the possibility that oil peak has not yet been achieved (Barros & Antunes, 2014). It must be noted, however, that the consistent growth in productivity seen more in ultra-deep and deep oil blocks, for other shallow wells have experienced fluctuating efficiency over the study period (Barros & Assaf, 2009).

For the Gulf of Mexico, it has been identified that changes in exploration technology has played a significant role in the offshore industry, increasing reserves and lowering resource depletion (Managi et al., 2005). Finally, in the Gulf of Mexico, environmental regulation has had a significantly negative impact on offshore production, although this impact is diminishing over time (Managi et al., 2006). Although these studies have improved our understanding in the specific context, a holistic assessment of efficiency is warranted since by the nature of the industry, local performance may be affected by international markets and conditions.

### **2.2.2 Ownership and efficiency in the oil industry**

Out of the various oil efficiency-related study issues examined, ownership has received the most interest. For starters, Al-Obaidan and Scully (1991), Eller et al. (2011), Wolf (2009), Sueyoshi and Goto (2012a, 2012b) and Ike and Lee (2014), have all found this topic interesting for academic interrogation. These studies have found it necessary to examine efficiency differences between state and privately-owned oil companies. Governments across the globe have controlling interests in some oil exploration and production companies with the aim of safeguarding national interests and benefiting from the resources of the industry. This may explain why NOCs actively compete with privately-owned IOCs. This industry is complex with numerous players ranging from governments to non-state-owned publicly traded and privately-owned enterprises (Bass & Chakrabarty, 2014). The research question is therefore, which is more efficient? NOCs (state-owned) or IOCs (privately-owned)? Moreover, how can efficiency and productivity change of the lesser efficient group be improved?

In the oil and gas efficiency literature, Al-Obaidan and Scully (1991) pioneered such interrogations. By assessing the efficiency of 44 oil companies, they observed that private firms are more operationally (technically) and price efficient than state-owned oil firms. In contrast, state oil firms perform equally as private firms in terms scale and allocative efficiency. This means that, whereas private oil firms are better 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 how well these firms choose the mix of resources for production. Al-Obaidan and Scully (1991) failed to include NOCs of OPEC members citing that their performance is due to accident of geography rather than resource allocation. However, the influence of OPEC in the oil and gas industry cannot be ignored (Barros, Gil-Alana, & Payne, 2011; Bremond, Hache, & Mignon, 2012).

Eller et al. (2011) filled this gap in Al-Obaidan and Scully's (1991) research by including OPEC NOCs in the sample. Unlike Al-Obaidan and Scully, their study employed both DEA and SFA. However, research findings were not that different. NOCs were still found to be among the least efficient firms at raising revenue from oil reserves and labour. This is probably because such NOCs are forced to subsidize fuel for domestic consumption and employ a larger workforce not necessary for purely commercial objectives (Eller et al., 2011). Although OPEC NOCs were included in this sample, Eller et al. (2011) failed to report any efficiency scores for such firms. It is on this basis that the recent work by Ike and Lee (2014) becomes relevant. Similar to previous studies, they observed IOCs to have higher performance. However, this study provides new insights that even among the NOCs, OPEC NOCs were among the worst performers. This is not too surprising since Wolf (2009) had earlier discovered that the impact of both state ownership and OPEC membership is significantly negative in upstream production. This was attributable to production quota policy of OPEC members having a negative influence on firm performance. Ike and Lee (2014), however failed to assess the impact of multinationality on efficiency and productivity change. Finally, although Sueyoshi and Goto (2012a, 2012b) have contributed to this debate, their papers were more conceptual than empirical. Ike and Lee (2014) used productivity indicators in their assessment. However, they failed to correct inherent biases by computing bootstrapped productivity indices. In addition, although their dataset was an unbalanced panel data, they removed some firms in order to achieve a balanced panel. This significantly reduced the sample size which biased the findings of the study (Kerstens & Woestyne, 2014).

Empirical arguments in the oil industry endorse the multi-objective nature of most NOCs. State-owned enterprises serve many masters, thereby causing economic inefficiency in their operations. The political overseers of NOCs are likely to require them to pursue various non-commercial objectives such as excessive employment, under-investing in reserves and shifting

resource extraction and exploration away from the future towards the present (Eller et al., 2011). NOCs may also be required to satisfy domestic demands at subsidized prices and thus appear inefficient relative to other private IOCs in generating revenue (Eller et al., 2011). It is therefore not surprising that most empirical evidence seem to point towards better performance of IOCs relative to NOCs. This notwithstanding, it should be noted that, the validity of the property rights hypothesis, and other ownership theories, has been disputed as more empirical evidence provide a weak support for this hypothesis (Boardman & Vining, 1989). Public enterprises have been seen to out-perform their private counterparts, especially, in environments where there is a natural monopoly, regulated duopoly and output is not priced by competitive forces (Boardman & Vining, 1989).

### **2.2.3 Multinationality and efficiency in the oil industry**

Multinationality in the oil industry has attracted the interest of Al-Obaidan and Scully (1995), Bass and Chakrabarty (2014), Cuervo-Cazurra et al. (2014) and Kim and Mahoney (2005). As yet the study by Al-Obaidan and Scully (1995) has been the only study seen, from literature reviewed, that comprehensively links multinationality to efficiency and productivity change in the oil and gas industry. Kim and Mahoney (2005), for example, merely used the oil and gas industry as the background in explaining the theoretical principles in property rights, transaction cost and agency theories. No concrete link to efficiency or productivity growth in the oil industry was examined. Similarly, Cuervo-Cazurra et al. (2014) found this industry as a rich source of conceptually appropriate examples in explaining theoretical extensions on state multinationals. Bass and Chakrabarty (2014), on their part, used the industry as the basis for developing a resource security theory that explains the intent of acquisitions of scarce resources by multinationals. Therefore, it is not surprising that Al-Obaidan and Scully has been a constant citation in efficiency-related studies in the oil industry.

It is important to note that Ike and Lee (2014) have given some thought to multinationality (international operations) in their work. They, however, only considered it as a mere control variable with little substance to their empirical arguments. In comparing the technical efficiencies of 44 multinational and local oil firms, Al-Obaidan and Scully found that multinational firms in the petroleum industry lose about 15% of their technical efficiencies because of transaction diseconomies. Local firms also out-perform multinationals when it comes to economic efficiency. Instead, multinationals have higher scale efficiencies than local firms probably because multinationals are able to spread investment costs over a large number of firms. In their view, multinationals enjoy a more stable stream of returns in investment over time, because they enjoy a lower business risk. This shows that multinationality offers firms an avenue for reducing risks associated with operations. It is important to examine whether international operations reduce the inefficiencies of state oil firms. This would provide an avenue for state firms to reduce the apparent inefficiencies caused by state ownership. This is something previous literature has failed to consider. Interacting ownership and multinationality may provide better insights since considering multinationality only as a control variable is not sufficient to provide policy insights.

### **2.3 Conceptual framework**

This study assesses the efficiency and dynamic productivity differences between state and privately-owned oil firms. Efficiency is assessed using both technical (or productive or operational) efficiency and scale efficiency. Dynamic productivity is assessed using the Malmquist Productivity Change Index (MPI). This notwithstanding, the components of productivity change, namely; Efficiency Change (EC); Technical Change (TC); Pure Efficiency Change (PEC); and Scale Change (SEC), are also compared to provide further

information on the nature of productivity differences. A more comprehensive explanation of the various dynamic productivity indices is presented in the methodology of the study. However, unlike previous studies, assessment of productivity is considered at both the ownership and operational location levels. A graphical depiction of the conceptual framework for this study has been presented in Figure 2.

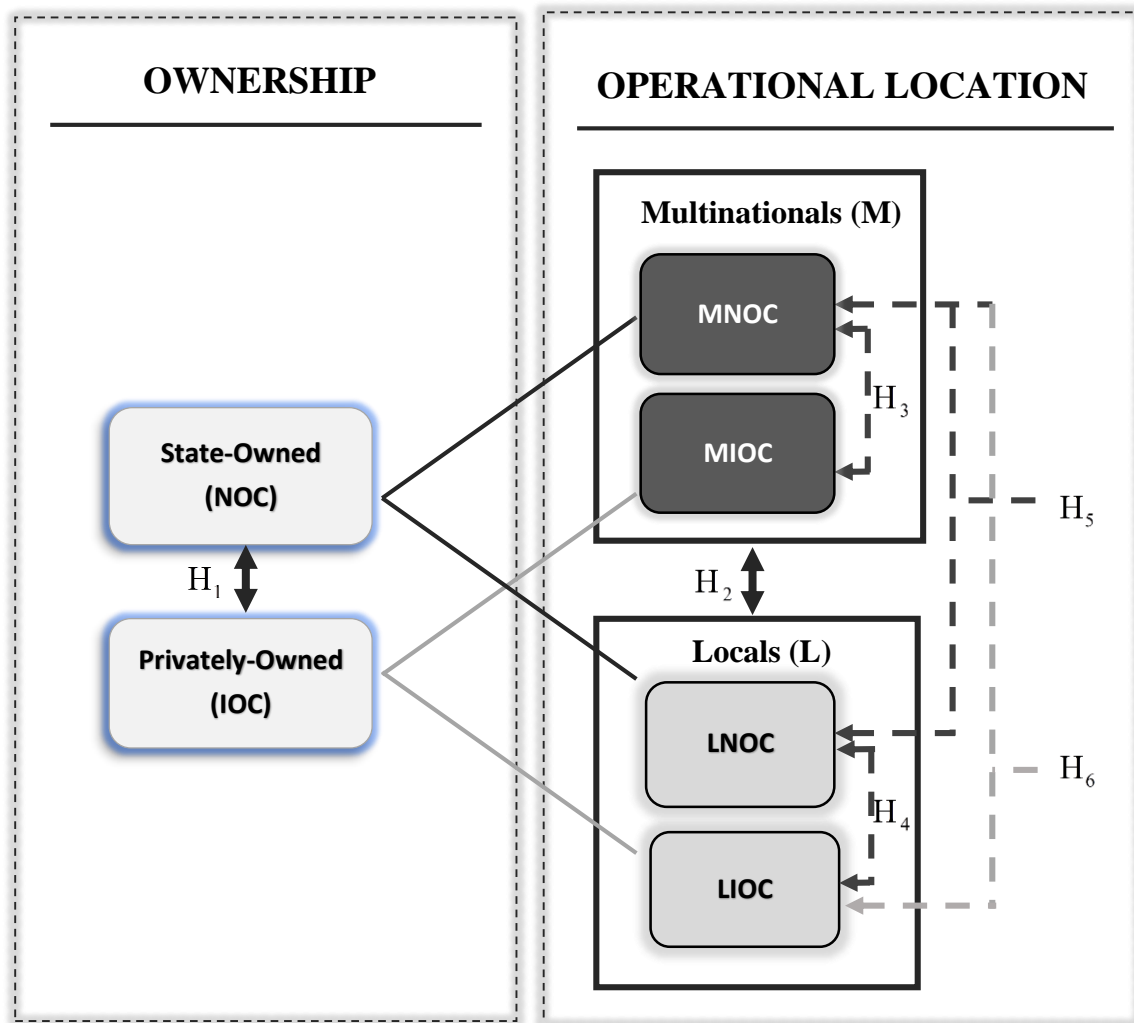


Figure 2: Conceptual Framework **Key:**

Source: Author (2015)

- NOC: National Oil Company  
 IOC: International Oil Company  
 MNOC: Multinational National Oil Company  
 MIOC: Multinational International Oil Company  
 LNOC: Local National Oil Company  
 LIOC: Local International Oil Company

Six hypotheses main are tested for each efficiency and productivity indicator. Hypothesis 1 examines the difference in the productive efficiency (H1a), scale efficiency (H1b) and dynamic productivity (H1c) of NOCs and IOCs. As with previous studies, it is expected that privately-owned/international oil companies would out-perform state-owned enterprises. This is the empirical position seen in several similar papers.

**Hypothesis 1:** *Private oil firms (IOCs) significantly out-perform state-owned oil firms (NOCs)*

The second hypothesis examines the differences in the productive efficiency (H2a), scale efficiency (H2b) and productivity change (H2c) of multinationals and locals. Based on the theoretical arguments of the portfolio diversification theory and the eclectic paradigm, it is expected that multinationals would significantly out-perform locals on all efficiency and productivity change measures.

**Hypothesis 2:** *Multinational oil firms (M) significantly out-perform local oil firms (L)*

Hypothesis 3 assesses whether there are significant differences in the average productivity changes (H3c) and productive (H3a) and scale (H3b) efficiencies of state multinationals (MNOCs) and private multinationals (MIOCs). Here, the focus is only on multinationals. No local state or local private firm would be included in this comparison. Since both firms are multinationals, it is expected that they would not significantly differ in their level of efficiency and productivity change.

**Hypothesis 3:** *State-owned multinational oil firms (MNOCs) perform equally as privately-owned multinational oil firms (MIOCs)*

Hypothesis 4 compares only local firms. No multinationals would be examined here. It is expected that local NOCs will out-perform local IOCs. This is because when competing with the government, it is expected that the government would have the advantage of state resources and risk capacity over local private firms.

**Hypothesis 4:** *State-owned local oil firms (LNOCs) significantly out-perform privately-owned local oil firms (LIOCs)*

For hypotheses 5 and 6, it is expected that a multinational NOCs would out-perform any local firm, whether state-owned (NOCs) or privately-owned (IOCs). This is primarily because multinationals can leverage the costs and risks associated with localized operations in the international market. Multinationals are expected to better diversify firm-specific or country-specific risks over several business units.

**Hypothesis 5:** *State-owned multinational oil firms (MNOCs) significantly out-perform state-owned local oil firms (LNOCs)*

**Hypothesis 6:** *State-owned multinational oil firms (MNOCs) significantly out-perform privately-owned local oil firms (LIOCs)*

## 2.4 Conclusion

The chapter begun with a theoretical review. The property rights and agency theories were used to explain the link between ownership and efficiency; whiles the portfolio diversification theory and eclectic paradigm were used to explain the multinationality-firm performance nexus. An empirical review of studies, especially on the ownership debate, was also provided. Based on relevant theories and the state of empirical knowledge on ownership, multinationality and efficiency, a conceptual framework was provided to guide the analysis of this study.

## **CHAPTER THREE**

### **CONTEXT OF THE STUDY**

#### **3.0 Introduction**

The context of the study provides an overview of the unique characteristics of the oil and gas industry. It aims at providing adequate background in order to clearly understand the empirical arguments presented in this study. This chapter is divided into three main sections. First, the structure of the international oil and gas industry is presented. This clearly shows the activities in the oil and gas value chain. The section also provides insights into major inputs in the industry and potential environmental concerns. Second, it provides an overview of the players in the industry. This section builds an initial understanding of the differences between the various types of oil companies that this study assesses. Finally, it provides an overview of major trends in the international oil industry during the study period to help understand the factors explaining the efficiency and dynamic productivity trends in the industry.

#### **3.1 Structure of the oil and gas industry**

The oil and gas industry, also called the petroleum industry, is one that encompasses several value-creation activities aimed at providing petroleum products to consumers. This includes processes of exploration, extraction, refining or processing, transporting and marketing of crude and natural gas-based products (Tordo et al., 2011). Investment in this industry, no matter the level of involvement requires heavy monetary and logistical commitments and in-depth operational expertise (Szilas, 1986). Activities in the oil and gas industry can be broadly segmented into two business functions- upstream and downstream (Sueyoshi & Goto, 2012a). There exist, however, a midstream function that links the two broad business segments (Weijermars, 2010). While the upstream sector comprises firms that undertake exploration,

development and production of crude oil and natural gas; the downstream sector comprises firms that undertake the refining, storage, distribution and marketing segments of the industry (Pirog, 2005). Understanding of the structure of this industry would be enhanced by taking a closer look at the oil and gas value chain and the main resources and consequences of the value creating activities.

### **3.1.1 The oil and gas value chain**

The value chain shows the various activities in the petroleum industry and the particular business segment they fall under. It must be noted that, various firms in the oil industry have active operations in all aspects of the value chain. Although the technical knowledge and inputs required at each segment are very different, large amount of investments are required to manage each segment (Mitchell & Mitchell, 2014). The value chain, presented in Figure 3, is based on the works of Wolf (2009) and Tordo et al. (2011).

This value chain can be broken down into three distinct areas of operation: upstream, downstream and midstream (KPMG, 2013). The value chain begins with two main upstream activities- exploration and production. These ensure that hydrocarbons are brought to the surface of the earth for further processing. Downstream activities in the value chain include crude refining, gas processing and marketing. The primary role of this segment is to ensure that extracted hydrocarbons are useful for the purposes of end-users. Between these two business segments is the midstream, primarily involved in transporting the outputs of these two business segments to the intended users.

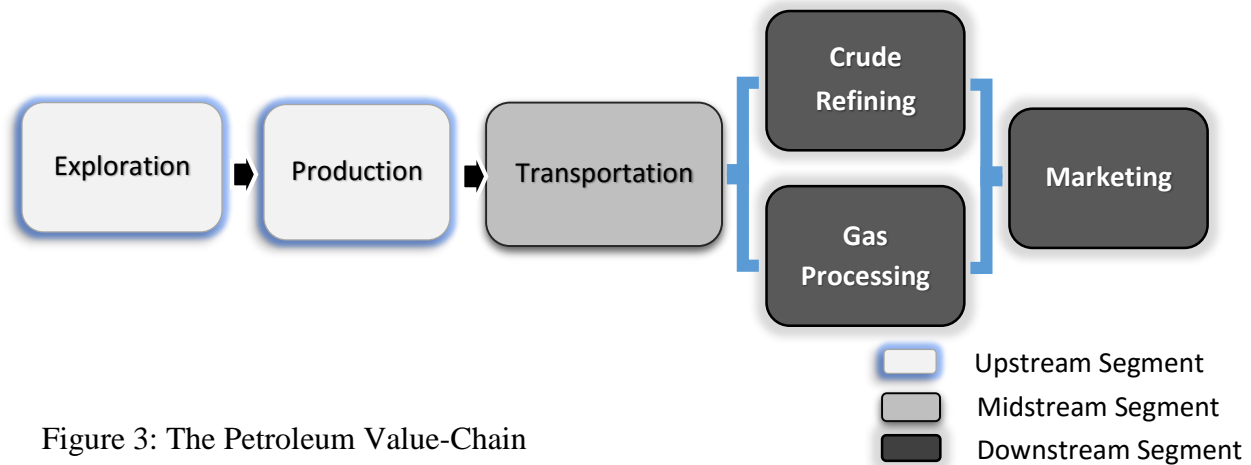


Figure 3: The Petroleum Value-Chain

Source: adapted from Wolf (2009) and Tordo et al. (2011)

### 3.1.1.1 Upstream Segment

The upstream segment is commonly called the exploration and production (E&P) segment of the industry (Weijermars, 2010). As the name indicates, two main activities are undertaken—hydrocarbon exploration and production. Exploration involves the use of well-advanced technology to find new oil resources, usually in commercial quantities. The task of finding and extracting oil and gas is usually delegated to IOCs, which possess the necessary expertise and financial resources to undertake the task (Easo, 2009). Once these resources are found, production or extraction follows after all necessary infrastructure is put in place.

As at 2014, there were about 5123 active oil exploration rigs in the world prospecting and producing oil and gas resources (OPEC, 2015). As a result, 77,834 thousand barrels per day of crude oil was extracted in 2014 representing a 2.08% increase from 2013 year's results (EIA, 2015). From current data available, increment in gas production between 2012 and 2013 was about 1.53% (EIA, 2015). Currently, there are about 200,363 billion standard cubic metres of natural gas and 1,489,865 million barrels of proven crude oil reserves yet to be extracted (OPEC, 2015).

### ***3.1.1.2 Midstream segment***

The primary aim of the midstream is the transportation of extracted and refined hydrocarbons. This may involve moving oil and gas to refineries or processing plants, as well as transportation of finished products to oil marketing firms and consumers. The midstream serves as an intermediary between the upstream and downstream, as well as downstream and consumers. In Canada, for example, transmission pipeline companies are a major component of the midstream petroleum industry providing a vital link between petroleum producing area and the population centres where most consumers are located (PSAC, 2014). Latest results show that there are 4912 tanker fleets with capacity to transport 472,169,000 deadweight tonnage (dwt) and 1612 liquid gas carriers with 73,742,000 cubic metres total capacity globally (OPEC, 2015). For midstream segment, pipeline length, tanker capacity, labour, capital assets and oil and gas outputs are the major inputs (Lee, Park, & Kim, 1996). Number of customers, revenue and quantity of oil and gas deliveries are some of the outputs of this segment (Kim, Lee, Park, & Kim, 1999).

### ***3.1.1.3 Downstream segment***

The downstream oil industry comprises oil refineries, petrochemical plants, petroleum products distributors or oil marketing companies, retail outlets and natural gas distribution companies (PSAC, 2014). This segment is crucial in the oil industry since it does not only convert hydrocarbons to domestically and industrially usable products, but also makes them available to consumers for consumption. Crude oil and natural gas extracted can be refined into aviation fuel, gasoline, liquefied petroleum gas, as well as other petrochemical products like tires and rubber. In the downstream, commodity price margins and pricing differentials through product quality differentiation are the main market-level influence factors in generating revenue for firms (Wolf, 2009).

### 3.1.2 Oil and gas reserves

In the oil and gas value chain, a mix of capital investments, personnel and oil and gas reserves are required in order to generate any output (Wolf, 2009). Among these inputs, oil and gas reserves are key to the continual existence of any production endeavour in this industry. Oil and gas reserves are among the key operational variables that determine the performance of an oil company (Energy Intelligence, 2013) since it is the key material input from which crude and natural gas can be extracted. Figure 4 gives a graphical depiction of oil and natural gas resource categorizations.

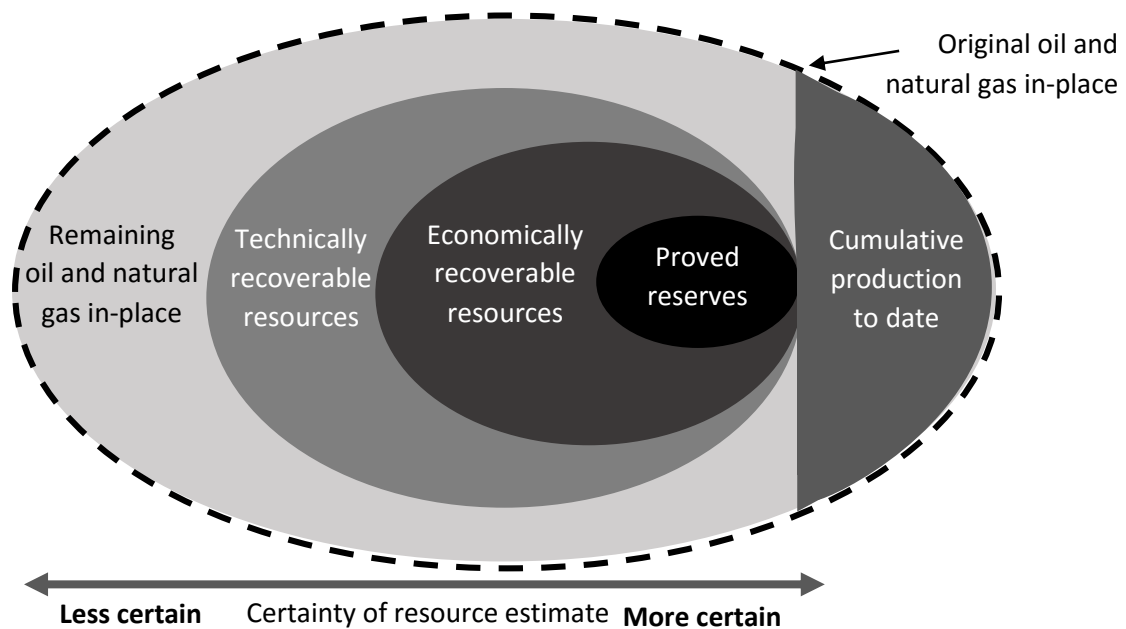


Figure 4: Stylized Representation of Oil and Natural Gas Reserves  
Source: EIA (2014)

Although Figure 4 is not drawn to scale, it helps to comprehend the size of proved oil reserves in relation to other oil and gas resources (EIA, 2014). Proved oil and gas reserves represent quantities of petroleum which, by analysis of geological and engineering data, can be estimated with a high confidence to be commercially recoverable from a given date forward, from known reservoirs and under current economic conditions (CIA, 2014). This is a small portion of remaining oil and natural gas available that, by scientific analysis, are certain to be recoverable.

Economically recoverable and technically recoverable resources may later be added to the proved oil reserves as and when scientific assessment proves them to be recoverable for commercial extraction (EIA, 2014).

### **3.1.3 Environmental impacts of petroleum value chain**

Although various economies depend on oil-based products in all spheres of life (Cunado & Gracia, 2003); like several other extraction industries, the petroleum industry has several environmental effects. Across all segments of the industry, environmental concerns have been raised (OPEC, 2014; Zhang, Cheng, Yuan, & Gao, 2011). Producing oil and gas would mean producing negative or undesirable outputs as well. This has attracted the research interest of Francisco et al. (2012), Sueyoshi and Goto (2012a) and Ismail et al. (2013). These emissions may have serious impacts on climate change. Examples of such emissions include: discharge of mud and wastewater; accidental oil spills; mono-nitrogen oxides (NO<sub>x</sub>), sulphur dioxide (SO<sub>2</sub>), and carbon dioxide (CO<sub>2</sub>); exposure to toxic and carcinogenic chemicals; and greenhouse emissions (Devold, 2009; Ismail et al., 2013; Szklo & Schaeffer, 2007). It is important that more research be dedicated to the harmful effects of such emissions on efficiency as well as mechanisms for reducing the recurrence of such incidences. This can be considered to be a direction for further research.

## **3.2 Players in the oil and gas industry**

Players in the oil and gas industry may be countries, inter-governmental organisations (IGOs) or oil firms. The oil and gas industry is also diverse, with a rich variety of players and entirely different regions of operation (OPEC, 2014). Countries are primarily involved in policy issues related to sustaining supply of oil products to meet domestic demands. They do this through IGOs such as: the Organisation of the Petroleum Exporting Countries (OPEC); International

Energy Agency (IEA); Organisation for Economic Cooperation and Development (OECD); and Organisation of Arab Petroleum Exporting Countries (OAPEC). An assessment of the performance of these sub-groups of oil block organisations or IGOs may be an interesting direction for further research. These organisations are primarily established to consolidate the complementary skills of members and create platforms for innovation, cooperation and creativity that will make full use of the available resources to provide sustainable development for the member nations (Dorrussen & Ward, 2008). The focus of this study, however, is rather on the oil companies within the international oil industry.

These oil firms are corporate entities that engage in value creating activities in the oil industry; and can be separated into two categories - NOCs and IOCs. NOCs are state controlled oil undertakings established to engage in oil exploration or production or other value-activities in the mid and downstream. NOCs dominate the proven oil reserves that are expected to supply the world's need for fuel (Stevens, 2008). IOCs, on the other hand, are privately controlled oil firms. Although over the years, IOCs have dominated, in terms of size, expertise and performance, gradually, NOCs are matching to these standards (Energy Intelligence, 2014). For example, the 2013 edition of the annual ranking of Petroleum Intelligence Weekly shows that state-owned firms are continuing to rise at the expense of most major IOCs (Energy Intelligence, 2013). This notwithstanding, IOCs, NOCs, service companies and other industry players may not have identical objectives or even the same business models (OPEC, 2014). Table 1 shows the top 10 oil companies according to the Petroleum Intelligence Weekly Ranking for 2013.

**Table 1: Top Ten Oil Firms in the World**

Company	Country	State Ownership Percentage	Operational Area	Outputs	
				Oil '000 b/d	Gas 'MMcf/d
Saudi Aramco	Saudi Arabia	100	Multinational	9988	10700
NIOC	Iran	100	Local	3680	15486
ExxonMobil	US	0	Multinational	2185	12322
CNPC	China	100	Multinational	3050	9047
PDV	Venezuela	100	Local	2905	4456
BP	UK	0	Multinational	2056	7393
Royal Dutch Shell	Netherlands	0	Multinational	1633	9449
Gazprom	Russia	50	Multinational	930	47050
Chevron	US	0	Multinational	1764	5071
Total	France	0	Multinational	1220	5880

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

Source: Energy Intelligence (2014)

Table 1 clearly shows the tight nature of competition within the industry. The top ten comprises an equal number of IOCs and NOCs. NOCs continue to control a majority of the crude and natural gas reserves. Some IOCs are classified as “major” international oil companies. This is primarily because of their scale of operation and asset base relative to the other oil companies. These include BP, ExxonMobil, Total, Royal Dutch Shell and Chevron (OPEC, 2013). These firms have been the dominant IOCs over the years (Stevens, 2008; Ike & Lee, 2014). The oil and gas industry is highly concentrated; 2011’s top 10 companies, for example, delivered 43% of the world’s oil supply (Mitchell & Mitchell, 2014). From Table 1, it is evident that when the operational area is the focus, the extent to which multinationality has become an important issue in the oil and gas industry becomes obvious. Most of these top 10 oil firms are multinationals. On this list, only NIOC and PDV are not multinationals and both are state-owned.

### 3.3 Major trends in the oil and gas industry

This section presents highlights of major trends in the oil and gas industry, for the 10-year study period, which can possibly affect the dynamic productivity in the industry. Information presented here represents a synthesis of reviews from two main sources. The first source is the US Energy Information Administration's International Energy Outlook<sup>1</sup>. This is an annual report that provides a review of the immediately preceding year and provides projections for subsequent years. The second source is the annual report of the Organisation of the Petroleum Exporting Countries<sup>2</sup> (OPEC). As the foremost inter-governmental agency in the oil and gas industry, the review of this organisation should not go without notice.

2000: During this period, crude oil prices remained above \$25 per barrel influenced by disciplined adherence of OPEC member states to announced production cutbacks. However, oil companies were slow and reluctant to invest in major oil field development and refill of low inventories because of the fear of return to the low prices of 1998. On the other hand, oil consumption in 2000 rose by slightly less than a million barrels per day.

2001: Oil prices in 2001 were generally below the OPEC preferred rate (\$22-\$28). This was primarily as a result of loose adherence by some OPEC members to announced cutbacks in production. Also, increase in non-OPEC production begun to materialize. Energy markets in 2001 were also influenced by a host of developments, such as high world oil prices persisting from 2000 into the first parts of 2001 which then weakened substantially in the third quarter of the year. Also, there was a global economic slowdown which was led by a mild recession in the United States; and the aftermath of

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<sup>1</sup> EIA (2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012)

<sup>2</sup> OPEC (2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012)

the September 11 terrorist attacks on the United States. Finally, world oil demand growth continued to be extremely sluggish during this year.

2002: In 2002, oil prices were within the OPEC preferred range. The global economy had been slowly recovering from the near-recession conditions the previous year, achieving 2.9% growth as compared to the 2.4% growth in 2001. OPEC states also demonstrated disciplined adherence to announced production cutbacks. However, in 2002, there was a drastic reduction in Venezuela's oil exports because of a general strike against the Chavez regime. Oil price volatility was worsened because of fears of a US-led war in Iraq. Indeed world oil prices rose by almost \$10 per barrel. This low supply and fear of war in Iraq resulted in price volatility and uncertainty in the market and the so-called war premium began to push prices higher.

2003: Generally, oil prices remained near the top of the OPEC preferred prices because of disciplined adherence to announced production cutbacks. Strike in Venezuela, possibility of internal conflicts in Nigeria and the prospects for a return to normalcy in the Iraq oil sector remained uncertain exacerbating price volatility. Although there were signs of renewed global economic strength throughout 2003, geo-political uncertainties and impact of the outbreak of SARS in Asia caused energy markets to be unsettled throughout the year. The Venezuelan strike, for example, effectively removed some 2 million barrels per day from the market thereby raising the risk of a supply shortfall at a critical time when US commercial stocks had fallen significantly, and the northern hemisphere was experiencing colder temperatures.

2004: 2004 saw strong economic growth in emerging economies resulting in increased oil demand. Oil prices, on the other hand, averaged about \$30 per barrel with prices remaining high well into 2005. This was a period that once again demonstrated the

complexity, sensitivity and unpredictability of the oil market. The year saw oil prices rise to previously unanticipated levels as a result of a combination of factors which was led primarily by a sudden surge in demand, particularly in Asia and US. Together with this were refining and distribution bottlenecks, which caused problems in the downstream and the heightened geopolitical tensions. Finally, even the weather wrecked some damages with hurricanes in the Americas causing havoc to oil production installations in the US Gulf of Mexico.

2005: High demands in China and US and geo-political tensions in some major oil producing countries resulted in crude oil futures prices exceeding \$60 per barrel in 2005. War in Iraq and uncertain prospects for a return to normalcy in Iraq's oil sector as well as prospects of unrest in Nigeria and Venezuela contributed to volatility in world oil markets. Global markets were well supplied with crude oil, with inventory levels of commercial stocks rising significantly. Also cardinal in 2005, was the steady global economy growth recovery from the slowdown witnessed in the second half of 2004.

2006: In 2006, the international oil market experienced further progress in adjusting to the new set of circumstances. The global economy exhibited strong growth in most major world oil producing regions in 2006. Despite monetary tightening, higher oil and commodity prices, as well as geo-political tensions, the world economy was successful in achieving a rate of growth of 5.4%, compared to the 4.8% growth in 2005.

2007: Averagely, world oil prices in all years since 2003 have been higher than the average for 2006. However, real prices in 2007 were nearly double that of 2003. Oil prices further rose into the third quarter of 2008, reaching \$147 per barrel in mid-July. Factors causing the rapid oil price increment since 2003, included strong growth in demand of Asia and the Middle East, coupled with no growth in production of OPEC states

between 2005 and 2007. This was primarily because of rising costs of oil exploration and development, due to a weaker U.S. dollar. Geo-political tensions, refinery outages, weather related problems and the activities of speculators all contributed to the 2007 market volatility. However, the global economy performed well, achieving a 5.2% rise.

2008: The global recession of 2008-2009 reduced world energy consumption. No other year since the great depression has the foundations of the global economy been shaken as it did in 2008. As the months went by, so did the global economy continue to get worse, with serious impact on the oil market, whose distinctive feature for most of the year was price volatility. By the middle of the year, oil prices soared to heights that were not only unimagined, but also, unsustainable. Prices, however, later came under unprecedented downward pressure as the financial crisis continued to sweep the world causing a contraction in global oil demand for the first time since 1983.

2009: Global economic recession that began in 2008 continued into 2009. This had a profound impact on world income and energy use. After the 4.9% annual expansion during the 2003 to 2007 period, worldwide GDP growth slowed to 3.0% in 2008 and further contracted by 1.0 percent in 2009. Energy use slowed by 1.2% in 2008 and then declined by an about 2.2% in 2009. Although the recession appeared to have ended by the end of year, the pace of economic recovery was uneven, with China and India leading and Japan and the European Union member countries lagging. On the supply side, many oil projects that were delayed during the second half of 2008 had not yet been revived. This notwithstanding, 2009 closed on a more positive note, with stronger than expected growth in emerging economies, such as China and India, and with most countries in the OECD region gradually emerging from the recession.

2010: 2010 was a time of relative stability in the international oil market, after the turbulence and uncertainties of 2008-2009 which was brought about by the financial sector meltdown and global recession. Oil prices rose as a result of growth in demand associated with signs of economic recovery and a lack of a sufficient supply response. Oil prices increased from about \$82 per barrel at the end of November 2010 to over \$112 per barrel on April 8, 2011. At the end of 2010 and into 2011, prices were driven even higher, as social and political unrest unfolded in several Middle Eastern and African economies. 2011 turned out to be much stronger than expected in terms of oil consumption. This was as a result of a good recovery by the world economy. Unprecedented government support to improve economic growth after the 2009 recession provided enough momentum for this recovery. This level of growth turned out to be around twice as high as previously forecast.

### **3.4 Conclusion**

The purpose of the chapter is to provide insights into how the industry operates and the major trends in the industry. Consequently, the value chain, major players in the industry, major issues of environmental concern as well as trends in the 10-year period of this study are all provided.

## **CHAPTER FOUR**

### **METHODOLOGY**

#### **4.0 Introduction**

The chapter explains the processes adopted for data collection and analysis as well as the estimation techniques employed. It specifically presents the research design, the data sources, sampling procedure as well as the methods used in the analysis. It provides more elaboration on how to estimate dynamic productivity using both the traditional Malmquist productivity change index and the biennial Malmquist index. These techniques are part of a broad range of literature in management science, operations management and economics used in evaluating efficiency of business units.

#### **4.1 Research design**

In this study, the quantitative approach to research is used since it allows for objective testing of theories by examining the relationship among variables which can be measured and analysed using statistical or mathematical procedures (Creswell, 2008). All statistical inferences are drawn using a panel data, thereby allowing the assessment of the changes in productivity over time within the industry. This also allows for generalization and replication of research findings necessary for policy formulation (Wooldridge, 2013). An experimental research design is adopted since the aim of this study is to investigate differences within and among the samples by manipulating or controlling for some variables (Creswell, 2012; Hair, Black, Babin, Anderson, & Tatham, 2006). Finally, a positivist or scientific paradigm guides the data collection and analysis procedure. Positivism is an objective theory verification paradigm that collects data to support or refute theory so that all necessary revision can be made (Creswell, 2008; Fisher, 2010).

## 4.2 Sampling and sources of data

The research sample comprises both national (state) and international (private) oil companies globally. Oil companies may be involved in either one or both of two industry segments - upstream and downstream segments. Whereas upstream deals with the exploration and extraction of oil and gas reserves, the downstream is more about processing or refining, distribution and marketing sides of the value chain. Most of the oil companies undertake value creating business activities in both upstream and downstream segments and hence are sometimes labelled as integrated oil companies. They are selected because they control both the upstream and downstream segments of the industry (Sueyoshi & Goto, 2012b). They have been the subject of most efficiency-related studies in the oil industry.

The source of data for this study is the annual rankings of Energy Intelligence's Petroleum Intelligence Weekly (PIW). Fifty (50) integrated oil companies globally are selected annually by PIW based on 6 operational characteristics namely: oil reserves; gas reserves; oil production; gas production; product sales; and refining capacity (Energy Intelligence, 2013; Wolf, 2009). In addition, net income, total assets, number of employees and percentage of government ownership are included in a very comprehensive dataset. The primary focus of the ranking is to permit meaningful comparisons of all types of oil companies whether state-owned or otherwise (Energy Intelligence, 2013). It must be noted that this is the source of data for many efficiency-related studies that focus on the efficiency of oil companies in the oil industry including Ike and Lee (2014), Wolf (2009) and Eller et al. (2011). This is the preferred data source since all firms on this list are internationally known firms with several years of active participation in the oil and gas industry (Sueyoshi & Goto, 2012a). In addition, these firms have been consistent in their performance over the past decade (Ike & Lee, 2014). A 10-year dataset from 2001 to 2010 is sampled for the study. This is primarily based on data availability.

### **4.3 Dynamic productivity estimation models**

#### **4.3.1 The Malmquist index**

The assessment of frontier efficiency and productivity of DMUs started with the prominent works of Debreu (1951), Koopmans (1951) and Shephard (1953). In a multiple-input, multiple-output framework, efficiency means obtaining the maximum outputs from a given a set of inputs, or reducing inputs while maintaining the current output levels (Banker et al., 1984). This definition of efficiency is for technical or productive or managerial efficiency (Farrell, 1957). Farrell (1957) defined input oriented technical efficiency in terms of the most radial reduction in inputs that is possible. In brief, efficiency and productivity change assessment involves identifying an efficient production boundary and then evaluating the efficiency or inefficiency of an input-output correspondence (representing an observed DMU) in relation to the constructed frontier. The estimation is performed using a parametric, econometric approach or nonparametric, mathematical programming approach (Berger & Humphrey, 1997; Coelli, Rao, O'Donnell, & Baltese, 2005; Fried, Lovell, & Schmidt, 2008). DEA, developed by Charnes, Cooper and Rhodes (1978) and extended by Banker et al. (1984) based on Farrell's (1957) work, is a nonparametric frontier technique that employs linear programming to evaluate the relative efficiency of homogeneous DMUs that use multiple inputs to generate multiple outputs, relative to an efficient, or a "best practice" frontier which envelopes the observed DMUs (Cooper, Seiford, & Zhu, 2011).

Since the seminal paper, there has been quite a number of methodological extensions and applications of DEA. One such advancement is the Malmquist Total Factor Productivity Index by Fare et al. (1992), an index used to evaluate change in resource use over time. Fare et al. (1992) merged the ideas of Farrell's efficiency assessment and the earlier work of Caves, Christensen and Diewert (1982) under the inspiration of Malmquist (1953). The Malmquist index has the merit of handling several inputs and outputs, with few assumptions and can be

decomposed into efficiency change (catching up) and technical change (frontier shift) components based on a constant returns to scale (CRS) assumption. The efficiency change component, or catching up effect, measures the change in technical efficiency of a DMU over time. Therefore, the changes in the productivity of the target DMU is attributable to management's efficient allocation of resources. The technical change or frontier shift component measures the effect of process or product innovation (Fare et al., 1994), that is, shifts in technology over time.

Assuming that for each time period  $t : 1, \dots, T$  and given that  $N$  oil companies at time  $t$  produce  $m$  non-negative outputs (denoted by  $y \in \mathfrak{R}_+^m$ ), using  $n$  non-negative inputs (denoted by  $x \in \mathfrak{R}_+^n$ ), the production possibility set (input-output combination set) can be defined as:

$$\psi^t = \{(x^t, y^t) \in \mathfrak{R}_+^{n+m} \mid x^t \text{ can produce } y^t\} \quad (1)$$

Assuming no output can be produced without inputs, ray unboundedness (constant returns to scale), monotonicity (strong free disposability) and convexity assumptions<sup>3</sup>, the output-oriented Farrell (1957) technical efficiency score,  $\phi_0^t(x^t, y^t)$ , of a given firm  $(x_o, y_o)$  at time  $t$  relative to frontier  $t$ , under constant returns to scale (CRS), can be computed by solving the following linear programming problem:

$$\begin{aligned} & \text{Max } \phi_0^t(x^t, y^t) \\ & \text{s.t} \\ & \sum_{j=1}^N \lambda_j^t x_{ij}^t \leq x_{i0}^t \quad \forall i = 1, 2, \dots, n \\ & \sum_{j=1}^N \lambda_j^t y_{rj}^t \geq \phi y_{r0}^t \quad \forall r = 1, 2, \dots, m \\ & \lambda_j^t \geq 0 \quad \forall j = 1, 2, \dots, N \end{aligned} \quad (2)$$

<sup>3</sup> Details of these assumptions of DEA can be found in Banker and Thrall (1992), Färe and Primont (1995) as well as Fried et al. (2008).

Where  $\phi_0^t(x^t, y^t)$  is the output-oriented efficiency score that measures the proportional increment in the output of a DMU necessary to be efficient given the level of input. Note that  $\phi_0^t(x^t, y^t) \geq 1$  if and only if  $(x^t, y^t) \in \psi^t$ , also,  $\phi_0^t(x^t, y^t) = 1$  if and only if  $(x^t, y^t)$  is on the frontier of the technology set (Fare et al., 1994). Note that this model is formulated using the CRS assumption. It can be reformulated on a variable returns to scale assumption by adding a third constraint  $\sum_{j=1}^N \lambda_j = 1$  to the model. A DMU is inefficient when  $\phi > 1$ . Notice here that the output-oriented Farrell efficiency score is greater than 1 for inefficient firms since it measures the ratio of expected output to current output. The inverse of this is the Shepard distance function, which expresses the output-oriented efficiency in the more logical manner from 0 to 1, where 1 represents an efficient firm.

In order to define the Malmquist index there is the need to define efficiency scores with respect to two different time periods which would measure the maximum proportional change in outputs necessary to make  $(x^{t+1}, y^{t+1})$  efficient in reference to technology in  $t$ . The result,  $\phi_0^t(x^{t+1}, y^{t+1})$ , may be less than 1 since  $(x^{t+1}, y^{t+1})$  may not belong to  $\psi^t$ . The proportional change in output necessary to make  $(x^{t+1}, y^{t+1})$  efficient in relation to the technology in time  $t+1$  can also be denoted as  $\phi_0^{t+1}(x^{t+1}, y^{t+1})$ . The Malmquist index according to Caves et al. (1982) with reference to the technology in time period  $t$  can, therefore, be defined as:

$$MPI_0^t = \frac{\phi_0^t(x^t, y^t)}{\phi_0^t(x^{t+1}, y^{t+1})} \quad (3)$$

A similar Malmquist index for the adjacent period can be defined in relation to the technology of time period  $t+1$  as:

$$MPI_0^{t+1} = \frac{\phi_0^{t+1}(x^t, y^t)}{\phi_0^{t+1}(x^{t+1}, y^{t+1})} \quad (4)$$

In order to make sense of these two indices, Fare et al. (1992) proposed a geometric mean of the two indices as the means of avoiding arbitrary values of the productivity change index. This can be expressed as:

$$MPI_0(x^t, y^t, x^{t+1}, y^{t+1}) = \left[ \frac{\varphi_0^t(x^t, y^t)}{\varphi_0^t(x^{t+1}, y^{t+1})} \times \frac{\varphi_0^{t+1}(x^t, y^t)}{\varphi_0^{t+1}(x^{t+1}, y^{t+1})} \right]^{\frac{1}{2}} \quad (5)$$

The expression in equation (5) requires that three different efficiency scores be computed in addition to that expressed in (2). These can be computed with reference to equations (6), (7) and (8):

$$\begin{aligned} & \text{Max } \varphi_0^{t+1}(x^t, y^t) \\ & \text{s.t} \\ & \sum_{j=1}^N \lambda_j^{t+1} x_{ij}^{t+1} \leq x_{i0}^t \quad \forall i = 1, 2, \dots, n \\ & \sum_{j=1}^N \lambda_j^{t+1} y_{rj}^{t+1} \geq \varphi y_{r0}^t \quad \forall r = 1, 2, \dots, m \\ & \lambda_j^{t+1} \geq 0 \end{aligned} \quad (6)$$

$$\begin{aligned} & \text{Max } \varphi_0^{t+1}(x^{t+1}, y^{t+1}) \\ & \text{s.t} \\ & \sum_{j=1}^N \lambda_j^{t+1} x_{ij}^{t+1} \leq x_{i0}^{t+1} \quad \forall i = 1, 2, \dots, n \\ & \sum_{j=1}^N \lambda_j^{t+1} y_{rj}^{t+1} \geq \varphi y_{r0}^{t+1} \quad \forall r = 1, 2, \dots, m \\ & \lambda_j^{t+1} \geq 0 \end{aligned} \quad (7)$$

$$\begin{aligned} & \text{Max } \varphi_0^t(x^{t+1}, y^{t+1}) \\ & \text{s.t} \\ & \sum_{j=1}^N \lambda_j^t x_{ij}^t \leq x_{i0}^{t+1} \quad \forall i = 1, 2, \dots, n \\ & \sum_{j=1}^N \lambda_j^t y_{rj}^t \geq \varphi y_{r0}^{t+1} \quad \forall r = 1, 2, \dots, m \\ & \lambda_j^t \geq 0 \end{aligned} \quad (8)$$

Equations (2) and (7) are known as own-period efficiency scores since they examine an input-output combination relative to the technology in the same year. This score will always be equal to or greater than 1 since they refer to the same year's frontier. Equations (6) and (8) are called cross-period or mixed-period efficiency scores. Cross-period efficiency scores can be equal to, less than or greater than 1. Note that cross-period scores less than 1 represent “super-efficiencies”, which means they are more than just strictly efficient. Using the Fare et al. (1994) decomposition, the Malmquist index in equation (5) can be further decomposed into efficiency change and technical change components by rewriting the  $MPI_0(x^t, y^t, x^{t+1}, y^{t+1})$  as:

$$MPI_0(x^t, y^t, x^{t+1}, y^{t+1}) = \underbrace{\left[ \frac{\varphi_0^t(x^t, y^t)}{\varphi_0^{t+1}(x^{t+1}, y^{t+1})} \right]}_{\text{Efficiency Change}} \times \underbrace{\left[ \frac{\varphi_0^{t+1}(x^{t+1}, y^{t+1})}{\varphi_0^t(x^{t+1}, y^{t+1})} \times \frac{\varphi_0^{t+1}(x^t, y^t)}{\varphi_0^t(x^t, y^t)} \right]^{\frac{1}{2}}}_{\text{Technical Change}} \quad (9)$$

A proof that the  $MPI_0(x^t, y^t, x^{t+1}, y^{t+1})$  in equations (5) and (9) are equivalent can be found at Appendix C. Whereas the efficiency change component (EC) measures productivity change attributable to managerial acumen, the technical change (TC) component is as a result of changes in the total industry technology (Tortosa-Ausina et al., 2008) depicting the impact of process or product innovation. Since the best practice technologies may exhibit variable returns to scale (VRS), it is desirable to redefine both components to see what is left over, and to see if what is left over can be given a meaningful economic interpretation (Lovell, 2003). The EC of Equation (9) can, therefore, be further decomposed into a pure efficiency change (PEC) and scale change (SEC) components with reference to the VRS ( $v$ ) and CRS ( $c$ ) frontiers as:

$$EC_0(x^t, y^t, x^{t+1}, y^{t+1}) = \underbrace{\left[ \frac{\varphi_{0v}^t(x^t, y^t)}{\varphi_{0v}^{t+1}(x^{t+1}, y^{t+1})} \right]}_{\text{Pure Efficiency Change}} \times \underbrace{\left[ \frac{(\varphi_{0v}^t(x^t, y^t) / \varphi_{0c}^t(x^t, y^t))}{(\varphi_{0v}^{t+1}(x^{t+1}, y^{t+1}) / \varphi_{0c}^{t+1}(x^{t+1}, y^{t+1}))} \right]}_{\text{Scale Change}} \quad (10)$$

The PEC component is the part of the efficiency (or inefficiency) truly attributable to management production decisions. The SEC however measures the effect of changes in the size of the firm on dynamic productivity of the firm. With the Malmquist index (and all its components) defined in this section, since Farrell efficiency scores are used in an output-oriented model, a Malmquist index less than 1 represents retrogression from time period  $t$  to time period  $t+1$ . But, progress is represented by values greater than 1. Consequently, productivity change is said to have stagnated if the decision-making unit records an index of 1. It should be noted that there have been several other methodological advancement to the traditional Malmquist index proposed (Lovell, 2003; Pastor & Lovell, 2005).

To illustrate the proposed technique for dynamic productivity, assume, in Table 2, a two-year hypothetical data of five different oil companies is provided. The output is thousands of barrels of crude oil produced per day (Y) by each company, whereas the input is millions of barrels of oil reserves (X).

**Table 2: Hypothetical Data of Oil Companies**

Firm	Year	DMU	X	Y
Anadarko		A1	1	2
BHP Billiton		B1	2	4
CNPC	ONE	C1	4	4
Devon		D1	4	3
ENI		E1	2	2
Anadarko		A2	3	3
BHP Billiton		B2	4	4.5
CNPC	TWO	C2	4	5
Devon		D2	6	3
ENI		E2	4	2

Source: Author (2015)

For a one-input-one-output case, the oil firms can be easily depicted in Figure 5, together with the CRS and the VRS frontiers, both in periods 1 and 2. Note that whereas the frontiers for period 1 are depicted using solid lines, that for period two are illustrated using dashed lines.

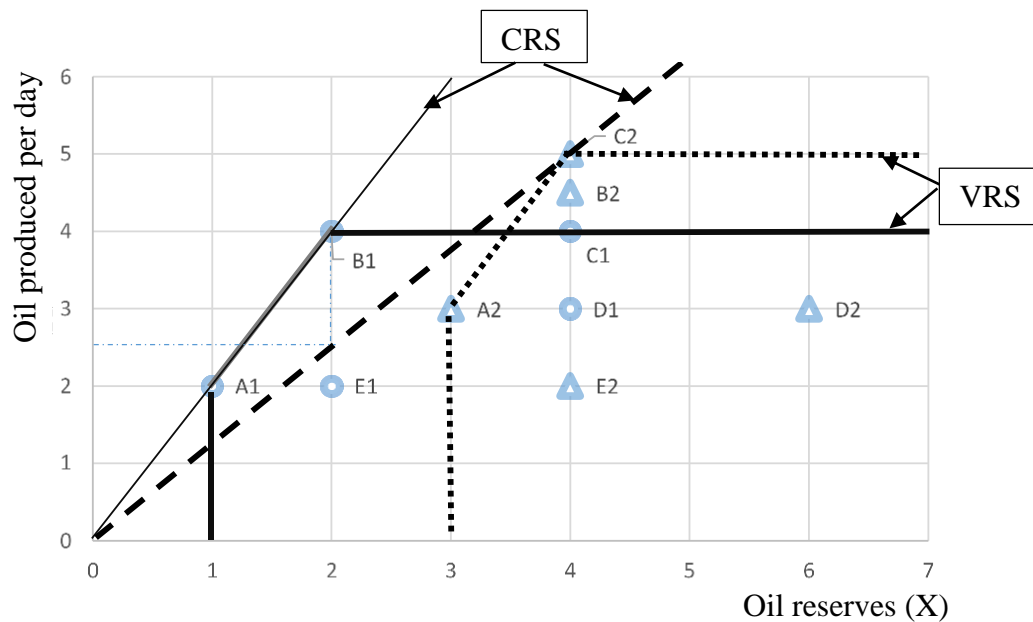


Figure 5: VRS and CRS Production Frontiers

Source: Author (2015)

Notice also that whereas firms in year 1 are represented by round bullets, the same firms in year 2 are represented by triangular bullets. The linear programming (LP) model to find the output efficiency of BHP Billiton (the subscript B) in year 1 (the superscript 1), relative to year 1 frontier (technology, represented by the left-hand-side of the equation) can be formulated based on the general model in Eqn. 2 as:

$$\begin{aligned}
 & \text{Max } \varphi_B^1(x^1, y^1) \\
 & \text{s.t} \\
 & \lambda_A + 2\lambda_B + 4\lambda_C + 4\lambda_D + 2\lambda_E \leq 2 \\
 & 2\lambda_A + 4\lambda_B + 4\lambda_C + 3\lambda_D + 2\lambda_E \geq 4\varphi_B^1 \\
 & \lambda_j \geq 0
 \end{aligned}$$

$$\Rightarrow \varphi_B^1(x^1, y^1) = 1$$

This model is formulated based on CRS assumption. It can be reformulated using a VRS assumption by introducing the convexity assumption:  $\lambda_A + \lambda_B + \lambda_C + \lambda_D + \lambda_E = 1$ . The result of this model, as can also be read from Figure 5,  $\varphi_B^1(x^1, y^1) = 4/4 = 2/2 = 1$ , shows that BHP Billiton (B) is efficient given its input-output combination in year 1 and considering how every other firm in the same year is performing. The three other LP models defined in Eqn 6, Eqn 7 and Eqn 8, for BHP Billiton can be formulated as follows:

$$\begin{aligned}
 & \text{Max } \varphi_B^2(x^1, y^1) \\
 & \text{s.t} \\
 & 3\lambda_A + 4\lambda_B + 4\lambda_C + 6\lambda_D + 4\lambda_E \leq 2 \\
 & 3\lambda_A + 4.5\lambda_B + 5\lambda_C + 3\lambda_D + 2\lambda_E \geq 4\varphi_B^1 \\
 & \lambda_j \geq 0
 \end{aligned}$$

$$\Rightarrow \varphi_B^2(x^1, y^1) = 0.625$$

$$\begin{aligned}
 & \text{Max } \varphi_B^2(x^2, y^2) \\
 & \text{s.t} \\
 & 3\lambda_A + 4\lambda_B + 4\lambda_C + 6\lambda_D + 4\lambda_E \leq 4 \\
 & 3\lambda_A + 4.5\lambda_B + 5\lambda_C + 3\lambda_D + 2\lambda_E \geq 4.5\varphi_B^1 \\
 & \lambda_j \geq 0
 \end{aligned}$$

$$\Rightarrow \varphi_B^2(x^2, y^2) = 1.11$$

$$\begin{aligned}
 & \text{Max } \varphi_B^1(x^2, y^2) \\
 & \text{s.t} \\
 & \lambda_A + 2\lambda_B + 4\lambda_C + 4\lambda_D + 2\lambda_E \leq 4 \\
 & 2\lambda_A + 4\lambda_B + 4\lambda_C + 3\lambda_D + 2\lambda_E \geq 4.5\varphi_B^1 \\
 & \lambda_j \geq 0
 \end{aligned}$$

$$\Rightarrow \varphi_B^1(x^2, y^2) = 1.78$$

Each of these scores can be estimated using the frontiers in Figure 5. Since all efficiencies are measured using an output orientation, the efficiency of an oil firm would be measured by the proportion by which the output of the firm can be increased without altering the current input level. This is measured by the distance between a firm and the nearest vertical distance to the frontier. Note that, the horizontal distance to the frontier can also be used in an input-oriented context. The CRS own-period efficiency score for B1 ( $\phi_B^1(x^1, y^1)$ ) can be estimated with reference to CRS frontier in period one as 1 (i.e. 4/4). On the other hand, the cross-period efficiency score of B1 ( $\phi_B^2(x^1, y^1)$ ) can be computed with reference to the frontier in period two as 0.625 (i.e. 2.5/4). For the output-oriented DEA model, a score less than 1 represents super-efficiency. This means that the firm is outside the production frontier. Therefore, only cross-period efficiencies can be super-efficient. When the VRS frontier is used, the cross-period or inter-temporal output efficiency score of B1 (i.e. B1 relative to frontier 2) is infeasible since a strictly vertical or output-oriented projection from B1 to frontier two, is not bounded by period two frontier.

The Malmquist productivity index and its components for BHP Billiton can therefore be estimated, using Eqn 9 as:

$$\begin{aligned}
 MPI_B(x^1, y^1, x^2, y^2) &= \underbrace{\left[ \frac{1}{1.11} \right]}_{\text{Efficiency Change}} \times \underbrace{\left[ \frac{1.11}{1.78} \times \frac{0.625}{1} \right]^{\frac{1}{2}}}_{\text{Technical Change}} \\
 MPI_B(x^1, y^1, x^2, y^2) &= 0.90 \times 0.62 \\
 MPI_B(x^1, y^1, x^2, y^2) &= 0.56
 \end{aligned}$$

This shows that BHP Billiton has retrogressed by 44% (i.e.  $(1 - 0.56) \times 100$ ) from its previous year's performance. Although it experienced regress due to management inefficiencies

(efficiency change = 0.90), the major cause of its regress was because it could not keep up with changes in overall technology of the industry (technical change = 0.56).

#### **4.3.2 Biennial Malmquist**

The measurement of productivity change using the Malmquist index was first introduced by Caves et al. (1982), based on the earlier work of Malmquist (1953). Fare et al. (1992), however, situated the Malmquist productivity index in DEA. The work of Fare et al. (1994) also provided insights into how to decompose the index into two factors - “efficiency change” or catch-up effect and “technical change” or frontier shift effect. This was, however, strictly based on a CRS assumption. Subsequent methodological advancements have further decomposed the efficiency change factor into “scale change” and “pure efficiency change” (Fare et al., 1994). Whereas the pure efficiency change component measures the part of efficiency change truly attributable to management decisions, the scale change component assesses efficiency changes attributable primarily to the size of the business operations. Computing the scale change requires that both CRS and VRS assumptions are considered (Essid, Ouellette & Vigeant, 2014; Balk, 2001). However, there may be infeasibilities in the LP solution when mixed-period or cross-period or inter-temporal efficiencies are computed under the VRS assumption since the observed input-output combination lies outside the frontier for the previous period (Ray & Desli, 1997; Wheelock & Wilson, 1999). This problem of infeasibilities is much more pronounced if the Ray and Desli (1997) decomposition is used. However, the same problem is implicit in the Fare et al (1994) and other decompositions (Pastor et al., 2011).

One solution to this problem is to use only the DMUs that have optimal solutions, thereby losing important information through infeasibilities (Xue & Harker, 2002). An alternative solution which avoids LP infeasibilities under VRS is to use one of the three proposed VRS

based Malmquist indices that can handle infeasibilities (Pastor et al., 2011). These are the sequential Malmquist (Shestalova, 2003), global Malmquist (Pastor & Lovell, 2007) and the biennial Malmquist (Pastor et al., 2011). However, whereas the sequential Malmquist index precludes measurement of technical regress (Shestalova, 2003), the global Malmquist, albeit transitive/circular, requires that the index is recalculated each time an additional time period is added to the sample (Asmild & Tam, 2007; Pastor et al., 2011). Although the biennial Malmquist index of Pastor et al. (2011) lacks the axiom of transitivity (like the sequential and adjacent Malmquist indices), it overcomes the shortfalls of these other two indices. It is therefore able to allow for technical regress and does not need to be recomputed when a new time period is added to the data set (Pastor et al., 2011). The basic idea here is, therefore, to generate a separate biennial frontier that will envelop all observations from all time periods, thereby side-stepping the issues of LP infeasibilities. The biennial CRS Malmquist index (with subscript  $c$ ) can be computed with reference to a biennial technology set that combines both time periods  $((x^t, y^t, x^{t+1}, y^{t+1}) \in \psi^B)$ . This can be expressed as:

$$BMPI_c(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{\varphi_c^B(x^t, y^t)}{\varphi_c^B(x^{t+1}, y^{t+1})} \quad (11)$$

Note that since the biennial frontier encapsulates both time periods unlike the traditional Malmquist index, there is no need to use the geometric mean in the definition (Pastor et al., 2011). This is because the reference frontier for both periods is the same biennial frontier. Equation (11) can be remodelled in reference to a VRS frontier by changing the subscript  $c$  to  $v$ . The biennial VRS Malmquist index is defined as:

$$BMPI_v(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{\varphi_v^B(x^t, y^t)}{\varphi_v^B(x^{t+1}, y^{t+1})} \quad (12)$$

Which can be further decomposed, using Ray and Desli's (1997) three factor decomposition, into the biennial pure efficiency change (BPEC), the biennial pure technical change (BPTC) components, and the biennial scale change (BSEC) components. As with the traditional adjacent period Malmquist index, the biennial efficiency change component is defined as:

$$BPEC_v(x^t, y^t, x^{t+1}, y^{t+1}) = \left[ \frac{\varphi_v^t(x^t, y^t)}{\varphi_v^{t+1}(x^{t+1}, y^{t+1})} \right] \quad (13)$$

The technical change component can be seen as the ratio of the BMPI in (12) and EC in (13).

This is the left over efficiency defined as:

$$\begin{aligned} BTC_v(x^t, y^t, x^{t+1}, y^{t+1}) &= \frac{BMPI_v(x^t, y^t, x^{t+1}, y^{t+1})}{EC_v(x^t, y^t, x^{t+1}, y^{t+1})} = \frac{\varphi_v^B(x^t, y^t) / \varphi_v^B(x^{t+1}, y^{t+1})}{\varphi_v^t(x^t, y^t) / \varphi_v^{t+1}(x^{t+1}, y^{t+1})} \\ &= \left[ \frac{\varphi_v^{t+1}(x^{t+1}, y^{t+1})}{\varphi_v^B(x^{t+1}, y^{t+1})} \times \frac{\varphi_v^B(x^t, y^t)}{\varphi_v^t(x^t, y^t)} \right] \end{aligned} \quad (14)$$

It is clear by comparing the last part of (14) to the technical change component of (9) that, there are little differences in how the two are computed. The BTC in (14) maintains all own-period efficiency scores like (9), however, the cross-period scores are rather computed in relation to the constructed biennial frontier. In addition, since the biennial frontier combines both periods, there is no need for a geometric mean in the definition of the BTC. BSEC index can also be computed as:

$$\begin{aligned} BSEC &= \frac{BMPI_c}{BMPI_v} = \frac{\varphi_c^B(x^t, y^t) / \varphi_v^B(x^t, y^t)}{\varphi_c^B(x^{t+1}, y^{t+1}) / \varphi_v^B(x^{t+1}, y^{t+1})} \\ &= \left[ \frac{\varphi_c^B(x^t, y^t)}{\varphi_v^B(x^t, y^t)} \times \frac{\varphi_v^B(x^{t+1}, y^{t+1})}{\varphi_c^B(x^{t+1}, y^{t+1})} \right] \end{aligned} \quad (15)$$

Using the same hypothetical data of 5 oil companies used in the previous section, the biennial frontier can be illustrated in Figure 6. The solution to this problem of VRS infeasibilities is to construct a biennial (global) VRS frontier that envelopes both period one and period two

frontiers, as illustrated in Figure 6. The biennial VRS frontier is the bold dashed-grey convex frontier that envelopes both frontiers of periods one and two.

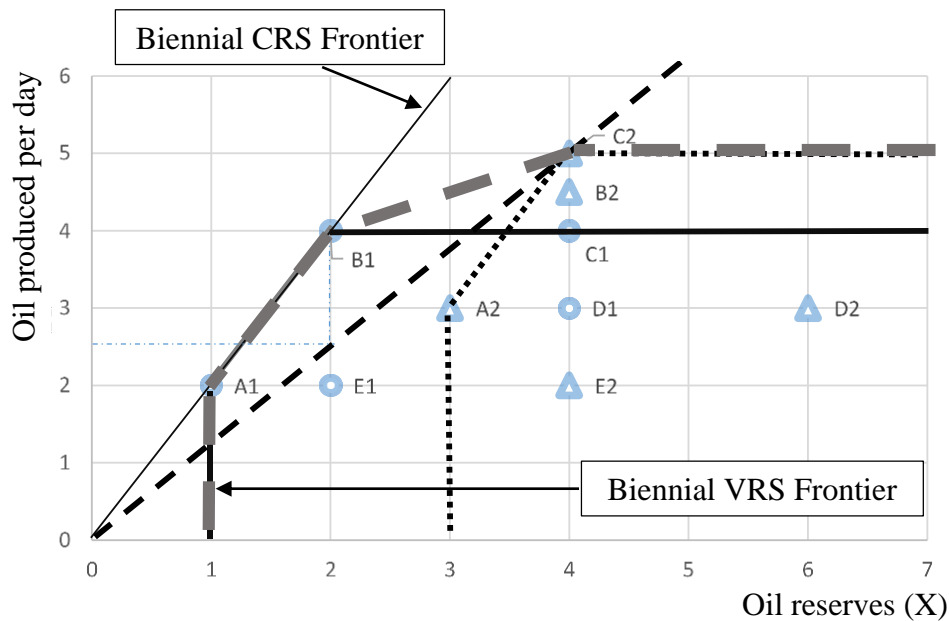


Figure 6: Biennial VRS and CRS Production Frontiers of Firms

Source: Author (2015)

By this, the cross-period frontier for B1 can be computed with reference to the biennial frontier since this now envelopes its own-period frontier as well (unlike the traditional Malmquist VRS frontier). The cross-period efficiency for B1 would therefore be 1 (i.e. 4/4). This can be formulated using LP as:

$$\text{Max } \varphi_{v,B1}^B(x^1, y^1)$$

s.t

$$1\lambda_{A1} + 3\lambda_{A2} + 2\lambda_{B1} + 4\lambda_{B2} + 4\lambda_{C1} + 4\lambda_{C2} + 4\lambda_{D1} + 6\lambda_{D2} + 2\lambda_{E1} + 4\lambda_{E2} \leq 2$$

$$2\lambda_{A1} + 3\lambda_{A2} + 4\lambda_{B1} + 4.5\lambda_{B2} + 4\lambda_{C1} + 5\lambda_{C2} + 3\lambda_{D1} + 3\lambda_{D2} + 2\lambda_{E1} + 2\lambda_{E2} \geq 4\varphi_B^1$$

$$\lambda_{A1} + \lambda_{A2} + \lambda_{B1} + \lambda_{B2} + \lambda_{C1} + \lambda_{C2} + \lambda_{D1} + \lambda_{D2} + \lambda_{E1} + \lambda_{E2} = 1$$

$$\lambda_j \geq 0$$

$$\Rightarrow \varphi_{v,B1}^B(x^1, y^1) = 1$$

Using notations in equation (12) the biennial VRS Malmquist index can be computed for DMU B as:

$$BMPI_v(x^t, y^t, x^{t+1}, y^{t+1}) = \phi_v^B(x^t, y^t) / \phi_v^B(x^{t+1}, y^{t+1}) = (4 / 4) \div (5 / 4.5) = 0.90.$$

### 4.3.3 Bootstrapping the Malmquist index

The Malmquist index by Fare et al. (1992) relies on four different deterministic DEA scores which lack statistical underpinnings (Simar & Wilson, 1999). DEA estimates are biased and are affected by the uncertainty resulting from sample variations (Gitto & Mancuso, 2012). Also, measuring such efficiency scores relies on relative efficiency since the true production frontier is unknown (Simar & Wilson, 2000). The solution to these problems is the use of the bootstrapping technique in DEA assessment proposed by Simar and Wilson (1998, 1999). In its simplest form, the bootstrap involves randomly selecting thousands of pseudo samples (using simple random sampling with replacement) from an observed set of sample data. The aim is to obtain the statistical properties of such efficiency scores including the means, medians, standard deviations, and confidence interval estimates.

Simar and Wilson (1999) have proposed bootstrapping algorithm for giving statistical properties to Malmquist productivity index and its components. This algorithm estimates confidence intervals for the indices and allows researchers to determine whether changes in productivity are real or statistically significant or merely due to chance (Simar & Wilson, 1999). The algorithm<sup>4</sup> of bootstrap Malmquist differs from that of the normal efficiency scores because of the inherent time dependencies in the estimation of Malmquist indices (Murillo-Melchor, Pastor, & Tortosa-Ausina, 2009). Unlike the bootstrap algorithm for the static DEA models, bootstrapping Malmquist indices requires that the effect of changes in time is

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<sup>4</sup> The bootstrapping algorithm for Malmquist Productivity Indices has been summarized following Simar and Wilson (1999) in Appendix D.

incorporated into the estimation. The underlining idea here is to approximate the sampling distribution of  $\hat{MPI}_i(x^t, y^t, x^{t+1}, y^{t+1})$  (the true unknown indices) of  $MPI_i(x^t, y^t, x^{t+1}, y^{t+1})$  through a DGP to obtain the bootstrap estimates  $\hat{MPI}_{*,i}(x^t, y^t, x^{t+1}, y^{t+1})$  (Gitto & Mancuso, 2012). The bias corrected estimates  $\hat{MPI}_i(x^t, y^t, x^{t+1}, y^{t+1})$  can be computed by:

$$\begin{aligned}\hat{MPI}_i^{t,t+1} &= MPI_i(x^t, y^t, x^{t+1}, y^{t+1}) - \hat{bias}_B[MPI_i(x^t, y^t, x^{t+1}, y^{t+1})] \\ &= 2MPI_i(x^t, y^t, x^{t+1}, y^{t+1}) - B^{-1} \sum_{b=1}^B \hat{MPI}_{*,i}(x^t, y^t, x^{t+1}, y^{t+1})\end{aligned}\quad (16)$$

Where  $B$  is the number of bootstrap samples which must be large (i.e.  $B \rightarrow \infty$ ). Simar and Wilson (1998, 1999, 2007) recommend the use of 2000 bootstrap samples. Bias correction introduces some additional noises that leads to the standard errors of the bias corrected estimates being larger than that of the original productivity change index (Essid et al., 2014). As such, Simar and Wilson (1998, 1999) postulate that bias correction can be made if the sample variance of the bootstrap scores is less than a third of the squared bootstrap bias estimates of the original scores. This is expressed as:

$$\sigma_{*,i}^2 < \frac{1}{3} \left( \hat{bias}_B[MPI_i(x^t, y^t, x^{t+1}, y^{t+1})] \right)^2 \quad (17)$$

Generating the bootstrap samples would also aid in the construction of confidence intervals for the dynamic productivity indices. This is achieved by sorting the bootstrap scores in ascending order and deleting  $((\alpha/2) \times 100)$  – percent of the elements at either ends of the sorted array, and then setting  $-b_\alpha^*$  and  $-a_\alpha^*$  equal to the endpoints of the resulting array (Simar & Wilson, 1999). The range of the  $(1 - \alpha)$  – percent confidence interval is therefore:

$$MPI_i(x^t, y^t, x^{t+1}, y^{t+1}) + a_\alpha^* \leq \hat{MPI}_i(x^t, y^t, x^{t+1}, y^{t+1}) \leq MPI_i(x^t, y^t, x^{t+1}, y^{t+1}) + b_\alpha^* \quad (18)$$

This shows the range of confidence within which the true dynamic productivity index is likely to fall. This interval can also be used for hypothesis test to see if the change in productivity is significant or merely due to chance. The estimate of Malmquist index is said to be significantly different from unity (no productivity change) if the confidence interval in Eqn. (18) does not include unity, however, the Malmquist index is said to not have significantly changed if the confidence interval includes unity (Simar & Wilson, 1999; Simon, Simon, & Arias, 2011; Essid et al., 2014). Finally, the same conditions presented in this section exist for bootstrapping any component of the Malmquist productivity change index.

#### **4.4 Model inputs and outputs**

DEA efficiency scores are sensitive to the quality of inputs and outputs used in the model (Coelli et al., 2005; Dyson, Allen, Camanho, Podinovski, Sarrico, & Shale, 2001). It is important to clearly define the inputs and outputs that would be used in the study. This is because appropriate selection of inputs and outputs ensures validity of efficiency estimates (Barros & Assaf, 2009). Three inputs and two outputs are selected in the measurement model. These are presented in Table 3. It is evident that these are the most widely accepted and used variables in efficiency and productivity change assessment in the oil industry.

##### **4.4.1 Outputs**

Oil and gas production, the end products of drilling activities, have been widely used as appropriate measures of upstream production activities. Physical production is the main driver of revenue and hence profits (Wolf, 2009). Therefore, maximizing production levels is an indication of better performance. All oil and gas producing firms have a goal of maximizing their oil and gas production in order to meet the growing demands, especially as oil and gas prices are determined by the market. Firms have the ability to directly regulate output quantities

not the prices of their products. Therefore, production, as measured in barrels and cubic feet, would be appropriate measures of not only managerial choice using best practice technology by a particular firm, but also, that of the entire market. In addition, under common law rule of capture, property rights to oil are recognized only when extracted (Kim & Mahoney, 2005). This means that an oil firm's true output cannot be measured under common law unless the resource in the soil is extracted. Therefore production quantities are the true measure of output of such firms.

The use of revenue as the measure of output may be preferred, since crude oil and gas production measured in quantities do not capture the effects of forcing NOCs to subsidize domestic energy prices (Eller et al., 2011). However, using revenue biases the efficiencies of NOCs as they are subject to home-country pricing regulations. Finally, it is also important to note that oil and gas outputs measured in quantity are more likely to be correctly measured and reported, as compared to financial revenue figure by most companies (Ike & Lee, 2014). Therefore, whereas oil outputs are measured in millions of barrels, natural gas outputs are measured in billion cubic feet. By industry standards, oil outputs comprise crude oil production, oil condensate and natural gas liquids produced at the end of each year (Anadarko, 2013; Apache, 2013). For gas outputs, natural gas production in an accounting year is its measure.

#### **4.4.2 Inputs**

The aim of this study is to assess how management of various categories of oil companies are able to convert inputs into valuable outputs. The quality and appropriateness of inputs used in the study is as important as the sophistication of any estimation technique employed in DEA study (Coelli et al., 2005). Three inputs were chosen in this study: total oil proved reserves, natural gas proved reserves and labour size are employed in all DEA estimations. The choice of these was mainly based on literature.

#### ***4.4.2.1 Oil and gas proved reserves***

Reserves represent quantities of liquids or hydrocarbons which have been proven, with reasonable certainty, by analysis of geoscience and engineering as commercially recoverable from known reservoirs under defined economic conditions, operation methods and government regulation (OPEC, 2013). Proved reserves comprise both proved developed and proved undeveloped reserves of companies. Current year reserves are estimated as the sum of last year's end of year reserves, extensions, discoveries and additions in current year and purchases of already in place resources. Current year production levels and sales of properties are subtracted from this value to get an estimate of proved reserves. During the year, there may be revisions of the previous year's estimates which may be positive or negative depending on the results of geoscience and engineering estimations (Apache, 2013). Upstream reserves are important components of the total assets of oil companies (Wolf, 2009; Eller et al., 2011). Oil and gas reserves are used as the main input proxy for material inputs necessary for producing oil and gas respectively. Proved reserves are used since they are the most certain oil and gas resource category recoverable (EIA, 2014).

#### ***4.4.2.2 Labour***

Labour is an important factor in microeconomic theory of production. It is an essential element in generating outputs. It is a major constituent of the total expenditure of many enterprises (Coelli et al., 2005). In this study, the widely used number of employees in the oil industry is used, instead of the alternative value of wages and salaries paid during the accounting year. This is because the number of employees is not biased by wage differentials across countries as well as the possibility of wages and salaries reported in a particular year containing some amount carried forward from previous years (Coelli et al., 2005).

**Table 3: Summary of Inputs and Outputs**

	<b>Variable</b>	<b>Unit of Measurement</b>	<b>Empirical Applications</b>
<b>Outputs</b>	$y_1$ : Oil Outputs	Thousands of barrels per day ('000 b/d)	Sueyoshi and Goto (2012a, 2012b), Kashani (2005a), Barros and Managi (2009), Barros and Assaf (2009), Al-Obaidan and Scully (1991, 1993, 1995), Thompson et al. (1996), Managi, et al. (2006), Francisco et al. (2012), Ike and Lee (2014)
	$y_2$ : Gas Outputs	Million cubic feet of natural gas per day (MMcf/d)	Sueyoshi and Goto (2012a, 2012b), Kashani (2005a), Barros and Managi (2009), Barros and Assaf (2009), Thompson et al. (1996), Managi, et al. (2006), Ike and Lee (2014)
<b>Inputs</b>	$x_1$ : Oil Reserves	Millions of barrels (MMBbls)	Sueyoshi and Goto (2012a, 2012b), Thompson et al. (1996), Managi, et al. (2006), Eller et al. (2011), Ike and Lee (2014)
	$x_2$ : Gas Reserves	Billion cubic feet (Bcf)	Sueyoshi and Goto (2012a, 2012b), Thompson et al. (1996), Managi, et al. (2006), Eller et al. (2011), Ike and Lee (2014)
	$x_3$ : Labour	Number of employees	Sueyoshi and Goto (2012a, 2012b), Hawdon (2003), Al-Obaidan and Scully (1991, 1993, 1995), Eller et al. (2011), Ike and Lee (2014)

Source: Author (2015)

#### 4.5 DEA estimation considerations

In this study, output orientation is selected for all estimations. With output orientation, the focus is to maximize outputs at given levels of inputs. A firm is seen to be more efficient if it produces the maximum possible output using the given levels of inputs. This is not new in the oil and gas efficiency-related-literature since Barros and Assaf (2009), Ike and Lee (2014) and

Eller et al. (2011) have all adopted output orientation. In this industry where cost of operation and expenditures vary across countries, it becomes imperative that an output orientation is used (Ike & Lee, 2014). In addition, in an industry where higher priority is mainly given to the ability of a firm to meet demands (Zhou et al., 2008), the output orientation is preferred.

In productivity assessment, an unbalanced panel will be used in estimations. Malmquist indices require that efficiency results in adjacent periods are compared. This is sometimes incorrectly interpreted to be a requirement that the data must be of a balanced panel nature (Hollingsworth & Wildman, 2003). As a result, some firms that are part of the technology are removed in the estimations in order to achieve a balanced panel. However, Kerstens and Woestyne (2014) and in a slightly different context, Asmild and Tam (2007), have noted that the use of a strictly balanced panel ignores a significant proportion of information. Therefore, all oil firms in the sample will be included in the production possibility set. Still, Malmquist productivity indices will only be computed for such firms if they have scores for at least two adjacent periods. This use of an unbalanced panel data for the estimation of the Malmquist index can be seen as an added contribution of this study since the majority of authors, excluding Kerstens and Woestyne (2014), tend to wrongly only use a balanced panel thereby disregarding potentially useful information from the efficiency and productivity change analysis.

#### **4.6 Instruments for data analysis**

Data used in the study are analysed using both basic descriptive and advanced inferential statistics like t-test and its nonparametric equivalents. All statistical results are generated using R version 3.1.3 in conjunction with the Benchmarking package version 0.24 (Bogetoft & Otto, 2011) and Frontier Efficiency Analysis with R (FEAR) version 2.0.1 package by Wilson

(2008). In addition, MaxDEA Pro 6.4b software was used for mainly confirmatory purposes and estimation of the biennial Malmquist indices.

#### **4.7 Conclusion**

In this chapter clarity was given to the scientific processes and assumptions adopted in this study. Quantitative, experimental and positivist ideologies are employed in analysing secondary data sourced from the Energy Intelligence Petroleum Intelligence Weekly database. Further explanations of the dynamic productivity estimation techniques are given. Both the traditional adjacent Malmquist and the biennial Malmquist indices, as well as their components, are presented. Finally, all inputs and outputs selected in this study and other DEA estimation assumptions employed have been fully explained and justified.

## CHAPTER FIVE

### DATA ANALYSES AND DISCUSSION OF FINDINGS

#### 5.0 Introduction

In this chapter, the results of the data analyses are presented in a logical manner. Discussions supported by both empirical and theoretical arguments are also presented with a view to drawing inferences from these results. By implication, all research objectives are independently addressed using the necessary statistical methods in this chapter.

#### 5.1 Description of data

Data for this study was sourced from Energy Intelligence's Petroleum Intelligence Weekly database. It is composed of state (i.e. NOCs) and privately (i.e. IOCs) controlled firms. They are further separated on a location basis; an important operations management concept. These include: firms that operate in more than one country (multinationals); and those who operate in only one country (locals). This data has wide geographic coverage, sampling firms headquartered in all 6 continents of the world which is another cross-country contribution of this study. In all, the observations cover the period from 2001 to 2010. To better understand the dynamics of the data, a contingency table of firms grouped by their ownership types and operational locations has been presented in Table 4.

**Table 4: Contingency Table of Ownership Type and Operational Location**

			Ownership Type		Total
			NOC	IOC	
Location	Local	<i>N</i>	145	39	184
		<i>% Ownership</i>	78.8%	21.2%	100.0%
		<i>% Operation</i>	62.5%	15.9%	38.5%
	Multinational	<i>N</i>	87	207	294
		<i>% Ownership</i>	29.6%	70.4%	100.0%
		<i>% Operation</i>	37.5%	84.1%	61.5%
Total	<i>N</i>	232	246	478	
	<i>% Ownership</i>	48.5%	51.5%	100.0%	
	<i>% Operation</i>	100.0%	100.0%	100.0%	

Table 4 shows four main patterns in the nature of the sample. First, there are similar proportions of NOCs and IOCs. Although 48.5% of the observations are NOCs and 51.5% IOCs, there is no significant difference in these two proportions, since a binomial test indicated that the proportion of NOCs of  $0.49$  was not lower than the expected  $0.50$ ,  $p = 0.552$  (two tailed). This therefore shows approximately equal involvement of both government and private oil firms in this industry. Governments are actively competing with private corporations for the benefits of this industry. Second, there appears to be more multinationals than local firms in this industry. Evidently, 61.5% of the firms are multinationals whereas only 38.5% are locals. This evidence clearly backs the view that *multinationality* is an important concept in the oil industry. Third, relatively more NOCs operate locally than IOCs. Out of the entire number of local firms, as many as 78.8% are NOCs compared with the remaining 21.2% being IOCs. Similarly, a look at the entire number of NOCs clearly shows that 62.5% of state controlled oil companies operate locally. This shows there is opportunity for state firms to go multinational if that proves beneficial. Finally, most private firms are more multinational than local. 70.4% of the 294 multinationals are IOC. Similarly, as many as 84.1% of the 246 IOCs are multinationals.

As productivity estimations are sensitive to the nature of the variables used in modelling, it is important to first describe the data. Inappropriate conclusions may be drawn if appropriate variables, in appropriate scales of measurement are not selected for the estimation (Dyson et al., 2001). This is to ensure that they conform to preliminary axioms required for a valid estimation. Summary statistics of the two outputs and three inputs used in this study are presented in Table 5. The mean, standard deviation, and number of samples for each variable based on the pooled data of the 10 years are shown, together with the maximums and minimums to gauge the range.

**Table 5: Summary Statistics of Variables Used (Pooled)**

		<b>Oil Output (<sup>'000</sup> b/d)</b>	<b>Gas Output (MMcf/d)</b>	<b>Oil Reserves (MMBbls)</b>	<b>Gas Reserves (Bcf)</b>	<b>Employees (Number)</b>
		<b>Y1</b>	<b>Y2</b>	<b>X1</b>	<b>X2</b>	<b>X3</b>
Pooled	Mean	1263.68	3950.61	19638.8	88289	84333.5
	Max	11035	53772	296501	1320000	1668642
	Min	21	69	61	420	1358
	SD	1576.46	7370.98	47090.1	207681	183467
	N	478	478	478	478	478
<b><i>Ownership:</i></b>						
IOC	Mean	891.95	3252.39	4539.74	26451.4	50060.8
	SD	777.56	4916.18	4236.8	117531	48203
NOC	Mean	1657.84	4690.97	35649	153858	120674
	SD	2046.31	9245.94	63715.7	256949	253899
<b><i>Operation:</i></b>						
Local	Mean	1311.22	2202.41	29006.1	128476	69340.1
	SD	1176.58	2347.11	45656.9	253183	77712.1
Multinational	Mean	1233.93	5044.72	13776.2	63138.2	93717.2
	SD	1782.97	9049.28	47100.7	168915	225382
Time	F-stat	0.085	0.068	0.164	0.038	0.319
Ownership <sup>a</sup>	t-stat	-5.35**	-2.11*	-7.42**	-6.90**	-4.17**
Operation <sup>b</sup>	t-stat	0.57	-5.12**	3.51**	3.10**	-1.7

\* $p < .10$ . \*\* $p < .05$ . \*\*\* $p < .01$ .

<sup>a</sup> Test of difference between state (NOC) and private (IOC) firms

<sup>b</sup> Test of difference between multinationals and locals

In Table 5, it is evident that the size of the range between the maximum and minimum values for each variable is high signifying that even the top oil companies used in this study have varying sizes. This is fully buttressed by the extent of the deviation from the sample means. The mean of oil outputs of 1,263.68 thousand barrels per day, has a standard deviation of 1,576.46. An annual summary statistics of the data has been attached in Appendix E. A look at the annual data shows not much differences over the years. Table 5 also shows some preliminary tests of differences in the samples. The F-statistic of a one way Anova test conducted to check for differences of variables across time showed no significant differences in the dataset over time. This shows that the oil industry has been quite stable for the 10 years under study with little variations in the general production and employment levels for this period.

Two other tests of differences were also conducted. A test of differences between state (NOCs) and privately (IOCs) controlled oil companies reveal significant differences across all inputs and outputs. NOCs control significantly more oil ( $M=35648.95$ ,  $SD=63715.70$ ) and gas ( $M=153859.19$ ,  $SD=256948.64$ ) reserves than the oil ( $M=4539.74$ ,  $SD=4236.80$ ) and gas ( $M=26451.39$ ,  $SD=117530.89$ ) reserves of IOCs. For employment levels, NOCs employ significantly higher average number of workers ( $M=120674$ ,  $SD=253899.03$ ) than the average of 50061 ( $SD=48203.02$ ) persons employed by IOCs. This picture is no different when it comes to outputs since for both outputs, NOCs out-perform IOCs. This shows that although it seems NOCs use more inputs compared to IOCs, this translates into more outputs levels than their private counterparts. Eller et al (2011) observed that state firms employ a relatively larger workforce, not necessarily for their commercial objectives. Rather, political pressure may be the cause of such large personnel numbers. For the reserves, state firms have been seen to dominate proven reserves and crude oil exports (Stevens, 2008), therefore their larger shares of oil and gas reserves are not surprising. Another observation which is consistent with the

literature reviewed is the higher production levels of such state firms. Eller et al. (2011) believe that, state firms shift exploration and production from future towards present, probably for present day political benefits. While it is possible that this over-employment of inputs may be offset by their increased production levels thereby reducing inefficiencies, it is also very possible that these higher inputs employed may make state firms too large to be optimal in their operations.

When the location of operation is the focus, evidence available show that there are significant differences in the averages for all variables employed except oil outputs and number of employees. For the oil outputs, there is no significant difference ( $t\text{-stat} = 0.57, p = .57$ ) between the average pooled outputs of multinationals ( $M=1233.93, SD=1782.97$ ) and locals ( $M=1311.22, SD=1176.58$ ). Multinationals, however, significantly produce more gas outputs ( $t\text{-stat} = -5.12, p = .00; M=5044.72, SD=9049.28$ ) than locals ( $M= 2202.41, SD=2347.11$ ). This shows that multinationals produced relatively more outputs than their local counterparts. An interesting observation is made when the input side of the picture is carefully assessed. Apart from employment levels where multinationals and local firms employ statistically similar average levels ( $t\text{-stat} = -1.70, p = .09$ ), locals use significantly more of all other inputs employed in this study. Local firms possess more oil and gas reserves, yet their oil and gas outputs are not better than that of multinationals. Using more inputs to produce less outputs is a major indication of inefficiency. It is therefore expected that multinationals may out-perform locals.

Table 6 presents a correlation matrix of all inputs and outputs used in this study. In nonparametric frontier analysis, the test of correlation between inputs and outputs is required as a precondition for robust analysis. This is to test the isotonicity property of DEA which requires that all inputs show a positive association with outputs (Cooper, Seiford, & Zhu, 2011; Thanassoulis, 2001).

**Table 6: Correlation Matrix of Inputs and Outputs**

	Oil Output	Gas Output	Oil Reserves	Gas Reserves	Employees
Oil Outputs	1				
Gas Outputs	.134**	1			
Oil Reserves	.850**	.089	1		
Gas Reserves	.284**	.651**	.375**	1	
Employees	.161**	.269**	.030	.145**	1

\*\*  $p < 0.01$

From Table 6, since all inputs show a significantly positive association with both outputs, the isotonicity property of DEA which requires that an output should not decrease with an increase in an input (Dyson et al., 2001; Honma & Hu, 2008; Wanke, Barros, & Faria, 2015), is not violated. The weak correlation among the inputs also signals the discriminatory power of the variables employed (Dyson et al., 2001).

## 5.2 Dynamic productivity in the international oil industry

The first objective of this study is to determine the dynamic productivities of oil firms and to determine the source of the change using bootstrapped Malmquist dynamic productivity indices. The goal is to ascertain whether productivity in the oil and gas industry is progressing, stagnating or retrogressing. The index is a biannual index that estimates productivity growth between two adjacent time periods. The yearly averages of the estimated productivity indices are shown in Table 7 as “MPI”. Geometric means are used since DEA efficiency estimates are ratios and can be skewed. Table 7 also shows the bias of each estimate and the bias corrected Malmquist productivity indices as “MPI\*”. The 95 percent confidence intervals also shown in the table indicate the statistical significance of the productivity indices.

**Table 7: Average Productivity <sup>a</sup>**

Period	MPI	Bias	MPI*	95% Confidence Interval	
				LB	UB
2001 - 2002	1.00	-0.0036	1.01	0.95	1.05
2002 - 2003	1.16	-0.0036	1.16***	1.09	1.23
2003 - 2004	0.98	0.0046	0.98	0.93	1.04
2004 - 2005	1.04	-0.0021	1.04**	1.00	1.08
2005 - 2006	1.01	-0.0048	1.02	0.98	1.06
2006 - 2007	0.97	0.0024	0.97	0.94	1.01
2007 - 2008	0.98	-0.0011	0.98	0.94	1.03
2008 - 2009	0.96	0.0048	0.96	0.92	1.01
2009 - 2010	1.03	0.0039	1.03*	1.00	1.07
<b>Geometric Average</b>	<b>1.014</b>		<b>1.014</b>	<b>0.97</b>	<b>1.06</b>

\* $p < .10$ . \*\* $p < .05$ . \*\*\* $p < .01$ .

<sup>a</sup> growth or decline is significant if confidence interval does not include 1

Preliminary results from Table 7, prior to any statistical consideration, show that the productivity of oil firms in the sample have progressed by an average of 1.4% (i.e.  $[1.014 - 1] \times 100$ ) annually during the sample period. This is primarily fuelled by periods of productivity growth in 2002-2003 (16% growth) and marginal growths in 2004-2005 (4%), 2005-2006 (1%) and 2009-2010 (3%). This notwithstanding, making statistical inferences via bootstrapping clearly show that the 1.4% average growth is not significant, and thereby more likely to have stagnated. This is because the confidence intervals contain the value one (Simar & Wilson, 1999; Tortosa-Ausina et al., 2008). Biannual estimates of productivity mostly showed stagnation for all periods except for 2002-2003, 2004-2005 and 2009-2010. The growth in 2002-2003 of 16% is the most significant growth in the industry during the period; this is followed by a 4% growth in 2004-2005 and 3% in 2009-2010. This is important since it shows that, although the average productivity for the entire period stagnated, productivity change in individual years differ.

The changes in the overall productivity of the oil industry can be explained in reference to trends in the oil and gas industry. In a period of loose adherence by OPEC members to announced production cutbacks in 2001, and a global slowdown led by a mild recession in US caused by the aftermath of September 11 2001 terrorist attacks, oil demands continued to be extremely sluggish (EIA, 2002; OPEC, 2002). The global economy experienced slow recovery in 2002. Although OPEC states demonstrated strict adherence to cutbacks, reduction in oil exports from Venezuela and fears of a US-led war in Iraq resulted in high oil prices (EIA, 2003). It is not surprising that there was stagnation in the industry from the Malmquist index for this period. However, between 2002 and 2003, there was significant productivity growth in the industry probably because of the high price environment caused by oil worker-strike in Venezuela, the possibility of internal conflicts in Nigeria and some other geopolitical uncertainties (EIA, 2004, OPEC, 2004). Oil firms may have been motivated to increase production levels because of the high prices. Productivity, however, fell between 2003 and 2004 probably because of supply bottlenecks in the downstream refining and distribution sectors and hurricanes causing havoc to oil production instalments in the US Gulf of Mexico (OPEC, 2005).

From 2004 to 2006, productivity growth were consistently recorded probably due to high oil demands in China and the US because of steady global economic growth in 2005 (EIA, 2007). In 2006, international oil markets further experienced progress due to much stronger economic growth in most major oil producing regions (EIA, 2007; OPEC, 2007). This notwithstanding, 2007 saw a decline in productivity which was sustained until end of 2009. In 2007, although there were high prices, there was no growth in crude production, especially among OPEC states (EIA, 2008). Coupled with this, the rising cost of oil exploration and development due to the weaker US dollar had a helping hand in the productivity regress (OPEC, 2008). 2008 came with much more pressure on productivity as the global economy succumbed to the 2008 great

depression. This resulted in reduced global energy consumption and contraction in economic growth and energy use. Indeed, many oil projects, which were delayed in 2008, were not revived in 2009 (EIA, 2010). Productivity growth was finally recorded from 2009 to 2010 due to the relative stability in the oil market during this period. Growth in oil demand was probably fuelled by government support at improving economic growth after the 2009 recessions (EIA, 2011).

Productivity estimates for the industry have also been categorised by proportions of firms that progressed, stagnated and retrogressed. This is to gather the average productivity estimates for firms in all three groups. Most importantly, this assessment provides a basis for understanding which group of firms caused the growth, stagnation or regress of the productivity for the particular period. These results are tabulated in Table 8.

**Table 8: Breakdown of Productivity Trends <sup>a</sup>**

Year	Progress		Regress		Stagnation	
	%	Mean	%	Mean	%	Mean
2001-2002	38.10	1.23	50.00	0.86	11.90	1.04
2002-2003	60.00	1.36	24.44	0.87	15.56	0.98
2003-2004	42.86	1.11	30.95	0.83	26.19	0.98
2004-2005	47.83	1.23	36.96	0.85	15.22	0.99
2005-2006	44.44	1.13	35.56	0.90	20.00	1.00
2006-2007	40.00	1.10	42.22	0.86	17.78	0.99
2007-2008	20.00	1.13	33.33	0.89	46.67	1.00
2008-2009	33.33	1.10	35.56	0.81	31.11	1.00
2009-2010	42.22	1.20	35.56	0.90	22.22	1.00
<b>Average</b>	<b>40.98</b>	<b>1.17</b>	<b>36.06</b>	<b>0.86</b>	<b>22.96</b>	<b>1.00</b>

<sup>a</sup> 95% confidence interval

Overall, although the average productivity of the sample has not significantly improved, relatively more firms in the industry experienced productivity growth. 40.98% of firms

experienced significant growth during this period. These firms experienced, on average, about 17% growth in productivity. This notwithstanding, their growth could not significantly improve the industry productivity since the proportion of firms who retrogressed and stagnated far outweighed those who experienced growth. 36.06% of the firms in the sample experienced significant productivity decline of 14% (i.e.  $[0.86 - 1] \times 100$ ), whereas 22.96% stagnated. Together, this accounts for 59.02% of the observations. Interestingly, in periods where a majority of firms significantly improved, the average productivity of the industry also improved. For example, in 2002-2003 where the industry experienced a significant progress, as many as 60% of the sample firms experienced an average statistically significant productivity improvement of 11%. A deeper understanding of the trends in the productivity of specific firms in the sample can be easily assessed by reference to the tables in Appendix F. This shows the biannual and the overall averages of the dynamic productivities of individual firms in the sample.

Although knowledge of the extent of productivity change in the industry for the sample period has been understood, what remains unknown is the cause of the productivity situation in the industry. Suitable explanations to this can be gained by decomposing the Malmquist productivity indices. Tables 9 and 10 show the two factor decomposition of the Malmquist index by Fare et al (1992). Whereas Table 9 shows the part of productivity attributable to managerial decisions- efficiency change (EC); Table 10 shows the part attributable to technological innovation in the industry - technical change (TC). Both tables include relevant statistical biases, the bias corrected scores for the efficiency change (EC\*) and Technical Change (TC\*), as well as the 95% confidence interval obtained through bootstrapping.

**Table 9: Average Efficiency Change**

Period			EC	Bias	EC*	95% Confidence Interval	
						LB	UB
2001	-	2002	0.95	-0.010	0.96	0.66	1.35
2002	-	2003	1.08	0.050	1.03	0.87	1.48
2003	-	2004	1.01	-0.040	1.05	0.78	1.23
2004	-	2005	1.02	-0.020	1.04	0.72	1.44
2005	-	2006	1.02	0.000	1.02	0.80	1.35
2006	-	2007	0.95	-0.040	0.99	0.71	1.18
2007	-	2008	0.97	-0.020	0.99	0.73	1.34
2008	-	2009	1.06	0.000	1.06	0.76	1.49
2009	-	2010	0.92	-0.030	0.95	0.68	1.21
<b>Geometric Average</b>			<b>1.00</b>		<b>1.01</b>	<b>0.74</b>	<b>1.34</b>

\* $p < .10$ . \*\* $p < .05$ . \*\*\* $p < .01$ .

**Table 10: Average Technical Change**

Period			TC	Bias	TC*	95% Confidence Interval	
						LB	UB
2001	-	2002	1.06	-0.020	1.08	0.75	1.50
2002	-	2003	1.07	0.100	0.97	0.79	1.31
2003	-	2004	0.97	0.030	0.94	0.82	1.24
2004	-	2005	1.02	-0.010	1.03	0.72	1.43
2005	-	2006	1.00	-0.030	1.03	0.76	1.26
2006	-	2007	1.03	0.030	1.00	0.84	1.35
2007	-	2008	1.01	-0.010	1.02	0.73	1.33
2008	-	2009	0.90	-0.030	0.93	0.65	1.25
2009	-	2010	1.12	0.020	1.10	0.87	1.51
<b>Geometric Average</b>			<b>1.02</b>		<b>1.01</b>	<b>0.77</b>	<b>1.35</b>

\* $p < .10$ . \*\* $p < .05$ . \*\*\* $p < .01$ .

Careful inspection of these two tables reveals that, the source of the overall productivity gain in the oil and gas industry was mainly due to improvements in overall technological innovation.

Technical growth of 2% per year on average could not be improved by efficiency growth by managers since efficiency change was stagnant (1.00). This 2% contribution is however not that different from 1 as statistical inference using bootstrapping reveals. Not surprisingly, in periods where significant productivity gains have been recorded, the main source of these gains has almost always been too close to call. In 2002-2003, for example, where 16% productivity gains were recorded, efficiency growth of 8% was almost equally matched by technical gains of 7%. Similar deductions can be made for the 2004-2005 and 2005-2006 periods. It was only in 2009-2010 that major disparities were observed. Although an efficiency decline of 8% was recorded, the technical growth of 12% was enough to offset this managerial lapses to improve the overall productivity in the industry by 3%. These results show that clearly the managerial innovation is not forthcoming in the oil industry. This notwithstanding, and most importantly, overall efficiency change did not at least retrogress. It seems management are still applying tried and tested production methods and processes which causes little or no change in their productivity. The situation, however, may differ for individual firms. Figure 7 graphically shows the trends in productivity in the oil and gas industry.

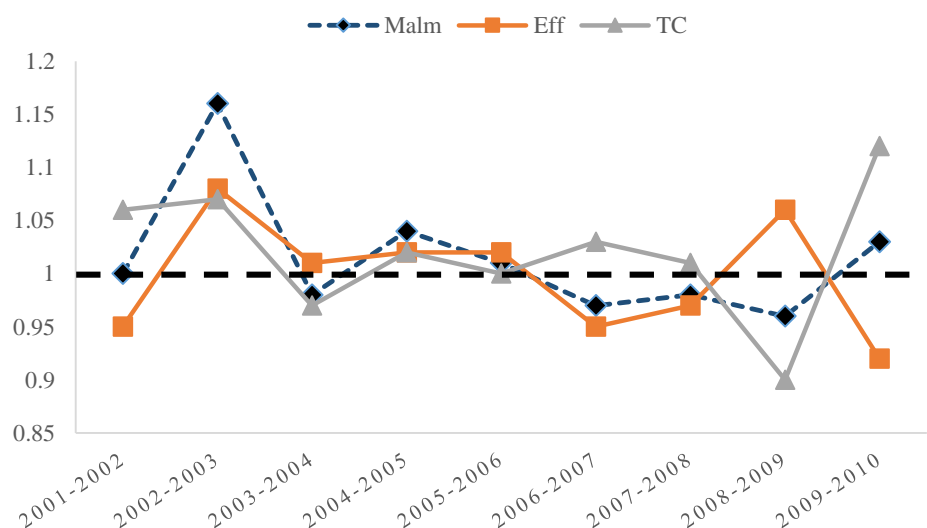


Figure 7: Trends in Productivity

Since managerial decision (efficiency change) is the focus here, it is important to observe that, managerial decision in dynamic productivity analyses can be further decomposed. Based on the Fare et al. (1994) decomposition, efficiency change can be attributable, in part, to how close the firm is getting to the optimal scale of operation over time (scale change –“SEC”) and its true ability to optimally allocate the various factors of production over time (pure efficiency change- “PEC”). These decompositions have been tabulated in Tables 11 and 12.

**Table 11: Average Scale Change**

Period			SEC	Bias	SEC*	95% Confidence Interval	
						LB	UB
2001	-	2002	0.98	-0.040	1.02	0.63	1.50
2002	-	2003	1.04	-0.010	1.05	0.80	1.37
2003	-	2004	1.04	-0.010	1.05	0.81	1.31
2004	-	2005	1.01	-0.010	1.02	0.67	1.47
2005	-	2006	1.02	0.000	1.02	0.78	1.36
2006	-	2007	0.97	-0.040	1.01	0.84	1.37
2007	-	2008	0.97	-0.030	1.00	0.69	1.32
2008	-	2009	1.06	0.020	1.04	0.73	1.59
2009	-	2010	0.92	-0.060	0.98	0.67	1.24
<b>Geometric Average</b>			<b>1.00</b>		<b>1.02</b>	<b>0.73</b>	<b>1.39</b>

\* $p < .10$ . \*\* $p < .05$ . \*\*\* $p < .01$ .

**Table 12: Average Pure Efficiency Change**

Period			PEC	Bias	PEC*	95% Confidence Interval	
						LB	UB
2001	-	2002	0.96	-0.030	0.99	0.62	1.52
2002	-	2003	1.04	0.030	1.01	0.81	1.46
2003	-	2004	0.97	-0.040	1.01	0.72	1.19
2004	-	2005	1.01	-0.060	1.07	0.60	1.56
2005	-	2006	1.00	-0.010	1.01	0.80	1.38
2006	-	2007	0.98	-0.040	1.02	0.72	1.28
2007	-	2008	1.00	-0.030	1.03	0.72	1.49
2008	-	2009	1.01	-0.050	1.06	0.65	1.50
2009	-	2010	0.99	-0.010	1.00	0.72	1.39
<b>Geometric Average</b>			<b>1.00</b>		<b>1.02</b>	<b>0.70</b>	<b>1.41</b>

\* $p < .10$ . \*\* $p < .05$ . \*\*\* $p < .01$ .

Estimates in Table 11 and Table 12 exhibit similar patterns. In most periods where average efficiency change fell (in Table 9), both scale and pure efficiency change also fell. However, comparison of the two Tables and Table 9, as well as observations from Figure 8, reveal that efficiency change to a large extent mostly mirrors scale changes.

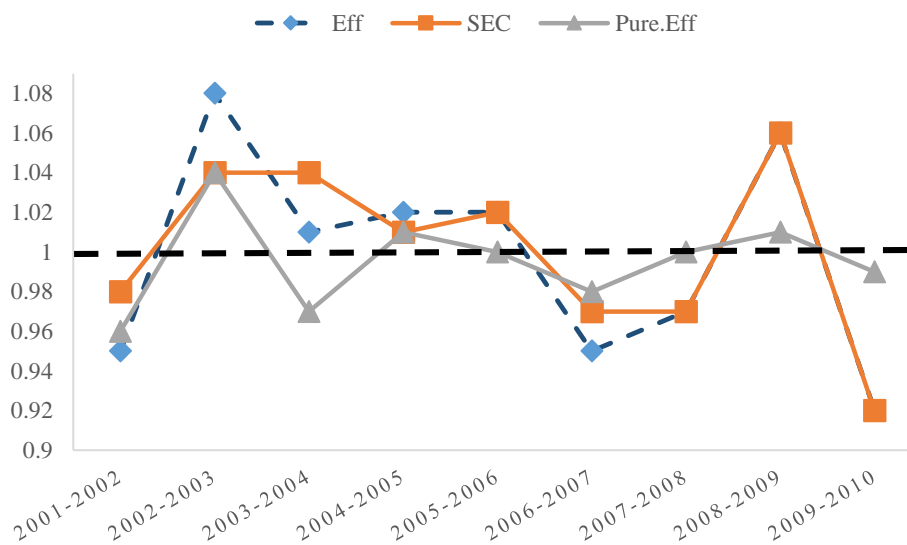


Figure 8: Trends in Frontier Shifts

Finally, rank correlation results, presented in Table 13, show that dynamic productivity is more associated with managerial decisions than technical change. That is, the relationship between managerial efficiency change and dynamic productivity (0.523,  $p$ -value < 0.01) is stronger than that between technical change and dynamic productivity (0.315,  $p$ -value < 0.01). Management needs to take advantage of this opportunity presented to be more innovative as this is more likely to lead to higher productivity over time. Another worthy point of note is that efficiency change (EC) is more strongly (0.771,  $p$ -value < 0.01) associated with scale change (SEC) than with pure efficiency change (0.548,  $p$ -value < 0.01). This shows that, the closer the oil and gas firm gets to its optimal scale of operation over time, the higher the likelihood it will lead to more managerial efficiency and hence overall dynamic productivity. This notwithstanding, managerial efficiency over time (PEC) is still paramount.

**Table 13: Spearman's Correlation of Productivity Indices**

	MPI	EC	TC	PEC	SEC
MPI	1				
EC	.523**	1			
TC	.315**	-.552**	1		
PEC	.543**	.548**	-.120*	1	
SEC	.242**	.771**	-.616**	0.081	1

\*  $p < 0.05$  \*\*  $p < 0.01$

### 5.3 Multinationality, ownership and efficiency in the international oil industry

This section assesses efficiency and dynamic productivity differences between oil companies classified based on ownership, location and both. This is to achieve the second objective of the study. Static DEA models would be used first. Here, technical or productive and scale efficiencies of each firm are computed. However, as a novelty, oil companies would also be compared using dynamic models. Static DEA models examine how well management are able to convert inputs into outputs. They reveal whether management of the firms have been able to produce the maximum possible output levels given certain levels of input, and whether there is capacity for improvements, all executed at a point in time. It therefore answers the question, “Which group is better?” For dynamic productivity, the focus is on whether the firm has improved from its production state between two time periods and hence provides an assessment of performance over time. Consequently, an inefficient firm in both year one and year two may be seen to have grown productively if its inefficiency in the second year is lower than its inefficiency in the first year. This answers the question, “Which group is growing faster?”

#### 5.3.1 Static efficiency comparisons

Since, in Table 5, no significant differences were observed for all variables there is justification to compute efficiencies for all firms using a pooled frontier. Therefore, efficiency scores estimated by reference to equation 2 are computed for all firms based on a pooled meta production possibility set that ignores the time dimension. Productive efficiencies on both a

VRS and CRS frontier are computed in order to estimate scale efficiencies (ratio of CRS efficiencies to VRS efficiencies) for each firm. Although output orientation is employed, the inverse of all measures is reported to allow for scores to be bounded by 0 and 1.

Therefore a firm is said to be efficient if its efficiency score is 1. Consequently, given two firms, the one with a higher score is a more efficient firm. Table 14 shows a summary of efficiency scores of the oil firms in the sample. In the table, scores estimated with CRS assumption are headed as “ceff” whereas that estimated in reference to a VRS frontier are headed “veff”. Scale efficiencies are headed “se”.

**Table 14: Average Productive Efficiencies of Firms (2001-2010)**

<b>Company</b>	<b>ceff</b>	<b>veff</b>	<b>se</b>	<b>Company</b>	<b>ceff</b>	<b>veff</b>	<b>se</b>
Adnoc	0.12	0.39	0.32	ONGC	0.43	0.59	0.73
Amerada Hess	0.76	0.78	0.97	PDO	0.57	0.74	0.77
Anadarko	0.73	0.80	0.92	PDV	0.29	0.54	0.53
Apache	0.75	0.83	0.91	Pemex	0.86	0.97	0.89
BG	0.80	0.83	0.96	Pertamina	0.32	0.40	0.79
BP	0.55	0.95	0.58	Petrobras	0.70	0.94	0.74
Burlington	0.92	0.97	0.95	Petro-Canada	0.91	0.96	0.94
Chevron	0.61	0.90	0.69	PetroChina	0.41	0.64	0.64
CNOOC	0.77	0.89	0.87	Petronas	0.31	0.72	0.43
CNPC	0.26	0.75	0.35	QP	0.50	0.62	0.81
CNR	0.89	0.95	0.94	Reliance	0.83	0.84	0.98
ConocoPhillips	0.58	0.86	0.68	Repsol	0.81	0.83	0.98
Devon Energy	0.86	0.92	0.93	Rosneft	0.25	0.40	0.63
Ecopetrol	0.77	0.81	0.95	Royal Dutch Shell	0.69	0.96	0.72
EGPC	0.39	0.43	0.92	Saudi Aramco	0.87	0.93	0.93
El Paso Energy	1	1	1	Sibneft	0.62	0.66	0.94
EnCana	0.91	0.96	0.95	Sidanco	0.10	0.18	0.58
Eni	0.59	0.76	0.78	Sinopec	0.72	0.80	0.89
ExxonMobil	0.52	0.98	0.53	Slavneft	0.27	0.36	0.74
Gazprom	0.54	0.96	0.56	Socar	0.12	0.14	0.81
INOC	0.11	0.36	0.31	Sonatrach	0.41	0.90	0.45
Inpex	0.86	0.87	0.99	SPC	0.25	0.32	0.78
Kazmunaigas	0.35	0.41	0.85	Statoil	0.88	0.91	0.97
KPC	0.67	0.79	0.85	Suncor	0.85	0.85	1.00

*ceff- CRS Efficiencies; veff – VRS Efficiencies, se – Scale Efficiencies*

*Table 14 (Continued)*

<b>Company</b>	<b>ceff</b>	<b>veff</b>	<b>se</b>	<b>Company</b>	<b>ceff</b>	<b>veff</b>	<b>se</b>
Libya NOC	0.28	0.51	0.55	Surgutneftegas	0.40	0.51	0.78
Lukoil	0.36	0.52	0.69	Talisman Energy	1	1	1
Marathon	0.76	0.78	0.98	Tatneft	1	1	1
NIOC	0.19	0.65	0.29	TNK-BP	0.79	0.81	0.98
NNPC	0.51	0.77	0.66	Total	0.55	0.77	0.72
Norsk Hydro	0.82	0.83	0.99	Tyumen Oil	0.51	0.56	0.90
Novatek	0.97	0.98	0.99	Unocal	0.77	0.78	0.99
Occidental	0.73	0.85	0.86	Uzbekneftegas	0.50	0.97	0.51
OMV	0.57	0.57	1.00	Yukos	0.60	0.75	0.80

*ceff*- CRS Efficiencies; *veff* – VRS Efficiencies, *se* – Scale Efficiencies

Oil firms can be generally segregated into state and privately-owned ones. However, even among the state firms, there is a sub-category of those owned by countries who are members of the OPEC. In this sample, they include Adnoc, KPC, Libya NOC, NIOC, NNPC, PDV, QP, Saudi Aramco and Sonatrach. In Table 14, most of these OPEC NOCs are among the least performing firms. For example, out of all the firms in the sample, Adnoc is the least efficient firm when a constant scale of operation is assumed (0.12). Libya NOC, NIOC, PDV and Sonatrach are among some of the least performing firms on the CRS assumption. Although their positions seem to improve when variable returns to scale is assumed, relative to the other firms, they are still among the least performing ones. They are also no better in operating at an optimal scale. NIOC (0.29), INOC (0.31) and Adnoc (0.32), for example, are the least scale efficient firms. This is consistent with the findings of Ike and Lee (2014) and Wolf (2009) who saw that OPEC NOCs are the worst performers because production quotas have adverse impacts on their efficiencies. This is probably because these firms may not be producing at their optimal capacities because of production restrictions imposed by OPEC. This does not mean that all OPEC NOCs are bad; a few observed very high scores. Saudi Aramco, KPC, NNPC and QP have been relatively good performers over the years.

On the other side of the table, the major IOCs (BP, Chevron, ExxonMobil, Royal Dutch Shell and Total) have been consistently among the best performing firms in the oil industry. All but Total Petroleum had VRS scores above 0.90. Even Total's score of 0.77 ranks high relative to most OPEC NOCs. The dominance of the major IOCs on the frontier is also not surprising since Stevens (2008) and Ike and Lee (2014) have previously documented their high performance. There are several other categories of oil companies being assessed in this study. Table 15 presents averages of the scores of all other categorizations of interest. Both nonparametric and parametric statistical tests of difference are also reported. DEA estimates have non-normal distributions and hence, nonparametric statistics are suitable. However, parametric test have been included for robustness checks.

**Table 15: Summary of Productive Efficiencies**

	ceff			veff		se	
	N	Mean	Median	Mean	Median	Mean	Median
<b>Ownership</b>							
IOC	246	0.69	0.69	0.83	0.87	0.84	0.90
NOC	232	0.48	0.45	0.67	0.70	0.71	0.73
Mann-Whitney		42228.5***		39358.5***		38409.5***	
T-test		10.12***		8.13***		7.41***	
<b>Location</b>							
Multinational (M)	294	0.66	0.67	0.83	0.87	0.80	0.83
Local (L)	184	0.48	0.42	0.62	0.63	0.74	0.78
Mann-Whitney		15852***		13314.5***		23660**	
T-test		-7.86***		-10.41***		-2.71***	
<b>Ownership and Location</b>							
LNOC	145	0.43	0.39	0.59	0.62	0.70	0.73
LIOC	39	0.64	0.69	0.70	0.71	0.89	0.95
MNOC	87	0.56	0.53	0.79	0.81	0.72	0.74
MIOC	207	0.70	0.70	0.85	0.89	0.83	0.88
Kruskal Wallis		97.46***		97.40***		47.44***	
Anova		43.34***		49.45***		19.93***	

\* $p < .10$ . \*\* $p < .05$ . \*\*\* $p < .01$

The first hypothesis tests whether differences exist between productive and scale efficiencies of state and private firms. As expected, at the 1% significance level, private firms (IOCs) significantly out-performed their state counterpart (NOCs) on all measures of efficiency. IOCs are 21% significantly more productively efficient than NOCs ( $t\text{-stat} = 10.12, p < 0.01$ ) when scale is constant and 16% more efficient ( $t\text{-stat} = 8.13, p < 0.01$ ) when variable scale is assumed. Private firms, on average, are also able to manage their scale of operations 13% better than their state counterparts ( $t\text{-stat} = 7.41, p < 0.01$ ). Therefore H1a and H1b are both supported.

Focus on operational location, for the second hypothesis, also reveals expected outcomes. Multinationals significantly out-perform local firms on all three types of efficiency scores. Multinationals, irrespective of ownership status, enjoy 21% more variable productive efficiencies than local firms ( $t\text{-stat} = -10.41, p < 0.01$ ). Although locals are only 6% less scale efficient than multinationals, this difference is significant ( $t\text{-stat} = -2.71, p < 0.01$ ). These dynamics can be better understood using the kernel density plots of the distribution of VRS efficiency scores and scale efficiencies based on location and ownership as presented in Figure 9. This way, a sense of which groups drive the structure of the distributional efficiency levels can be ascertained. Nonparametric kernel-based density estimates, which is basically a smoothed histogram of the actual efficiency levels, are used here because they are also nonparametric just like the efficiency scores. Evidence of multimodality are observable. The fact that most part of the distribution of efficiencies of multinationals is above that of locals in most cases, as in the upper panel of the figure, shows that multinationals out-perform local firms in terms of both pure managerial and scale efficiency. Similarly, efficiency distributions indicate that private firms (IOCs) out-performed their state counterparts (NOCs). The former gather greater probability mass on the right tail suggesting that a greater number of the private

oil firms were located close to the efficiency boundary. H2a and H2b are therefore also supported.

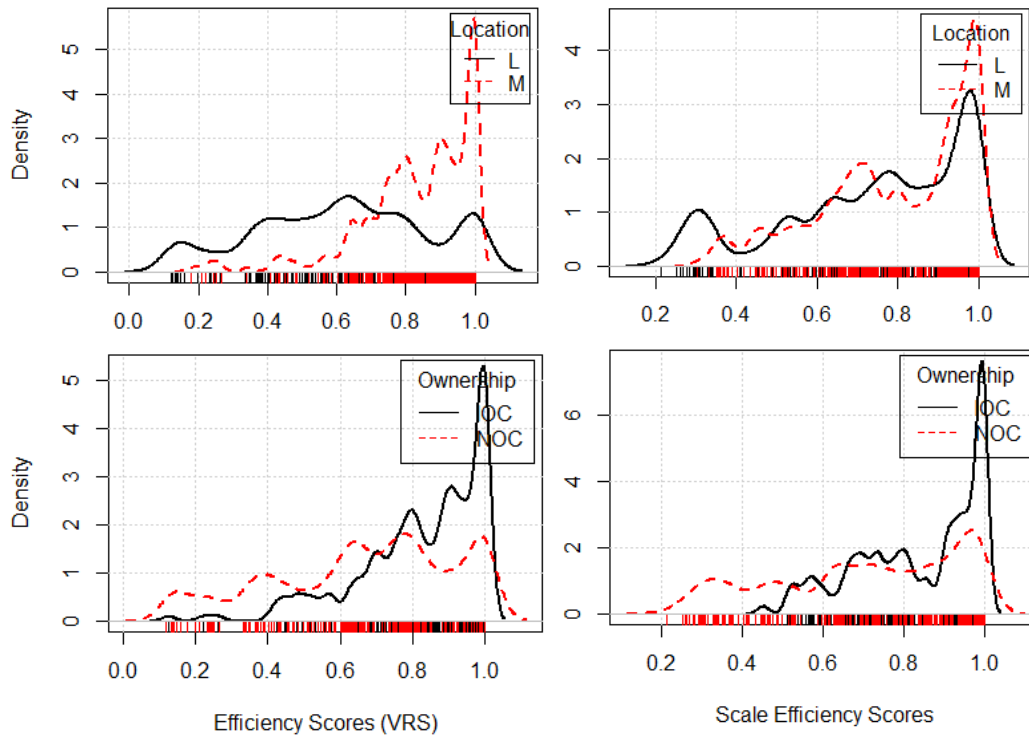


Figure 9: Kernel Density Plots of Productive Efficiencies

IOCs out-perform NOCs on all three indicators. This is both theoretically and empirically justifiable. Theoretically, this stands at par with the views of proponents of both the agency and property rights theories. Property rights theorists believe that private firms are more efficient because they are able to better reduce (internalize) all externalities associated with their property rights (Demsetz, 1967; Alchian & Demsetz, 1973). This means that IOCs are better able to maximize the present value of their investments. From the agency theory perspective, with shareholder controls and incentives, management of IOCs more efficiently manage business activities. This is because there are lower agency problems in private oil firms (IOCs) than state (NOCs). Empirically, Al-Obaidan and Scully (1991), Ike and Lee (2014) and Eller et al. (2011) all observed that IOCs out-perform NOCs. This is probably because NOCs

are sometimes forced to subsidize fuel for domestic consumption. They may also be forced to employ a larger workforce which may not necessarily be for commercial objectives (Eller et al., 2011). For scale efficiency, significant differences between NOCs and IOCs were observed in this study contrary to what Al-Obaidan and Scully (1991) observed. They saw that IOCs are just as scale efficient as NOCs. But note that they failed to consider OPEC NOCs as part of their samples. OPEC NOCs have been seen to be less efficient among NOCs (Ike & Lee, 2014). Deviations from Al-Obaidan and Scully (1991) findings may also be attributable to time differences in the study periods. Whereas Al-Obaidan and Scully (1991) covered a dataset from 1979 to 1983, this study provides more current insights by looking at the period from 2001 to 2010.

When multinationals are compared with locals, multinationals are seen to significantly outperform locals on all three efficiency indicators. Starting with the scale efficiencies, the results are consistent with the views of Al-Obaidan and Scully (1995). Multinationals are able to spread their operations across several locations thereby achieving an optimal scale. Although Al-Obaidan and Scully (1995) also saw that locals are more cost efficient than multinationals, this view is not a contradiction to the findings of this study. Unlike their study, this study did not assess cost efficiencies of these oil firms. It rather assesses the technical or productive efficiencies. The findings in the current study therefore present another dimension to the multinationality perspective. Multinationals are able to diversify business risks and enjoy ownership and locational advantages available in the host-country due to international operations (Driesen & Laeven, 2007; Rugman, 2010). Locals, on the other hand, have not internationally diversified their operations. Thus, country-specific challenges may directly affect operations and thereby cause their relative inefficiency as compared to multinationals. They are therefore not able to use their ownership advantages to enjoy locational advantages through international operations.

When the two concepts are interacted four separate categories of oil firms are generated: state multinationals (MNOC); private multinationals (MIOC); state locals (LNOC); and private locals (LIOC). Kruskal Wallis test of differences in the productive efficiencies of these firms show significant differences across all three measures of efficiency. Since the results of the Kruskal Wallis and Anova tests are consistent, Tukey's HSD multiple comparison tests were conducted to test the four other hypotheses. The results of the pairwise comparisons are presented in Appendix G. Since oil firms are of different sizes, these tests are examined using the VRS and scale efficiencies.

Hypothesis three examines the difference in the efficiencies of MNOCs and MIOCs. It was expected that they would not differ significantly since multinationality was expected to bring both firms similar efficiency gains. When productive efficiencies are compared, although MIOCs ( $M= 0.87$ ) seem to have higher efficiencies than MNOCs ( $M= 0.79$ ), the difference is not significant ( $d= -0.06$ ,  $p = 0.07$ ). MIOCs, however, have significantly higher scale efficiencies than MNOCs ( $d= -0.11$ ,  $p = 0.00$ ). MIOCs deal with the size of operation 11% better than MNOCs. Consequently, whereas H3a is supported, there was no statistical basis to support H3b.

Next, LNOCs and LIOCs are compared. Significant differences exists in the productive efficiencies ( $d= -0.11$ ,  $p= 0.02$ ) and scale efficiencies ( $d= -0.19$ ,  $p = 0.00$ ). Although it was expected that LNOCs would out-perform LIOCs, the contrary was rather seen. LIOCs are both more productive and scale efficient than LNOCs. This suggests that local state firms really suffer in operating only in their home country. Compared to even local private oil firms, they are no better. Therefore, both H4a and H4b are not supported.

To test whether multinationality actually makes any difference in the efficiencies of state firms, MNOCs and LNOCs are compared. MNOCs were expected to significantly out-perform

LNOCs because of the multinationality dimension. Indeed, this view was partly supported from the multiple comparison test. MNOCs significantly out-performed their local counterparts on productive efficiencies ( $d= 0.19, p =0.00$ ). However, the ability of both MNOCs and LNOCs to efficiently manage size of operation is not significantly different ( $d= 0.01, p = 0.96$ ). Indeed, these two categories of firms have the lowest scale efficiencies. Therefore, whereas H5a is supported, H5b is not supported in this study.

Finally, comparing the efficiencies of MNOCs and LIOCs reveal some interesting dynamics. First, a cursory glance at the scores before statistical inference show that whereas MNOCs have 9% more productive efficiencies, they are still 17% less scale efficient than LIOCs. This shows that state firms, irrespective of locational diversity of their operations have a problem of size. This view is statistically important as the differences in their scale efficiencies are significant ( $d= -1.17, p = 0.00$ ). The higher productive efficiency of MNOCs over LIOCs, however is not statistically significant ( $d= 0.09, p = 0.10$ ). H6a and H6b are therefore not supported.

These findings show that MNOCs are just as productively efficient as MIOCs. However, MIOCs are operating at a more optimal scale of operation than MNOCs. This shows that international operations allow MNOCs to move from total dependence on government resources (Choudhury & Khanna, 2014) mitigating against the influence of political actors. Therefore, because such NOCs have diversified their operations, they are able to offset inefficiencies due to state ownership thereby allowing them to enjoy the same levels of efficiency as their private multinational counterparts. However, state influences such as employment decisions are still affecting the ability of such state firms to achieve the optimal scale of operation. This is probably why MIOCs are still significantly better at handling the size of operation (scale) than MNOCs. The view that multinationality improves firm efficiency is further supported since MNOCs were seen to significantly out-perform LNOCs. Multinationality, therefore, provides an avenue for state firms to mitigate their inefficiencies.

However, MNOCs are no better than LNOCs when it comes to operating at the optimal firm scale (scale efficiency). Size is a major issue for state firms since LIOCs were even seen to be operating at a significantly more efficient size than their state counterparts (LNOCs). Over-employment is therefore a major issue with state-owned firms.

### 5.3.2 Dynamic productivity comparisons

One key contribution of this study is the use of not only static models, but dynamic DEA models to compare differences among selected groups of firms in the international oil industry. All tests were conducted based on the same hypotheses as those tested in the static models in the previous section. However, unlike the static model, statistical inferences are drawn based on the bias corrected productivity indices using the approach by Simar and Wilson (1999). Therefore, reported in Table 16 are the means, medians and test-statistics for statistical inferences.

**Table 16: Dynamic Productivity Differences**

	MPI	EC	TC	PEC	SEC
<b>Ownership</b>					
IOC	1.038 (1.00)	1.027 (1.01)	1.014 (1.01)	1.057 (1.02)	1.021 (1.00)
NOC	1.058 (1.00)	1.058 (1.00)	1.040 (1.00)	1.030 (1.01)	1.040 (1.01)
Mann-Whitney	21006	20864	20944	22364	20069
T-test	-0.5634	-0.9672	-1.3232	1.1304	-1.2217
<b>Location</b>					
Multinational	1.022 (1.00)	1.022 (1.01)	1.005 (1.00)	1.047 (1.03)	1.021 (1.01)
Local	1.090 (1.00)	1.077 (1.01)	1.063 (1.01)	1.038 (1.00)	1.046 (1.02)
Mann-Whitney	18968	19883	20420	17269	20556
T-test	1.5293	1.4332	2.5447**	-0.3575	1.4112

*Mean(Median)*

\* $p < .10$ . \*\* $p < .05$ . \*\*\* $p < .01$

*Table 16 (Continued)*

	MPI	EC	TC	PEC	SEC
<b>Ownership and Location</b>					
LNOC	1.090 (1.00)	1.092 (1.02)	1.054 (1.00)	1.036 (1.01)	1.055 (1.02)
LIOC	1.092 (0.96)	1.010 (1.01)	1.106 (1.08)	1.047 (0.99)	1.004 (1.00)
MNOC	1.006 (1.00)	1.030 (1.01)	1.017 (1.00)	1.021 (1.02)	1.016 (1.01)
MIOC	1.029 (1.00)	1.003 (1.00)	0.999 (1.00)	1.058 (1.03)	1.024 (1.00)
Kruskal Wallis	0.2559	0.8491	4.1677	3.7924	1.7935
Anova	1.221	1.604	3.586**	0.507	1.709

*Mean(Median)*\* $p < .10$ . \*\* $p < .05$ . \*\*\* $p < .01$ 

Evident from Table 16 is the marginal productivity gains of locals compared to multinationals. Whereas locals experienced an average productivity gain of 9%, multinationals experienced only a 2.2% productivity increment. Locals also out-performed multinationals on several other indicators including: efficiency change; technical change; and scale change. It was only on pure efficiency change that multinationals were able to outweigh the 3.8% gains of locals by only 0.9%. It seems as if firms operating locally are growing at a faster pace than multinationals. That said, however, differences between the means are not significant for all indicators except technical change. This means that statistically, local firms are better able to better take advantage of improving technological advancement in the industry than their multinational counterparts. However, H2c is not supported since there is no statistically significant difference in the dynamic productivity of locals and multinationals.

Judging from the ownership point of view, it seems as if state firms (NOCs) are growing at a faster pace than private ones (IOCs). Whereas NOCs experienced an average productivity growth of 5.8%, IOCs recorded 3.8% increment in productivity. However, this difference is not statistically significant to support H1c. NOCs also recorded 5.8% efficiency growth, 4% technical growth and 4% scale growth which are all higher than IOCs' 2.7%, 1.4% and 2.1%

growths in efficiency change, technical change and scale efficiency change respectively. IOCs only out-performed NOCs on pure efficiency change by 2.7%.

In examining the third hypothesis, which compares MNOCs and MIOCs, although for overall productivity growth MIOCs recorded a 2.9% growth compared with that of MNOCs (0.6%), the same picture cannot be painted for individual components of the productivity index. Whereas MNOCs are better able to manage the production process and take advantage of changes in technology, MIOCs are able to manage their size of operation better. Differences, however, are not statistically significant. Even for the technical change whereas overall statistically significant differences exist, multiple comparisons reveal no significant differences between the averages of MNOCs and MIOCs ( $d= 0.02, p = 0.91$ ). The only pairwise differences was between MIOCs and LIOCs. Since there is no significant difference in the dynamic productivity of MNOCs and MIOCs, H3c is supported.

Comparing LNOCs against LIOCs show a similar pattern. No significant differences statistically exist in the dynamic productivities of these two groups of firms. This means that being a state firm does not make a firm better or worse off over time as compared to a private firm, as far as both firms operate locally. H4c is therefore not supported. This notwithstanding, what is quite surprising is the fact that LNOCs over time were able to better manage their scale of operation (5.5%) than LIOCs (0.4%). Taking the investigations into whether multinationality is able to make a state firm grow over time, although not statistically significant, local NOCs (LNOCs) seem to out-perform multinational NOCs (MNOCs) on all indices. This seems to suggest that some other factors, other than multinationality, determines growth over time. Finally, comparing MNOCs against LIOCs seems to support the view that some other factors determine productivity over time since LIOCs out-perform MNOCs on overall productivity. However, MNOCs are surprisingly able to better manage their scale of operation as compared with LIOCs.

It is important to note that dynamic productivity does not indicate which DMU is better (more efficient), but rather it informs on which DMU is growing at a faster pace. Locals are seen to be experiencing more, albeit insignificant, productivity gains than multinationals. However, when decomposed, multinationals have significantly larger pure efficiency changes than locals. This signifies that, whereas locals are benefiting more from improvement in exploration and drilling technology at the industry levels, multinationals are still relatively more efficient in managerial acumen in allocation of the factors of production. NOCs are also seen to be growing at a faster pace than private firms (IOCs). NOCs are also seen to be experiencing higher scale changes than IOCs. This shows that state firms, although relatively inefficient, are experiencing a higher level of growth in their productivity than private firms. This is not surprising since Energy Intelligence (2014) observed that over the years, although IOCs have dominated in terms of size, expertise and performance; gradually, NOCs are matching to these standards. When ownership and location are interacted, although overall MIOCs are seen to be experiencing higher growth in productivity, MNOCs out-perform MIOCs when it comes to scale change. Coupled with this, LNOCs are experiencing a higher growth towards an optimal scale of operation.

Based on these, it is encouraging to know that state firms are experiencing some levels of productivity gains over time. More importantly, their ability in managing scale of operations over time is seen to be growing for all classes of state-owned firms. For LNOCs it is possible that they are experiencing higher local benefits over time than what they may have gained internationally. Local diversification of investment may also explain their productivity gains. Political support and the growing interest of citizens in state accountability may also be possible contributions towards the productivity gains. For MNOCs, it is possible that state backing provides them with the necessary financial and risk tolerance capacity to compete with their private counterparts over time (Cuervo-Cazzura et al., 2014). Although it is equally

possible that state backing may result in increased host-country hostility due to a combination of ideological conflicts and perceived threats to national security in host countries (Cuervo-Cazzura et al., 2014), it does not seem that state-owned multinational oil firms are experiencing that. A note of caution is warranted, however, since a cursory glance at the results show that most of the productivity gains are only marginal. State firms need more managerial innovation and less state influences to continue to grow over time. Table 17 presents a summary of the conclusions on all hypotheses tested.

**Table 17: Summary of Hypotheses**

<b>Hypothesis</b>	<b>Conclusion</b>
H1 IOCs significantly out-perform NOCs in terms of:	
<i>H1a Productive Efficiency</i>	Supported
<i>H1b Scale Efficiency</i>	Supported
<i>H1c Dynamic Productivity</i>	Not Supported
H2 Multinationals significantly out-perform locals in terms of:	
<i>H2a Productive Efficiency</i>	Supported
<i>H2b Scale Efficiency</i>	Supported
<i>H2c Dynamic Productivity</i>	Not Supported
H3 MNOCs perform as equally as MIOCs in terms of:	
<i>H3a Productive Efficiency</i>	Supported
<i>H3b Scale Efficiency</i>	Supported
<i>H3c Dynamic Productivity</i>	Supported
H4 LNOCs significantly out-perform LIOCs in terms of:	
<i>H4a Productive Efficiency</i>	Not Supported
<i>H4b Scale Efficiency</i>	Not Supported
<i>H4c Dynamic Productivity</i>	Not Supported
H5 MNOCs significantly out-perform LNOCs in terms of:	
<i>H5a Productive Efficiency</i>	Supported
<i>H5b Scale Efficiency</i>	Not Supported
<i>H5c Dynamic Productivity</i>	Not Supported
H6 MNOCs significantly out-perform LIOCs in terms of:	
<i>H6a Productive Efficiency</i>	Not Supported
<i>H6b Scale Efficiency</i>	Not Supported
<i>H6c Dynamic Productivity</i>	Not Supported

#### 5.4 Estimating scale efficiency changes

The final objective of this study compares scale efficiency change estimated using two different estimation techniques - the traditional Malmquist index (Fare et al., 1992) and the biennial Malmquist (Pastor et al., 2011). Oil firms are among the largest firms globally because of the capital intensive nature of their activities. Also, based on the range in Table 5, these firms under study are of varying sizes. Therefore, effectively measuring how well firms are able to manage the impact of their size on productivity, is crucial. Ray and Desli (1997) proposed an internally consistent measure of scale change, which is estimated as the ratio of the Malmquist computed using the CRS assumption to that computed using the VRS assumption. However, as discussed previously, this is prone to linear programming infeasibilities when VRS assumption is used. Pastor et al. (2011) have proposed a biennial Malmquist index that solves this infeasibility issues. Therefore, the results of these two indices are compared.

Table 18 presents a summary of the firms that recorded infeasibilities in the estimation process while using the traditional indicators. The third column of the table shows the number of times an infeasible solution was recorded for a particular firm out of the total number of times the productivity index was computed for a firm. The fifth column therefore shows the proportion of infeasible solutions to the total captured in the fourth column. The average scale efficiencies of these firms are also presented in the table.

**Table 18: Firms with Infeasible Solutions**

No	Company	Infeasible	Total	% inf	Scale Change
1.	Amerada Hess	5	8	62.50	0.9458
2.	Anadarko	4	9	44.44	0.9990
3.	Apache	4	7	57.14	0.9939
4.	BG	7	8	87.50	0.9971
5.	Burlington	3	3	100.00	-
6.	CNOOC	2	3	66.67	0.9809
7.	CNR	4	5	80.00	0.9749
8.	Devon Energy	2	8	25.00	0.9982
9.	Ecopetrol	3	7	42.86	1.0245
10.	EnCana	2	7	28.57	0.9914
11.	Inpex	1	1	100.00	-
12.	Marathon	5	9	55.56	1.0027
13.	Novatek	2	2	100.00	-
14.	Occidental	1	6	16.67	1.0026
15.	OMV	4	6	66.67	0.9392
16.	Petro-Canada	4	4	100.00	-
17.	Reliance	1	1	100.00	-
18.	Sibneft	1	2	50.00	0.9238
19.	Suncor	1	1	100.00	-
20.	TNK-BP	5	7	71.43	0.9919
		<b>61</b>	<b>104</b>	<b>58.65</b>	<b>0.9829</b>

*Inf: infeasible*

Evidently, 20 unique firms recorded infeasible solutions when the scale change was computed. With Amerada Hess, for example, 5 out of 8 indices computed were infeasible. This means that 62.5% of the information about its ability to measure scale change is lost through linear programming infeasibilities. Therefore, its average scale change of 0.9458 is biased since the results account for only the three feasible solutions. For other firms, all solutions (100%) were infeasible, therefore no average scale change could be computed for these firms. Companies like Burlington, Inpex, Novatek, Petro-Canada, Reliance and Suncor, all experienced this phenomenon. This means that managerial understanding of the ability of these firms to manage their size cannot be conveyed. Therefore, the overall average scale change of 0.9829 for all firms in the sample is biased and not truly representative of the overall scale change of these firms under consideration.

Basic descriptive statistics for both the traditional Malmquist and biennial Malmquist have been presented in Table 19. The productivity index and its two basic decompositions have been presented based on the CRS and VRS assumptions. Although 66 firms are sampled in this study, 4 of these firms appeared only ones in the sample. Therefore, although these firms are part of the production possibility set, productivity indices are not computed for these firms. Therefore, we have the averages of 62 firms for the period from 2001-2010.

**Table 19: Descriptive Statistics for Malmquist Indices**

		Traditional Malmquist		Biennial Malmquist	
		CRS	VRS	CRS	VRS
MPI	Mean	1.0104	1.0126	1.0091	1.0088
	SD	0.0630	0.0510	0.0597	0.0491
	Max	1.2849	1.1950	1.2437	1.1771
	Min	0.8834	0.8895	0.8644	0.8964
	N	62	62	62	62
	#Contradictions	1	6	1	6
EC	Mean	0.9969	0.9973	0.9969	0.9973
	SD	0.0580	0.0440	0.0580	0.0440
	Max	1.2252	1.1668	1.2252	1.1668
	Min	0.8633	0.8928	0.8633	0.8928
	N	62	62	62	62
	#Contradictions	0	0	0	0
TC	Mean	1.0136	1.0154	1.0123	1.0115
	SD	0.0297	0.0224	0.0272	0.0206
	Max	1.0843	1.1027	1.0729	1.0838
	Min	0.9420	0.9737	0.9370	0.9706
	N	62	62	62	62
	#Contradictions	5	8	5	8

Several deductions can be made from the results in Table 19. First, both methods seem to agree on the nature of overall productivity in the industry. That is, whenever the traditional Malmquist shows productivity growth, the biennial Malmquist also presents same conclusions. For example, both methods show progress for overall productivity, a regress for efficiency change and progress for technical change. Second, both methods seem to show that the

traditional Malmquist index seem to provide slightly higher scores for the MPI and the TC. Third, the results for the efficiency change in both methods are the same. This is since efficiency change indices are not affected by the problem of infeasibilities as no mixed-period efficiencies are estimated here. Unlike the other comparisons, there are no contradictions between the traditional and biennial Malmquist indices. Finally, some few contradictions were recorded for the MPI and the TC. That is, for individual firms, whereas one method showed progress another showed a regress. However, from a careful look at these values, it is possible that these firms may have stagnated and the disparity is probably due to statistical noises in the estimations. For example, Amerada Hess showed overall productivities of 1.0117 and 0.9929 for the traditional and biennial Malmquist indices respectively when the VRS technology is imposed. However, these scores seem to suggest more of stagnating position than a change. Statistical considerations based on both parametric and nonparametric investigations have been presented in Table 20. Note that since the two indices are estimated for the same firms, paired samples and Wilcoxon signed-rank tests are employed.

**Table 20: Comparisons of Malmquist Indices**

Pairs	Paired Samples t-test		Wilcoxon Signed Ranks	
	t	Sig.	V	Sig.
TMPI (VRS) - BMPI (VRS)	2.317	0.024	509	0.007
TMPI (CRS) - BMPI (CRS)	1.149	0.255	871	0.595
TEC (VRS) - BEC (VRS)	-	-	0.000	1.000
TEC (CRS) - BEC (CRS)	-	-	0.000	1.000
TTC (VRS) - BTC (VRS)	2.303	0.024	507	0.007
TTC (CRS) - BTC (CRS)	1.109	0.271	869	0.585

In Table 20, results of the traditional Malmquist index are prefixed by “T” whereas that by the biennial Malmquist is - “B”. It is clear that in using both parametric and nonparametric tests the same conclusions are arrived at. There are no significant differences in the productivity

indices computed using the CRS assumption. This shows that using the biennial Malmquist would not bias the conclusions that is expected to be arrived at from the CRS traditional Malmquist indices. For the efficiency change component, since both methods arrive at exactly the same conclusion, differences could not even be drawn from the statistical tests.

Differences become visible, for the other indices except efficiency change, when the VRS assumption is considered for the other indices except efficiency change. Whereas the results of the traditional Malmquist index (VRS) is significantly larger than that of the biennial Malmquist index ( $t = 2.317, p = 0.024$ ), that of the traditional technical change is significantly larger than the results of the biennial technical change when VRS is imposed ( $t = 2.303, p = 0.024$ ). This is also expected since the results of the traditional Malmquist will not provide a full picture of the overall productivity of the industry since it inherently does not include infeasible decision-making units in the averaging.

Based on these findings the results for the scale change can be compared. Here, Ray and Desli (1997) approach for computing scale change is compared. They define the scale change as the ratio of the CRS Malmquist to the VRS Malmquist. Since the number of observations for the traditional scale change is not the same as that for the biennial Malmquist, because of the problem of infeasibilities, independent sampling was assumed. Therefore statistical comparisons presented in Table 21 are based on independent samples tests.

**Table 21: Comparison of Scale Changes**

	<b>Traditional</b>	<b>Biennial</b>	<b>t</b>	<b>Sig.</b>	<b>U</b>	<b>Sig.</b>
Mean	0.9971	1.0003	-0.535	0.594	1956	0.312
SD	0.0267	0.0264				
Max	1.0984	1.0932				
Min	0.9151	0.9181				
N	56	62				

The first observation that can be made from Table 21 is that whereas the number of observations for the traditional scale efficiency is 56, the biennial one is 62. It should be remembered from Table 18 that, 6 firms had 100% of their solutions as infeasible. Even for the remaining 56, not all firms had feasible solutions each time the index was calculated. On the contrary, the biennial scale change provides results for all 62 firms and for each time the index is computed. Another observation is the similarities in the descriptive statistics presented. The standard deviations, maximum and minimum values are all very similar. What seem different are the mean scores. Whereas the traditional scale change suggests a marginal regress (0.9971) the biennial scale change presents a marginal progress (1.0003). On the face of it, the conclusion may be that these two indices are providing contrary conclusions, however, both scores are very close to one signifying more of a stagnation than a change.

This view is buttressed by the results of t-test and Mann-Whitney test that reveal no significant differences between the two indices. A comparison of the univariate density estimates in a permutation test of equality for the two indices which was conducted also showed no differences in the two densities ( $p = 0.48$ ). What this reveals is that computing the scale changes using the biennial Malmquist indices would not bias the results of firms with feasible solution in the traditional Malmquist. However, most importantly, appropriate estimates for firms that were previously infeasible would be ascertained to aid in managerial decision-making.

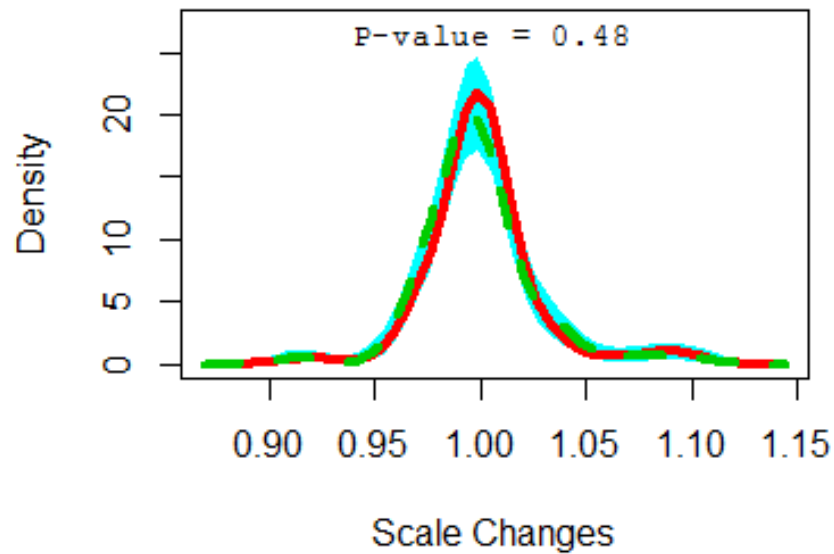


Figure 10: Test of Equality of Densities

**Table 22: Scale Changes for Firms with Infeasible Solutions**

No	Company	Traditional Scale Change	Biennial Scale Change
1	Amerada Hess	0.9458	0.9846
2	Anadarko	0.9990	1.0054
3	Apache	0.9939	0.9947
4	BG	0.9971	0.9976
5	Burlington	-	0.9985
6	CNOOC	0.9809	0.9794
7	CNR	0.9749	0.9923
8	Devon Energy	0.9982	0.9884
9	Ecopetrol	1.0245	1.0147
10	EnCana	0.9914	0.9962
11	Inpex	-	1.0000
12	Marathon	1.0027	1.0037
13	Novatek	-	1.0016
14	Occidental	1.0026	0.9986
15	OMV	0.9392	0.9708
16	Petro-Canada	-	1.0118
17	Reliance	-	1.0030
18	Sibneft	0.9238	1.0031
19	Suncor	-	1.0003
20	TNK-BP	0.9919	0.9723
		<b>0.9829</b>	<b>0.9958</b>

These findings are consistent with Pastor et al. (2011). The biennial Malmquist index is more advantageous since it avoids the linear programming infeasibilities. This is because understanding the contributions of the various decompositions of dynamic productivity is crucial (Pastor et al., 2011). No empirical weaknesses were identified when the biennial Malmquist was applied. It provided results consistent with the traditional CRS Malmquist index while correcting the infeasibilities on the VRS frontier. More empirical consideration of the biennial Malmquist index when estimating scale efficiency changes in the oil and gas industry is therefore necessary.

## **5.5 Conclusion**

This chapter has provided ample results and discussions that answers all research questions of this study. Firms selected for this study are from all continents in the world and are representative of the oil and gas industry because of the high concentration of world reserves and production among these firms. Objective one reviewed the dynamic productivity in the industry during the study period. For a period of terrorist attack in one of the world's biggest economies, war in Iraq, massive strikes in Venezuela, geopolitical tensions in Nigeria and a great depression in economic activities, overall productivity growth was very marginal. Objective two was then achieved by the use of both static and dynamic DEA models. For the third objective, the traditional Malmquist index was compared with the biennial Malmquist index. The results show that the biennial index provides results consistent with the traditional index while providing solution to the infeasibility problem in the traditional indicators.

## CHAPTER SIX

### SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

#### 6.0 Introduction

Chapter Six is divided into three sections. First, a summary of the aims and objectives of the work and some key findings are provided. Based on these, conclusions are drawn on each research objective. Finally, recommendations for practice and directions for further research are provided.

#### 6.1 Summary of the study

The study sought to examine differences in the efficiency and productivity change of state and private oil companies in the international oil industry. Since previous studies had already been conducted in this regard, the unique contributions of this work were to first add the multinationality dimension to the debate of state versus private firm performance superiority considerations in the industry. Coupled with this, this study not only examined this relationship using static frontier models, but also dynamic models; something previous authors had failed to consider. At the methodological level, biennial Malmquist index was, for the first time, applied and compared with the adjacent Malmquist index in the international oil industry.

This study used data from Energy Intelligence's Petroleum Intelligence Weekly database of the top 50 oil companies annually for a 10 year period from 2001 to 2010. This database gathers and stores data on oil and gas reserves, production quantities, sales, refining capacity, total assets and number of employees; making it one of the most used database in efficiency and productivity analysis in the international oil industry. Since the database selects 50 firms each year for the 10 years, 500 different samples were gathered; however, after data cleaning to take out observations with missing information, 478 observations on 66 unique oil firms were sampled over the ten years. These firms sampled have a wide geographic coverage since they

are headquartered and operational in all 6 continents of the world. Due to their geographic differences and their high concentration in the international oil industry, these firms selected presented a valid representative sample to assess efficiency and productivity differences in the international oil industry.

For the analysis, productivity trends of firms were first assessed over the 10 year study period. A bootstrapped Malmquist productivity change index was used to assess the overall productivity with the bootstrapping creating an avenue for statistical inferences especially because of the confidence intervals it generates. Furthermore, this index was decomposed into two main components - efficiency change and technical change to assess the source of the overall dynamic productivity in the industry. The efficiency change component was then further decomposed into pure efficiency change and scale change based on Fare et al. (1994). Firms were then segregated based on ownership and location in order to answer the research questions attributable to the second objective. On the ownership basis, firms were divided into state-owned (NOCs) and privately-owned (IOCs) firms. Same firms were also divided into multinationals and locals, based on the locational criterion. Note that, whereas locals operate in one country, multinationals operate in more than one country. Finally, interacting the ownership and multinationality criteria allowed for segregation of these same firms into four other categories - state multinationals (MNOCs); private multinationals (MIOCs); state locals (LNOCs); and private locals (LIOCs). The major findings identified in this study included:

- a. Although there are similar proportions of state and private oil firms in the sample, there are more multinationals than locals. Coupled with this, whereas more state firms operate locally, the majority of private firms operate multinationally.
- b. State firms use more inputs than private firms. State firms control more oil and gas reserves and employ a significantly larger employee size than private firms. State firms, however, produce more oil and gas outputs than private firms.

- c. Multinationals produce more outputs than locals; however, locals control and use more inputs. Locals possess more oil and gas reserves yet their oil and gas outputs are not better than that of multinationals.
- d. Annual productivity growth in the industry for the study period, 2001 to 2010, has been marginal at only 1.4% per annum. This was mainly fuelled by growth in industry technology than growth in managerial efficiency. However, there is a stronger positive correlation between managerial efficiency changes and productivity showing that higher levels of managerial efficiency is associated with higher levels of productivity growth. When managerial efficiency is decomposed, it has a stronger association with scale efficiency than pure efficiency change.
- e. Private oil and gas firms are more productively efficient than state ones. Private firms are also operating at a more efficient scale that is closer to the optimal production level than state firms. Multinationals also out-performed local firms on all indicators of efficiency.
- f. Multinational-state firms (MNOCs) are not that different from multinational-private firms (MIOCs) on productive efficiency. MNOCs are also significantly better (productively) than local state firms (LNOCs).
- g. State firms, irrespective of location of operation, suffer from a problem of scale inefficiencies. LNOCs and MNOCs are not significantly different in terms of scale inefficiency. All classes of private firms significantly out-performed their state counterparts in terms of scale efficiency.
- h. In the dynamic context, it seems that state firms are experiencing higher productivity gains than private ones. Similarly, locals are growing at a faster rate than multinationals although not significantly different. What is more interesting is that all classes of state firms are experiencing a higher scale efficiency growth. However, it does not seem to be large

enough, and sustainable, since these growths are not that different from those of non-state actors.

- i. Generally, both the traditional and biennial Malmquist indices seem to agree on the nature of overall productivity. Indeed, for the efficiency change component, the results are exactly the same for the 2 indices. The biennial Malmquist would not bias conclusions expected to be arrived at using the traditional CRS Malmquist index. The results of the traditional Malmquist estimated using the VRS frontier is significantly different from that of the biennial Malmquist index. It seems the traditional Malmquist overstates productivity change and understates technical change indices.
- j. The biennial scale efficiency change provides information on all observations each time the index is computed. It avoids the linear programming infeasibilities in the traditional Malmquist index. Computing scale changes using the biennial Malmquist provides unbiased results for firms that also have feasible solutions in the traditional Malmquist.

## **6.2 Conclusions of the study**

The findings of this study has brought to the fore some important issues that need ample consideration in the ownership-performance assessments debate in the international oil market. First, multinationality as a concept in the oil industry is well received and adopted probably because governments all over the world see the oil and gas industry to be important in ensuring national sovereignty and continual supply of energy. This is probably why there are more multinationals than locals in the oil industry. However, it does not go without notice that the multinationality concept is better received by private firms. Most state-owned oil firms seem to be content with local operations. Therefore, there are more avenues for state firms to benefit from the advantages of multinationality presented in this study.

Evident in this study is the size of the resource employments of state firms relative to private ones. State firms have a larger workforce size, and control and use more oil and gas reserves to generate outputs. Over-employment of these resources is a major cause of their inefficiencies. However, their relatively higher levels of outputs in comparison with private firms seem to reduce such inefficiencies. Multinationality, on the other hand, is seen to result in higher production levels. Although multinationals use less inputs than locals, by pursuing international diversification, they are able to produce more outputs. This is because such firms are able to avoid country-specific economic downturns and inefficiencies. Going multinational will therefore result in significantly higher production levels.

An assessment of the overall changes in productivity of the oil and gas industry seem to show that, probably as a result of the events in the world economy, oil firms have not experienced that much productivity growth. The study period encapsulates technical or systematic trends like the September 11<sup>th</sup> terrorist attacks, strikes in Venezuela, geopolitical tensions in Nigeria and Iraq and the great depression interlaced with periods of relative economic growth. Post 2010, however, should see more productivity growth because of the dedication of various governments and intergovernmental organisations towards avoiding another depression, as well as declining fears of the western-led war in the Middle East. There is a more positive outlook in light of the growing oil demands of emerging economies, the discovery of more oil reserves globally, and increased US oil and gas production due to fracking. However, operations managers and policy makers should not lose sight of the geopolitical tensions in Nigeria, Syria and several other oil producing countries in the Middle East. Further tensions between Russia, Ukraine and the European Union also need careful considerations. This is important because as seen in this study, the industry productivity seem to relate with such tensions and world events. These technical or industrial trends have had serious repercussions

on firm productivity for this period. More managerial innovation is required as efficiency change is more associated with productivity rather than technical change.

Another important finding is how state ownership is associated with higher levels of inefficiency as compared with private ownership. Multinationality is also associated with higher levels of efficiency than local operations. Further results also indicate that multinationality drives state-owned oil firms towards higher levels of productive efficiency. Multinationality is therefore a means for state-owned oil firms to spread their business risk across international boundaries thereby gaining improved levels of efficiency in their operations. This notwithstanding, multinationality does not seem to mitigate scale inefficiencies of such state oil firms. State firms, irrespective of location of operation, suffer from a problem of over-employment of input resources. Therefore, operations managers must note that, whereas state firms can go multinational to reduce operational inefficiencies, additional considerations should be undertaken towards improving their scale inefficiencies.

When the dynamic perspective is considered, the evidence that state firms are growing in productivity at a faster pace than private firms is an encouraging sign for persons in favour of state ownership. Perhaps, although state owned firms are sometimes deemed to be slow in adopting new technologies, the dynamic comparisons appear to show that the trend is changing. It is also possible that because state firms start from low technological base, any small improvements becomes visible. The interesting empirical observation that state firms, irrespective of location of operation, are growing faster in scale efficiency provides a more encouraging outlook. This is because, from the results, scale inefficiency is seen to be a pervasive issue for state firms. However, state firms must be careful when relying on this finding because the productivity gains of these state firms over their private counterparts are statistically insignificant when statistical considerations are provided. State firms need to provide more sustainable managerial innovations by not only relying on technical changes but

also on sound managerial decisions. More efforts must be paid in reducing any political influences that may force these state firms to hire higher levels of employees which may not be for bottom-line purposes.

Finally, for the final objective of this study, the biennial Malmquist index was seen to provide results consistent with the traditional adjacent period Malmquist index. However, the biennial Malmquist is more advantageous because it provides a more complete assessment for even observations which would otherwise have been seen as infeasible using the traditional Malmquist index. The biennial Malmquist index therefore has enough empirical and ample policy-oriented usefulness since results on all observations can be computed.

### **6.3 Recommendations**

From the findings and conclusions, several recommendations on policy, practice and further research can be made. Recommendations are clearly delineated to aid in better conceptualization of thoughts.

For policy:

- a. First, dynamic productivity in the oil industry has been shown to be probably due to major events in the industry and world economy. Major world events that have repercussions on oil supply need better and quicker attention because delays in solving such technical trends may have serious effects on the productivity of individual firms as well as the entire industry.
- b. Second, the concept of multinationality has been tested and proven to lead to higher production levels and efficiency. For state firms, multinationality is able to lead to even significantly higher productive efficiency levels. Persons involved in policy decisions concerning state firms should make multinational operation one key policy goal for

future operation. This is because international diversification of operations can reduce the inefficiencies state firms face.

For practice:

- a. Overall dynamic productivity of oil firms were seen in this study to reflect seriously the technical events in the industry. However, in the same study, it is seen that management innovation is more closely related to firm productivity than technical factors. The implication for management is that management decisions on optimal input mix, investments in efficient production techniques, managing the size of operation and choice of operational decisions would have a higher likelihood of improving firm dynamic productivity. More managerial innovation is needed if the generally stagnated position of the industry is to be improved.
- b. Although multinational operation has been seen to significantly improve firm productive efficiency, it has little effect of scale efficiencies of state-owned firms. State firms have a larger workforce which is probably why they suffer from the scale inefficiencies. They also control larger reserves, which in itself is not bad. However, relative to its production levels, there is more room to cut wastages in the production process. Therefore, when going multinational, additional considerations should be taken in order to cut wastages preventing state firms from achieving an optimal scale of operation.

For further research:

- a. Productivity in the industry was seen to be explained by changes in the oil market, however, because the study did not explicitly investigate how specific major events impact on performance, further research can investigate the impact of economic shocks,

global downturns and booms and other economic factors on efficiency and productivity in the industry.

- b. Chen et al. (2014) and other researchers, have seen performance differences between several other classes of state firms, such as firms with majority state ownership, minority state ownership, central government-owned firms, state asset management firms among others. Further research can explore how the degree of government ownership affects performance by assessing performing differences between the various typologies of state ownership.
- c. This study explained how going multinational can lead to efficiency gains. However, it failed to consider the composition of the multinational portfolio. Firms in the study were assumed to be operating a well-diversified portfolio of international sites for operation. With geopolitical tensions in particular states, further research can explore how the choice of international exploration and production destinations can affect firm performance in the oil industry. This would provide firms that are aiming to go multinational with indications of the kinds of multinational destinations and which of these destinations offer them the higher likelihood of operational success.
- d. Whereas this study has provided very useful insights using upstream oil industry data, a more complete picture would be presented if both the upstream and downstream business segments are considered. This is because most of these firms sampled have business units in both segments of the industry. Further research can consider efficiency and productivity of oil firms in both the upstream and downstream segments of the industry.
- e. In the study two important issues, ownership and multinationality, were critically assessed. However, other environmental factors may have even stronger impact on firm efficiency and dynamic productivity. The efficiency and productivity changes can be

regressed on environmental variables such as degree of vertical integration and firm size to understand the determinants of performance. This second stage assessment should provide more policy-oriented findings.

- f. The biennial Malmquist index used in this study has provided policy and empirically appropriate results. There is room for more applications and advances in the use of this technique. Suggestions for methodological advancement of the biennial Malmquist index includes bootstrapping the index and advancing the index into non-radial modelling techniques like a slack-based biennial Malmquist index. The biennial Malmquist index can be compared with other dynamic productivity indicators like the Luenberger productivity indicator and the Hicks-Moorsteen productivity index.
- g. This study also examined efficiency and productivity differences between state and private firms using technical and scale efficiencies as well as Malmquist indices using technical efficiencies. Whereas technical efficiency provides output augmenting and input minimizing benchmarks, it fails to take into consideration price elements. It is appropriate to examine, for example, how oil firms efficiently gain the maximum revenue by incurring the minimum cost. It is possible that local oil firms are able to operate at a lower cost than multinationals. Therefore, further research should explore arguments made in this study using cost, revenue and profit efficiencies as well as their Malmquist versions.
- h. Finally, in the oil industry, there are other powerful players that play important roles. For example, OPEC has an active influence on supply decisions that can affect oil prices on the world market. Further study should not ignore the influence of the other players in the industry. Studies on efficiency and productivity differences between intergovernmental organisations like OPEC, OAPEC and IEA using metafrontier and global frontier techniques are warranted.

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## **APPENDICES**

## APPENDIX A

## Firms sampled for this study

Company	ID	Country	Operational Location	Ownership	Times Sampled
Adnoc <sup>a</sup>	1	UAE	L	NOC	10
Amerada Hess	2	US	M	IOC	9
Anadarko	3	US	M	IOC	10
Apache	4	US	M	IOC	8
BG	5	UK	M	IOC	9
BP <sup>b</sup>	6	UK	M	IOC	10
Burlington	7	US	M	IOC	4
Chevron <sup>b</sup>	8	US	M	IOC	10
CNOOC	9	China	M	NOC	4
CNPC	10	China	M	NOC	5
CNR	11	Canada	M	IOC	6
ConocoPhillips	12	US	M	IOC	10
Devon Energy	13	US	M	IOC	9
Ecopetrol	14	Colombia	L	NOC	9
EGPC	15	Egypt	L	NOC	10
El Paso Energy	16	US	L	IOC	1
EnCana	17	Canada	M	IOC	8
Eni	18	Italy	M	IOC	10
ExxonMobil <sup>b</sup>	19	US	M	IOC	10
Gazprom	20	Russia	M	IOC, NOC	10
INOC	21	Iraq	L	NOC	2
Inpex	22	Japan	M	IOC	2
Kazmunaigas	23	Kazakhstan	L	NOC	5
KPC <sup>a</sup>	24	Kuwait	L	NOC	10
Libya NOC <sup>a</sup>	25	Libya	L	NOC	3
Lukoil	26	Russia	M	IOC	10
Marathon	27	US	M	IOC	10
NIOC <sup>a</sup>	28	Iran	L	NOC	10
NNPC <sup>a</sup>	29	Nigeria	L	NOC	9
Norsk Hydro	30	Norway	M	IOC	6
Novatek	31	Russia	L	IOC	4
Occidental	32	US	M	IOC	8
OMV	33	Austria	M	IOC	7
ONGC	34	India	M	NOC	10
PDO	35	Oman	L	NOC	10
PDV <sup>a</sup>	36	Venezuela	L	NOC	10
Pemex	37	Mexico	L	NOC	10
Pertamina	38	Indonesia	M	NOC	10

*Continued*

<b>Company</b>	<b>ID</b>	<b>Country</b>	<b>Operational Location</b>	<b>Ownership</b>	<b>Times Sampled</b>
Petrobras	39	Brazil	M	IOC	10
Petro-Canada	40	Canada	M	IOC	5
PetroChina	41	China	L	NOC	5
Petronas	42	Malaysia	M	NOC	10
QP <sup>a</sup>	43	Qatar	L	NOC	10
Reliance	44	India	L	IOC	2
Repsol	45	Spain	M	IOC	10
Rosneft	46	Russia	L	NOC	10
Royal Dutch Shell <sup>b</sup>	47	The Netherlands	M	IOC	10
Saudi Aramco <sup>a</sup>	48	Saudi Arabia	M	NOC	10
Sibneft	49	Russia	L	IOC	3
Sidanco	50	Russia	L	IOC	2
Sinopec	51	China	M	NOC	10
Slavneft	52	Russia	L	NOC	1
Socar	53	Azerbaijan	L	NOC	10
Sonatrach <sup>a</sup>	54	Algeria	M	NOC	10
SPC	55	Syria	L	NOC	8
Statoil	56	Norway	M	NOC	10
Suncor	57	Canada	M	IOC	2
Surgutneftegas	58	Russia	L	IOC	10
Talisman Energy	59	Canada	M	IOC	1
Tatneft	60	Russia	M	IOC	1
TNK-BP	61	Russia	L	IOC	8
Total <sup>b</sup>	62	France	M	IOC	10
Tyumen Oil	63	Russia	L	IOC	2
Unocal	64	US	L	IOC	4
Uzbekneftegas	65	Uzbekistan	L	NOC	3
Yukos	66	Russia	L	IOC	3

<sup>a</sup> OPEC NOCs<sup>b</sup> Major IOCs

L – Local Firms

M – Multinational Firms

IOC - Private Oil Firms

NOC – State Oil Firms

## APPENDIX B

## Tabular Taxonomy of Efficiency Related Papers in Oil and Gas Industry

No	Author (Year)	Main Research Issue	Method	Efficiency Measure	Inputs	Outputs	Sample/Country/ Study Period	Sector
1.	Al-Obaidan, A.M., & Scully, G.W. (1991)	Ownership	Aigner-Chu deterministic frontier SFA Maximum likelihood gamma frontier function	T.E, SE, PE EE, A.E.	• Total assets	• Total revenue  • Barrels of crude oil produced + barrels of crude oil refined	44 oil companies (1979-1983)	Upstream
2.	Al-Obaidan, A.M., & Scully, G.W. (1993)	Backward Vertical Integration	Aigner-Chu deterministic frontier SFA Maximum likelihood gamma frontier function	T.E, SE, EE	• Total assets	• Total revenue  • Barrels of crude oil produced + barrels of crude oil refined	55 oil companies (1979-1982)	Upstream
3.	Al-Obaidan, A.M., & Scully, G.W. (1995)	Multinationality	Aigner-Chu deterministic frontier SFA Maximum likelihood gamma frontier function	T.E, SE, EE	• Total assets	• Total revenue  • Barrels of crude oil produced + barrels of crude oil refined	44 oil companies (1976-1982)	Upstream
4.	Barros, C., & Antunes, O.S. (2014)	Productivity Change. Malmquist vs Luenberger	Luenberger Productivity Indicator DEA	MPI EC TC	• Operational cost  • Investment premium • Taxes	• Production of oil	9 Angolan oil blocks (2002-2008)	Upstream
5.	Barros, C.P., & Assaf, A. (2009)	Bootstrapping	DEA Bootstrapping Bootstrapped truncated regression	T.E	• Operational cost • Investment premium • Taxes	• Gross production	9 Angolan oil blocks (2002-2007)	Upstream

*TE- Technical Efficiency, SE- Scale Efficiency, PE- Price Efficiency/Revenue Efficiency, EE- Economic Efficiency/Profit Efficiency, AE- Allocative Efficiency, MPI- Malmquist Productivity Change Index, EC- Efficiency Change, TC- Technical Change, SFA- Stochastic Frontier Analysis, DEA- Data Envelopment Analysis*

Continued

No	Author (Year)	Main Research Issue	Method	Efficiency Measure and Estimate	Inputs	Outputs	Sample/Country/ Study Period	Sector
6.	Barros, C.P., & Managi, S. (2009)	Growth Accounting vs Productivity Method	DEA	MPI EC TC	• Operational cost • Investment premium • Taxes	• Gross production	9 Angolan oil blocks (2002-2007)	Upstream
7.	Eller, S.L., Hartley, P.R., & Medlock, K.B. (2011).	Ownership	DEA SFA	Rev Efficiency	• Oil reserves • Natural gas reserves • Number of employees	• Revenues	78 oil firms (2006)	Upstream
8.	Francisco, C.A.C., de Almeida, M.R., & de Silva, D.R. (2012)	Environmental Efficiency	DEA Bad Outputs	T.E	• Amount of water consumed • Percentage of Idleness	• Processed oil • Effluents (Undesirable) • Age of Refinery (Uncontrollable)	10 Brazilian Refineries (2004)	Downstream
9.	Hawdon, D. (2003)	Regulation	DEA Bootstrapping	T.E	• Employment • Length of pipelines	• Gas Consumption • Number of Customers	Country-level data of 33 countries (1998, 1999) Gas Industry	Downstream
10.	Ike, C.B., & Lee, H. (2014)	Ownership	DEA Slack Based MPI Regression	T.E MPI EC TC	• Oil reserves • Gas reserves • Number of employees	• Oil production • Gas Production	38 oil companies (2003-2010)	Upstream
11.	Ismail, J., Tai, J.C., Kong, K.K., Law K.H., Shirazi, S.M., & Karim, R. (2003)	Environmental Efficiency	DEA Correlation Environmental Indices	T.E Indices (GWPI, PAE, WUI)	• Assets • Employee Numbers	• Revenue	17 Oil Companies (2008)	Upstream

## Continued

No	Author (Year)	Main Research Issue	Method	Efficiency Measure and Estimate	Inputs	Outputs	Sample/Country/ Study Period	Sector
12.	Kashani, H.A. (2005a)	Regulation	DEA SFA Regression	E.C PEC SEC T.E MPI	• 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
13.	Kashani, H.A. (2005b)	State Intervention	DEA SFA Regression	E.C PEC SEC T.E MPI	• Construction Cost • Variable Cost • Water depth • Revenue depth • Number of partners	• Oil Production • Gas Production	37 Gas Fields in Norway. (1972-2000)	Upstream
14.	Kim, T.Y., Lee, J.D., Park, Y.H., & Kim, B. (1999)	International Comparison, Determinants of Productivity	Multilateral Tornqvist Managerial Index System Analysis Nonparametric Efficiency Analysis	A.E S.E M.E	• Labour • Capital (Assets) • Administration	• Total volume of gas supplied • Revenue from gas transportation	28 Natural Gas transmission and distribution companies operating 8 countries (1987-1995)	Downstream
15.	Lee, J.D., Park, S.B., & Kim, T.Y. (1996)	International Comparison	Edgeworth Index ANOVA		• Capital • Labour • Administration	• Gas deliveries	28 natural gas transportation utilities in 8 countries (1987-1995)	Downstream

*TE- Technical Efficiency, SE- Scale Efficiency, PE- Price Efficiency/Revenue Efficiency, EE- Economic Efficiency/Profit Efficiency, AE- Allocative Efficiency, MPI- Malmquist Productivity Change Index, EC- Efficiency Change, TC- Technical Change, SFA- Stochastic Frontier Analysis, DEA- Data Envelopment Analysis*

Continued

No	Author (Year)	Main Research Issue	Method	Efficiency Measure and Estimate	Inputs	Outputs	Sample/Country/ Study Period	Sector
16.	Managi, S., Opaluch, J.J., Jin, D., & Grigalunas, T.A. (2005)	Technology Change	Regression	TC	<ul style="list-style-type: none"> <li>• Drilling distance per exploratory well</li> <li>• Drilling distance per development well</li> <li>• Total number of exploratory and development wells</li> <li>• Price of oil &amp; gas</li> <li>• Water depth</li> </ul>	<ul style="list-style-type: none"> <li>• Quantity of oil and gas reserves discovered in barrels of oil equivalent</li> </ul>	370 Drilling wells in gulf of Mexico-US (1947-1998)	Upstream
17.	Managi, S., Opaluch, J.J., Jin, D., & Grigalunas, T.A. (2006)	Technology Change	SFA	TFP TC	<ul style="list-style-type: none"> <li>• Oil reserves</li> <li>• Gas reserves</li> <li>• Water depth</li> <li>• 5 yr. ex drill mills ratio</li> </ul>	<ul style="list-style-type: none"> <li>• Porosity</li> </ul>	370 Drilling wells in gulf of Mexico-US (1947-1998)	Upstream
18.	Price, C.W., & Weyman-Jones, T. (1996)	Privatization	DEA SFA	MPI T.E	<ul style="list-style-type: none"> <li>• Number of employees</li> <li>• Length of gas mains transmission and distribution system</li> </ul>	<ul style="list-style-type: none"> <li>• Domestic gas sales</li> <li>• Industrial gas sales</li> <li>• Commercial gas sales</li> <li>• Number of Customers</li> <li>• Gas using appliances sold</li> </ul>	12 distribution regions in UK (1977-78 to 1990-91)	Downstream

*TE- Technical Efficiency, SE- Scale Efficiency, PE- Price Efficiency/Revenue Efficiency, EE- Economic Efficiency/Profit Efficiency, AE- Allocative Efficiency, MPI- Malmquist Productivity Change Index, EC- Efficiency Change, TC- Technical Change, SFA- Stochastic Frontier Analysis, DEA- Data Envelopment Analysis*

Continued

No	Author (Year)	Main Research Issue	Method	Efficiency Measure and Estimate	Inputs	Outputs	Sample/Country/ Study Period	Sector
19.	Sueyoshi, T., & Goto, M. (2012a)	Conceptual Paper: Environmental Efficiency and Ownership	DEA Bad Outputs	T.E	<ul style="list-style-type: none"> <li>• Amount of Oil Reserves</li> <li>• Amount of Gas Reserves</li> <li>• Total operating cost</li> <li>• Number of employees</li> </ul>	<ul style="list-style-type: none"> <li>• Oil Production</li> <li>• Gas Production</li> <li>• CO2 emission (Undesirable)</li> </ul>	19 oil firms. (2005-2009)	Upstream
20.	Sueyoshi, T., & Goto, M. (2012b)	Conceptual Paper: Environmental Efficiency and Ownership	DEA Bad Outputs	T.E	<ul style="list-style-type: none"> <li>• Amount of Oil Reserves</li> <li>• Amount of Gas Reserves</li> <li>• Total operating cost</li> <li>• Number of employees</li> </ul>	<ul style="list-style-type: none"> <li>• Oil Production</li> <li>• Gas Production</li> <li>• CO2 emission (Undesirable)</li> </ul>	19 oil firms. (2005-2009)	Upstream
21.	Thompson, R.G., Dharmapala, P.S., Diaz, J., Gonzalez-Lima, M.D., & Thrall R.M. (1996)	Conceptual Paper	DEA	Multipliers T.E	<ul style="list-style-type: none"> <li>• Total production costs</li> <li>• Total proven reserves of crude</li> <li>• Total exploratory and development wells drilled</li> <li>• Total proven reserves of natural gas</li> </ul>	<ul style="list-style-type: none"> <li>• Oil Production</li> <li>• Gas Production</li> </ul>	30 oil companies (1983-1985)	Upstream
22.	Thompson, R.G., Dharmapala, P.S., Rothenberg, L.J., & Thrall R.M. (1994)	DE/ AR and Profitability	DEA AR Discriminant Analysis	Cone ratio T.E Minimum and Maximum Profit Ratio	<ul style="list-style-type: none"> <li>• Total Cost</li> <li>• Proved reserves (combined)</li> </ul>	<ul style="list-style-type: none"> <li>• Additions to reserves (combined)</li> <li>• Sales of production from reserves</li> </ul>	14 integrated oil companies in US (1980-1987)	Upstream

Continued

No	Author (Year)	Main Research Issue	Method	Efficiency Measure and Estimate	Inputs	Outputs	Sample/Country/ Study Period	Sector
23.	Thompson, R.G., Dharmapala, P.S., Rothenberg, L.J., & Thrall R.M. (1996)	Application of DEA AR and CR	DEA Assurance Region (AR) Multiplier model	O.E. AR Minimum Profit Ration Slack based	• 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
24.	Wolf, C.(2009)	Ownership	Regression		• Oil and gas reserves • Total assets • State ownership Percentage • OPEC membership (Binary) • Ratio of oil and gas reserves • Number of employees	• Annual oil and gas production • Revenues • Net income	87 oil firms (1987-2006)	Upstream

*TE- Technical Efficiency, SE- Scale Efficiency, PE- Price Efficiency/Revenue Efficiency, EE- Economic Efficiency/Profit Efficiency, AE- Allocative Efficiency, MPI- Malmquist Productivity Change Index, EC- Efficiency Change, TC- Technical Change, SFA- Stochastic Frontier Analysis, DEA- Data Envelopment Analysis*

## APPENDIX C

### Proof that the Malmquist Productivity Change Index is equal to the product of its decomposition

The Malmquist Productivity Change Index (MPI) is defined in Eqn. 1 as:

$$MPI(x^t, y^t, x^{t+1}, y^{t+1}) = \left[ \frac{\varphi^t(x^t, y^t)}{\varphi^t(x^{t+1}, y^{t+1})} \times \frac{\varphi^{t+1}(x^t, y^t)}{\varphi^{t+1}(x^{t+1}, y^{t+1})} \right]^{\frac{1}{2}} \quad \text{Eqn. 1}$$

The Efficiency change index (EC) and Technical change (TC) are also defined in Eqn. 2 and Eqn. 3 respectively below:

$$EC'(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{\varphi^t(x^t, y^t)}{\varphi^{t+1}(x^{t+1}, y^{t+1})} \quad \text{Eqn. 2}$$

$$TC'(x^t, y^t, x^{t+1}, y^{t+1}) = \left[ \frac{\theta^{t+1}(x^{t+1}, y^{t+1})}{\theta^t(x^{t+1}, y^{t+1})} \times \frac{\theta^{t+1}(x^t, y^t)}{\theta^t(x^t, y^t)} \right]^{\frac{1}{2}} \quad \text{Eqn. 3}$$

Therefore, the objective is to prove that:

$$MPI(x^t, y^t, x^{t+1}, y^{t+1}) = [EC'(x^t, y^t, x^{t+1}, y^{t+1})] \times [TC'(x^t, y^t, x^{t+1}, y^{t+1})] \quad \text{Eqn. 4}$$

By substituting Eqn. 1, Eqn. 2 and Eqn. 3 into Eqn. 4, the relationship can be rewritten as:

$$\begin{aligned} & \left[ \frac{\varphi^t(x^t, y^t)}{\varphi^t(x^{t+1}, y^{t+1})} \times \frac{\varphi^{t+1}(x^t, y^t)}{\varphi^{t+1}(x^{t+1}, y^{t+1})} \right]^{\frac{1}{2}} \\ & = \left[ \frac{\varphi^t(x^t, y^t)}{\varphi^{t+1}(x^{t+1}, y^{t+1})} \right] \times \left[ \frac{\varphi^{t+1}(x^{t+1}, y^{t+1})}{\varphi^t(x^{t+1}, y^{t+1})} \times \frac{\varphi^{t+1}(x^t, y^t)}{\varphi^t(x^t, y^t)} \right]^{\frac{1}{2}} \end{aligned} \quad \text{Eqn. 5}$$

However, the LHS of Eqn. 5 is replaced by  $MPI(x^t, y^t, x^{t+1}, y^{t+1})$  as expressed in Eqn. 1. Eqn. 5 can therefore be expressed as:

$$MPI(x^t, y^t, x^{t+1}, y^{t+1}) = \left[ \frac{\varphi^t(x^t, y^t)}{\varphi^{t+1}(x^{t+1}, y^{t+1})} \right] \times \left[ \frac{\varphi^{t+1}(x^{t+1}, y^{t+1})}{\varphi^t(x^{t+1}, y^{t+1})} \times \frac{\varphi^{t+1}(x^t, y^t)}{\varphi^t(x^t, y^t)} \right]^{\frac{1}{2}} \quad \text{Eqn. 6}$$

Removing the squared root from the Technical efficiency change section of Eqn. 6 will result in:

$$[MPI(x^t, y^t, x^{t+1}, y^{t+1})]^2 = \left[ \frac{\varphi^t(x^t, y^t)}{\varphi^{t+1}(x^{t+1}, y^{t+1})} \right]^2 \times \left[ \frac{\varphi^{t+1}(x^{t+1}, y^{t+1})}{\varphi^t(x^{t+1}, y^{t+1})} \times \frac{\varphi^{t+1}(x^t, y^t)}{\varphi^t(x^t, y^t)} \right] \quad \text{Eqn. 7}$$

The Efficiency change section of Eqn. 7 can therefore be expanded. As a result, Eqn. 7 can be presented as:

$$\begin{aligned} & [MPI(x^t, y^t, x^{t+1}, y^{t+1})]^2 \\ &= \left[ \frac{\varphi^t(x^t, y^t)}{\varphi^{t+1}(x^{t+1}, y^{t+1})} \times \frac{\cancel{\varphi^t(x^t, y^t)}}{\cancel{\varphi^{t+1}(x^{t+1}, y^{t+1})}} \times \frac{\cancel{\varphi^{t+1}(x^{t+1}, y^{t+1})}}{\varphi^t(x^{t+1}, y^{t+1})} \times \frac{\varphi^{t+1}(x^t, y^t)}{\cancel{\varphi^t(x^t, y^t)}} \right] \end{aligned} \quad \text{Eqn. 8}$$

The result of this is:

$$[MPI(x^t, y^t, x^{t+1}, y^{t+1})]^2 = \left[ \frac{\varphi^t(x^t, y^t)}{\varphi^t(x^{t+1}, y^{t+1})} \times \frac{\varphi^{t+1}(x^t, y^t)}{\varphi^{t+1}(x^{t+1}, y^{t+1})} \right] \quad \text{Eqn. 9}$$

Making  $MPI(x^t, y^t, x^{t+1}, y^{t+1})$  the subject will mean finding the square root of the right-hand side of Eqn.9. This can be presented as:

$$MPI(x^t, y^t, x^{t+1}, y^{t+1}) = \left[ \frac{\varphi^t(x^t, y^t)}{\varphi^t(x^{t+1}, y^{t+1})} \times \frac{\varphi^{t+1}(x^t, y^t)}{\varphi^{t+1}(x^{t+1}, y^{t+1})} \right]^{\frac{1}{2}} \quad \text{Eqn. 10}$$

The LHS can then be expressed as indicated in Eqn 1 as follows:

$$\left[ \frac{\varphi^t(x^t, y^t)}{\varphi^t(x^{t+1}, y^{t+1})} \times \frac{\varphi^{t+1}(x^t, y^t)}{\varphi^{t+1}(x^{t+1}, y^{t+1})} \right]^{\frac{1}{2}} = \left[ \frac{\varphi^t(x^t, y^t)}{\varphi^t(x^{t+1}, y^{t+1})} \times \frac{\varphi^{t+1}(x^t, y^t)}{\varphi^{t+1}(x^{t+1}, y^{t+1})} \right]^{\frac{1}{2}} \quad \square \quad \text{Eqn. 11}$$

Eqn. 10 is the final formula of the Malmquist productivity change index. Careful comparison with Eqn.1 will reveal that the two equations are equal. Therefore, it can be concluded that, the Malmquist productivity change index is a product of the Efficiency Change and the Technical Change indices.

## APPENDIX D

### Bootstrap Algorithm for Malmquist Productivity Index

The procedure for bootstrapping the Malmquist index and its components is based on the Simar and Wilson (1999). The bootstrapping approach involves generating a large number of pseudo samples and applying the original estimators to each of these new samples. This process can be summarized as follows:

1. Compute the Malmquist productivity index  $MPI_j(x^t, y^t, x^{t+1}, y^{t+1})$  for each firm  $j = 1, \dots, N$  by solving the linear programming models (2), (6), (7) and (8)
2. Construct a pseudo dataset  $\{(x_{jt}^*, y_{jt}^*); j = 1, \dots, N; t = 1, 2\}$  to form the reference bootstrap technology using bivariate kernel density estimation and the adaption of the reflection method proposed by Simar and Wilson (1999).
3. Compute the bootstrap estimate of the Malmquist index  $\hat{MPI}_j(x^t, y^t, x^{t+1}, y^{t+1})$  for each firm by applying the original estimators to the pseudo sample obtained in step 2.
4. Repeat steps 2 to 3 a large number of  $B$  times in order to provide a set of estimates for each firm.

This algorithm is computer intensive and therefore better handled by statistical programming software. The same algorithm is applied in bootstrapping the various decompositions of the Malmquist productivity index, by simply replacing the estimator with the particular component to be bootstrapped.

**APPENDIX E**  
**Annual Summary Statistics**

Year		Oil Output ('000 b/d)	Gas Output (MMcf/d)	Oil Reserves (MMBbls)	Gas Reserves (Bcf)	Employees (Numbers)
		Y1	Y2	X1	X2	X3
2010	Mean	1318.16	4324.64	25917.44	89535.00	102176.40
	Max	10007	49188	296501	1168599	1670000
	Min	28	118	61	1376	4019
	Std. Dev.	1586.05	7171.80	61436.36	205318.60	241446.70
	N	50	50	50	50	50
2009	Mean	1291.00	4049.62	23181.14	86014.04	102957.10
	Max	9713	44633	264100	1045700	1670000
	Min	21	116	81	1693	3452
	Std. Dev.	1560.79	6501.50	52765.73	191369.10	241055.50
	N	50	50	50	50	50
2008	Mean	1283.78	4283.06	18863.16	84013.96	97267.37
	Max	10846	53018	264100	1045700	1670000
	Min	57	486	452	1898	3584
	Std. Dev.	1697.77	7594.55	45150.11	192473.80	241722.60
	N	49	49	49	49	49
2007	Mean	1319.68	4148.79	19044.17	83212.77	94612.32
	Max	10413	53056	264200	987340	1670000
	Min	134	284	506	1025	1724
	Std. Dev.	1687.13	7751.35	46043.31	190622.30	248095.90
	N	47	47	47	47	47
2006	Mean	1315.92	4077.77	18595.68	83042.68	91848.28
	Max	10475	53772	264300	992990	1589000
	Min	49	431	407	918	1678
	Std. Dev.	1697.85	7834.01	45488.28	190267.00	236033.00
	N	47	47	47	47	47
2005	Mean	1320.00	3814.53	18391.04	82584.47	68606.36
	Max	11035	53135	264200	943900	439220
	Min	134	222	572	1639	1700
	Std. Dev.	1750.55	7751.17	45446.17	192409.90	96322.10
	N	47	47	47	47	47
2004	Mean	1255.46	3945.20	18131.63	96201.26	69088.65
	Max	9830	52574	262700	1140000	424175
	Min	76	299	560	1793	2214
	Std. Dev.	1624.64	7750.54	44820.70	232048.40	93222.48
	N	46	46	46	46	46

*Table 1: Continued*

		<b>Oil Output (<sup>'000</sup> b/d)</b>	<b>Gas Output (MMcf/d)</b>	<b>Oil Reserves (MMBbls)</b>	<b>Gas Reserves (Bcf)</b>	<b>Employees (Number)</b>
<b>Year</b>		<b>Y1</b>	<b>Y2</b>	<b>X1</b>	<b>X2</b>	<b>X3</b>
2003	Mean	1229.15	3703.85	17797.33	88823.88	66373.48
	Max	9045	52244	259400	988400	417229
	Min	111	192	578	938	2111
	Std. Dev.	1483.22	7579.75	43578.50	211052.00	90819.44
	N	48	48	48	48	48
2002	Mean	1154.23	3553.85	17592.13	100097.10	71553.83
	Max	8013	48000	261800	1320000	419598
	Min	49	109	136	1440	2003
	Std. Dev.	1353.98	7025.50	42409.46	250686.30	92230.95
	N	48	48	48	48	48
2001	Mean	1143.70	3565.87	18302.30	89544.87	76128.70
	Max	8301	49500	261798	1300000	510000
	Min	77	69	450	420	1358
	Std. Dev.	1411.82	7376.30	43023.67	231438.80	100031.50
	N	46	46	46	46	46

## APPENDIX F

## Dynamic Productivities of individual firms

ID	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average
	-	-	-	-	-	-	-	-	-	
	2002	2003	2004	2005	2006	2007	2008	2009	2010	
1	1.27	0.81	1.18	1.07	1.08	0.94	0.98	0.88	2.19	1.11
2	1.22	0.90	1.12	0.94	0.95	1.01	0.95	1.06	-	1.01
3	0.94	1.04	0.89	0.83	1.01	1.38	0.95	1.07	1.00	1.00
4	-	-	0.96	0.96	0.90	1.03	0.97	1.13	0.92	0.98
5	-	0.96	1.08	1.19	1.25	1.06	0.83	0.98	0.89	1.02
6	0.96	0.96	1.16	1.05	0.97	0.96	1.01	1.07	1.00	1.01
7	-	0.95	1.04	0.94	-	-	-	-	-	0.97
8	0.99	0.95	0.98	0.92	1.04	1.05	0.97	1.00	1.09	1.00
9	-	-	-	-	-	-	1.07	0.63	1.25	0.94
10	-	-	-	-	-	0.92	1.00	0.98	0.88	0.94
11	-	-	-	-	0.78	1.08	0.87	1.17	0.93	0.95
12	0.90	1.43	0.88	1.11	1.08	1.04	0.97	1.08	0.97	1.04
13	-	0.95	1.09	0.88	0.85	0.99	1.00	0.96	1.00	0.96
14	1.35	0.62	1.08	1.24	0.95	1.18	1.15	-	-	1.05
15	0.83	1.08	0.91	0.99	0.99	0.95	1.12	1.28	0.79	0.98
16	-	-	-	-	-	-	-	-	-	-
17	0.88	1.15	1.11	0.89	1.62	0.56	0.98	-	-	0.98
18	1.07	1.00	1.07	1.13	1.04	0.95	0.98	1.05	1.01	1.03
19	1.01	0.99	1.06	1.01	1.05	1.01	0.89	0.99	1.04	1.01
20	0.96	1.17	0.95	1.36	1.12	0.95	0.99	0.83	1.09	1.04
21	-	-	-	-	-	-	-	-	0.95	0.95
22	-	-	-	-	-	1.03	-	-	-	1.03
23	-	-	-	-	-	-	0.96	0.28	1.22	0.69
24	1.04	1.52	0.95	1.09	0.91	1.04	1.22	0.89	1.02	1.06
25	-	-	-	-	-	-	-	0.90	1.14	1.01
26	0.42	1.46	0.67	1.04	1.02	1.01	1.02	1.18	1.03	0.93
27	0.81	1.13	0.79	0.90	1.18	0.81	1.13	1.17	0.96	0.98
28	0.94	1.10	1.06	0.99	1.07	1.01	0.99	1.00	0.99	1.02
29	-	1.20	0.74	1.02	0.92	0.99	0.93	0.94	0.88	0.94
30	1.09	1.13	1.16	1.00	1.08	-	-	-	-	1.09
31	-	-	-	-	-	-	-	0.92	1.10	1.01
32	-	0.93	-	-	0.93	0.91	0.93	1.02	1.13	0.97
33	-	-	-	2.97	1.04	1.08	0.97	0.96	1.04	1.22
34	0.87	1.28	1.34	0.84	1.07	1.03	0.99	1.01	0.99	1.03
35	0.94	1.36	0.68	0.90	1.00	0.90	1.08	1.03	1.09	0.98
36	1.03	0.95	1.06	0.99	0.95	0.61	0.81	1.07	0.89	0.92
37	2.27	1.08	1.04	1.02	1.04	1.05	0.94	1.00	0.99	1.11
38	1.01	0.99	1.14	0.30	0.91	1.30	1.05	1.12	1.24	0.94
39	1.04	0.96	0.96	1.08	0.96	0.92	1.02	1.08	0.96	1.00

## Continued

ID	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average
	-	-	-	-	-	-	-	-	-	
	2002	2003	2004	2005	2006	2007	2008	2009	2010	
40	1.17	1.21	0.97	0.88	-	-	-	-	-	1.05
41	0.99	1.01	0.99	0.99	-	-	-	-	-	0.99
42	0.94	0.62	0.99	0.90	1.02	1.05	0.94	0.94	0.76	0.90
43	0.85	4.92	1.13	1.40	0.82	1.11	1.21	1.06	1.23	1.28
44	-	-	-	-	-	-	-	-	1.60	1.60
45	1.05	1.15	1.12	1.28	1.17	1.00	0.99	0.97	0.97	1.07
46	0.65	5.22	0.58	2.36	0.76	1.26	0.72	1.01	1.08	1.15
47	1.00	1.32	1.29	0.92	0.95	1.00	1.02	0.80	1.08	1.03
48	0.95	1.14	1.07	1.16	0.95	0.98	1.00	0.89	1.03	1.02
49	1.35	1.64	-	-	-	-	-	-	-	1.49
50	2.08	-	-	-	-	-	-	-	-	2.08
51	1.03	1.12	0.99	1.03	1.04	0.93	1.01	1.03	1.10	1.03
52	-	-	-	-	-	-	-	-	-	-
53	0.99	1.00	1.00	0.84	1.17	0.96	1.06	0.90	0.94	0.98
54	0.77	1.41	0.97	1.09	1.02	0.99	1.02	0.90	0.88	0.99
55	-	-	0.78	1.27	0.89	0.52	1.00	1.06	0.96	0.90
56	1.09	1.04	1.00	0.96	1.00	1.17	1.10	1.00	0.94	1.03
57	-	-	-	-	-	-	-	-	1.48	1.48
58	1.12	1.09	0.96	1.06	1.03	0.92	0.95	1.02	0.93	1.00
59	-	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-	-
61	-	-	0.89	1.12	1.61	0.79	0.71	0.83	0.67	0.91
62	1.10	1.02	1.02	0.98	0.96	1.07	0.98	0.97	1.10	1.02
63	0.81	-	-	-	-	-	-	-	-	0.81
64	0.97	0.96	0.91	-	-	-	-	-	-	0.95
65	-	-	-	-	-	-	-	0.92	1.04	0.98
66	0.85	1.54	-	-	-	-	-	-	-	1.15
<b>Average</b>	<b>1.00</b>	<b>1.16</b>	<b>0.98</b>	<b>1.04</b>	<b>1.01</b>	<b>0.97</b>	<b>0.98</b>	<b>0.96</b>	<b>1.03</b>	<b>1.014</b>

## APPENDIX G

## Tukey HSD Multiple Comparisons of Productive Efficiencies

Dependent Variable	(I) OL	(J) OL	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
veff	LNOC	LIOC	-.10648315*	.03581613	.016	-.1988231	-.0141432
		MNOC	-.19453080*	.02692690	.000	-.2639529	-.1251087
		MIOC	-.25662402*	.02150246	.000	-.3120610	-.2011871
	LIOC	LNOC	.10648315*	.03581613	.016	.0141432	.1988231
		MNOC	-.08804766	.03826303	.099	-.1866962	.0106008
		MIOC	-.15014088*	.03466060	.000	-.2395017	-.0607800
	MNOC	LNOC	.19453080*	.02692690	.000	.1251087	.2639529
		LIOC	.08804766	.03826303	.099	-.0106008	.1866962
		MIOC	-.06209322	.02536967	.070	-.1275005	.0033140
	MIOC	LNOC	.25662402*	.02150246	.000	.2011871	.3120610
		LIOC	.15014088*	.03466060	.000	.0607800	.2395017
		MNOC	.06209322	.02536967	.070	-.0033140	.1275005
scale	LNOC	LIOC	-.18693204*	.03458163	.000	-.2760893	-.0977748
		MNOC	-.01277103	.02599880	.961	-.0798003	.0542582
		MIOC	-.12699447*	.02076133	.000	-.1805206	-.0734683
	LIOC	LNOC	.18693204*	.03458163	.000	.0977748	.2760893
		MNOC	.17416101*	.03694420	.000	.0789127	.2694093
		MIOC	.05993757	.03346594	.279	-.0263432	.1462184
	MNOC	LNOC	.01277103	.02599880	.961	-.0542582	.0798003
		LIOC	-.17416101*	.03694420	.000	-.2694093	-.0789127
		MIOC	-.11422344*	.02449524	.000	-.1773763	-.0510706
	MIOC	LNOC	.12699447*	.02076133	.000	.0734683	.1805206
		LIOC	-.05993757	.03346594	.279	-.1462184	.0263432
		MNOC	.11422344*	.02449524	.000	.0510706	.1773763

\*. The mean difference is significant at the 0.05 level.