THE EFFICIENCY OF THE OIL FUTURES MARKETS: INFORMATION, PRICE DISCOVERY AND LONG MEMORY

SAADA ABBA ABDULLAHI

A Thesis Submitted to the University of Abertay Dundee for the award of

the Degree of Doctor of Philosophy

UNIVERSITY
of
ABERTAY DUNDEE

Dundee Business School

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Dedication

To my son Mohammed Hassan Hassan

Acknowledgement

First, I would like to thank Almighty God, for providing me with different opportunities and progress throughout my life. My great gratitude also goes to my supervisors Prof. Reza Kouhy, Prof. Heather Tarbert and Dr. Zahid Mohammad for their support, guidance and constructive comments in the process of writing this thesis. I also want to express my appreciation to Dr. Kazem Falahati (External examiner) and Prof. Mohamed Branine (Internal examiner) for their contributions and comments.

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Saada Abba Abdullahi

Declaration

I, Saada A. Abdullahi hereby certify that this thesis has been written by me, that it is the record of work carried out by me and that it has not been submitted in any previous application for a higher degree.

Signature of candidate [redacted]....   Date ...12/11/12.........

Certification

I certify that this thesis is the true and accurate version as approve by the examiners, and that all relevant ordinance and regulations have been fulfilled.

Signature of Director Study .[redacted]..12/11/12

Abstract

This thesis investigates the efficiency of the crude oil futures markets by addressing four important issues using different theoretical and methodological perspectives. Data of different frequencies was employed in the analysis covering the period 2000 to 2011. First, the short and long term efficiency is examined by testing the unbiasedness of the oil futures price in predicting the expected spot price using the Johansen (1988) and the Engle-Granger (1987) cointegration tests, and the Error Correction Model (ECM). The results suggest that the oil futures markets are unbiased in the long term but not in the short term, and the inefficiency is not caused by the time-varying risk premium. The results also show that the oil futures market are unbiased in the multi-contract and multi-market framework but not in all maturities. Second, the price discovery relationship between the oil spot and futures markets and across contract is investigated by employing the Vector Error Correction Model (VECM), Gonzalo-Granger (1995) common factor weight approach and the Garbade-Silber (1983) short run dynamic model. Empirical results indicate that price discovery is initiated in the futures market because it impounds more information than the spot market. However, the results of the cross-contract analysis show that the three-month futures contract leads one-month contract in price discovery while the relationship changes in the short term. Third, the price change and trading volume relationship is examined in the oil futures markets using the generalized method of moments (GMM), Granger causality test, impulse response function and variance decomposition approaches. The findings reject the postulation of a positive relationship between price change and trading volume, suggesting that they are not driven by the same information. Additionally, the results suggest that trading volume cannot predict price changes in all the oil markets. Lastly, this thesis investigates long memory in the oil futures return using the GARCH models, and the results indicate that both the short and long memory models support predictability in returns which violates the weak form efficient hypothesis. In sum, the findings provide new evidence on the informational efficiency of the international oil futures markets, which have significant implications for hedgers, speculators, financial analysts and policymakers. The thesis recommends that market participants and regulators should look at various aspects of these markets for effective strategies and policy implementation.

Table of Content

List of Tables

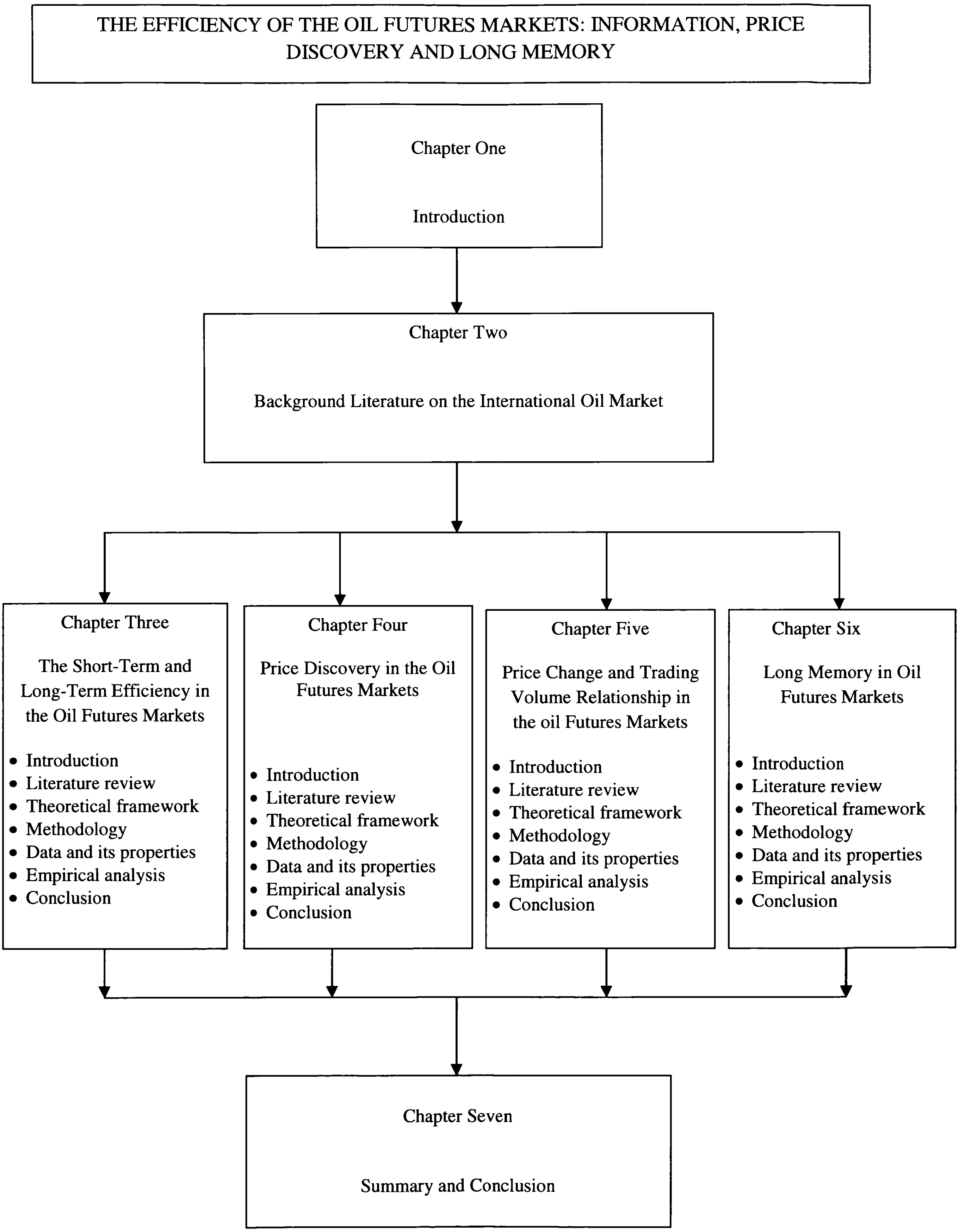
List of Figures

List of Abbreviations

ADF	Augmented Dickey-Fuller Unit Root Test
AIC	Akaike Information Criterion
ARCH	Autoregressive Conditional Heteroskedasticity Model
APARCH	Asymmetric Power Autoregressive Conditional Heteroskedasticity Model
API	The American Petroleum Institute scale for measuring the specific gravity of crude oil
BP	British Petroleum Company
CFW	Common Factor Weight Approach
DF	Dickey-Fuller Unit Root Test
DGP	Data Generating Process
DME	Dubai Mercantile Exchange
ECM	Error Correction Model
EIA	Energy Information Administration U.S
EMH	Efficient Market Hypothesis
EGARCH	Exponential GARCH Model
FIAPARCH	Fractional Integrated APARCH Model
FIEGARCH	Fractional Integrated EGARCH Model
FIGARCH	Fractionally Integrated GARCH Model
FPE	Final Prediction Error Criterion
GARCH	Generalized Autoregressive Conditional Heteroskedasticity Model
GARCH-M-ECM	GARCH in Mean Error Correction Model
GMM	Generalized Method of Moments Approach
GS	Garbade-Silber Short –Run Dynamic Model
HYGARCH	Hyperbolic GARCH Model
ICE	London Intercontinental Exchange

I (*d*)	Integrated of Order d
IGARCH	Integrated GARCH Model
IS	Information Share Approach
IPE	London International Petroleum Exchange
IV	Instrumental Variable
JB	Jarque-Bera Normality Test
KPSS	Kwiatkowski, Phillips, Schmidt and Shin Unit Root Test
LR	Log Likelihood Ratio Test
MDH	Mixture of Distribution Hypothesis
NYMEX	New York Mercantile Exchange
OLS	Ordinary Least Squares Method
OPEC	Organization of Petroleum Exporting Countries
PT	The Permanent-Transitory Component
PP	Phillips-Perrons Unit Root Test
SIC	Schwartz Information Criterion
SIMEX	Singapore International Monetary Exchange
VAR	Vector Autoregressive Model
VECM	Vector Error Correction Model
WTI	West Texas Intermediate Crude oil
WTRG's	West Texas Research Group
ZA	Zivot-Andrew Unit Root Test

Figure1.1: The Structure of Thesis



CHAPTER ONE

Introduction

Crude oil has been one of the most important global and actively traded commodities since the mid-1950s, and changes in its prices have strong influence on the economy at international, national and local levels. A large number of empirical literature have documented the impact of high and volatile oil prices on macroeconomic variables such as economic growth (Cologni and Manera, 2009), investment (Chen et al , 2007), inflation (Hahn, 2003; Yang et al, 2004), commodity markets (Chaudhuri, 2001) and the global financial markets (Cheong, 2009) and even (the likelihood of) recession (Hamilton, 1983). On another front, fluctuation in oil prices may affect hedging decisions, or distort relative prices and the optimal allocation of resources (Elder and Serletis, 2008). Prolonged volatility in oil prices can also expose market participants to high risk and to heavy losses in turn (Cheong, 2009). Moreover, substantial fluctuation in oil prices can give potential opportunities to exploit arbitrage gain.

However, despite policies and strategies implemented to improve price stability, the international crude oil market has faced higher price volatility in recent years. This volatility has been caused by many factors, including changes in supply and demand, transaction costs and reserves (Pindyck, 2001). Other factors, such as low spare capacity, weakness of the US dollar, geopolitical concerns, competition, speculative activities, military conflict, natural disasters and OPEC decisions have also contributed to the rise in prices (Berkmen et al, 2005; Charles and Darne, 2009; Cheong, 2009). Recently, the unrest caused by the so-called Arab spring has also driven prices up (WTRG's, 2012). Since the year 2000, when oil was sold at an average of $25.21 per barrel, prices have been steadily increasing, reaching $28.20 in 2002, $46 in 2004 and $71.81 by 2006. They reached the highest price ever-$145 per barrel in July 2008, from where they declined to $33 in December 2008; in 2009 they began at $45 and stood at an average of $70-$80 per barrel until late 2010. Prices then rose sharply to $113.93 in late April 2011, before decreasing to approximately $97 per barrel by December 2011. This was followed by an increase again in 2012, rising to above $100 per barrel in February 2012. Such volatility in oil prices indicates the possibility of the existence of market inefficiency.

According to Fama (1970), an efficient oil futures market is that in which prices fully reflect all relevant and available information, so that arbitrage opportunities cannot be exploited consistently. The futures market for oil was established since the early 1980s to allow market participants to hedge the high risk and uncertainty in oil prices due to the unreliable spot market (Foster, 1994). This market allows speculators willing to accept risk to trade oil futures in order to profit while consumers, producers, distributors and other economic bodies use the futures price in making their investment decisions. Today, the oil futures markets trade more than 80 per cent of the world's crude oil production and also make significant contribution in determining oil prices. Therefore knowledge of whether or not these markets are operating efficiently is crucial particularly with continuous price fluctuation because it can assist investors and market participants in making effective investment decisions, as well as portfolio risk management. Moreover, it can guide energy policymakers to adopt the most appropriate policies and strategies for both the oil industry and the global economy. Despite the extensive research in this area, most of the existing literature has focused on the performance of the US West Texas Intermediate (WTI) oil market, the world's most actively traded crude oil futures contract. However, others such as the UK Brent Blend and Dubai Fateh have received less attention, and need to be investigated in order to increase a better understanding of the international oil futures markets.

This thesis contributes to the literature by examining the performance of the international crude oil markets: the West Texas Intermediate and Brent crude oil futures markets. The UK Brent Blend is the world's second marker crude, used to set the price of more than 70% of world crude oils and its market trades the second most-active oil futures contracts. These two markets have therefore been selected because they trade the world's benchmark crude oils and their spot and futures markets are well-established. Furthermore, this thesis employs recent advances in econometric methodology, and the data used covers the period of recent oil price increases.

The broad objective of the thesis is to examine the efficiency of the crude oil futures markets during the period from January 2000 to May 2011. In doing so, the thesis has four specific objectives, which are:

- To examine the short term and long term efficiency of the oil futures markets.
- To investigate price discovery in the oil futures markets.

- To examine the price change and trading volume relationship in the oil futures markets.
- To investigate the long memory properties of the oil futures markets.

Although these objectives are based on different theoretical perspectives and methodological approaches, they are each concerned with the markets' informational efficiency. These issues and their individual contributions, literature review, methodology and results are discussed in separate chapters. This chapter provide a brief discussion on the findings and the structure of the thesis.

The structure of this thesis is as follows. Chapter two discusses the background literature on the oil industry and its international oil market, providing an understanding of the history of oil and the role played by different economic bodies in the development of the modern oil industry. The chapter discusses the growth and development of the oil spot and futures markets.

Chapter three examines the efficiency of the crude oil futures markets in the short- and long-term by testing the unbiasedness hypothesis; that is, the assumptions of risk neutrality and rational expectations of the market participants. This chapter further investigates the multi-market and multi-contract efficient hypothesis in the crude oil futures markets. Long-term efficiency is investigated using Johansen (1988) and the Engle-Granger (1987) cointegration tests, while short-term efficiency is investigated using the Error Correction Model (ECM), allowing for existence of a constant and a time-varying risk premium. The data used in this chapter are monthly closing spot and futures prices at one, two and three-months contract to maturities during the sample period from January 2000 to May 2011; the results indicates that the WTI crude oil futures market is weak form efficient within one and three-month maturities in the long term, while the Brent market is only weak form efficient at one-month maturity. The short-term efficiency test indicates that both markets are weak form inefficient, and specifically that the time-varying risk premium is not the cause of the inefficiency in all markets. Furthermore, the empirical evidence show that both the multi-contract and multi-market efficiency test provides mixed conclusion on the semi-strong efficient hypothesis across the markets and maturities.

Chapter four studies the price discovery between the crude oil spot and futures markets and across the futures contracts using three standard models: the Vector Error Correction Model (VECM), Gonzalo-Granger (1995) common factor weight approach and the Garbade-Silber (1983) short run dynamic model. The data analysed are daily closing spot and futures prices at one- and three-month contracts from January 2000 to May 2011. The empirical results show that the process of price discovery occurs in the WTI and Brent futures markets in all the maturities. The results of the cross-contract analysis indicate that the three-month futures contract leads the one-month futures contract in price discovery in all markets; however, in the short term, the relationship changes with one-month contract dominating the process.

Chapter five analyses the price change and trading volume relationship in the oil futures markets using the generalized method of moments (GMM), Granger causality test, impulse response function and variance decomposition approaches. This chapter used data for daily futures prices and their corresponding trading volumes for one-month over the period from January 2008 to May 2011. The results rejects the assumption of a positive contemporaneous relationship between trading volume and price change in both the WTI and Brent markets, which contrasts with the mixture of distribution hypothesis. Moreover, the results show that neither trading volume nor returns have the power to predict the other in all markets, which rejects the sequential arrival hypothesis and the noise trader model but supports the market efficient hypothesis.

Chapter six investigates long memory in the oil futures prices using the GARCH-class models. The data used in the analysis are daily closing futures prices at one- and three-month contracts to maturities from January 2000 to May 2011. Empirical results from the long memory models show that FIGARCH, FIEGARCH, FIAPARCH and HYGARCH support the presence of a high degree of persistence, which decays at a slow hyperbolic rate in the WTI and Brent returns at the different maturities. Additionally, the results of the short memory models, GARCH, EGARCH and APARCH, also confirm that the returns exhibit predictability component which violates market efficiency.

Chapter seven summarizes and concludes the findings of this thesis, discusses the policy implications of the research and also offers suggestions for future work.

CHAPTER TWO

Background Literature on the International Oil Market

2.1 Introduction

This chapter provides a brief discussion on the oil industry and its international market. The chapter enables the reader to understand the history of oil, oil production, oil pricing, and the spot and futures markets for oil. This chapter discusses the role and contribution made by different economic bodies to the development of the modern oil industry. Overall, this chapter aims to increase understanding of the oil industry in general and the development of the oil futures market in particular.

The international oil market plays a significant role in global economic development, particularly considering the increase in the importance of oil, of which global consumption has reached approximately 85.6 million barrels a day (EIA, 2009). Oil contributes to the social, economic and political activities of almost any country, and given its importance, changes in oil price have economic impact on both exporting and importing oil countries (Moosa, 1995). Empirical evidence has revealed that higher oil prices may cause transfer of income from oil consumers to the producer; unemployment; high cost of production; a decrease in consumer confidence; a reduction in investment, and inflation to oil importing countries (Nandha and Faff, 2008). For the oil exporting countries, decrease in oil prices may create serious budgetary problems (Abosedra and Baghestani, 2004), while high oil prices can lead to Dutch Disease syndrome through an increase in inflation, appreciation in the real exchange rate, and decrease in the manufacturing output and employment (Mohammadi, 2011).

Since the First World War, oil has become a commodity of strategic interest and of high importance especially to industrialized countries whose economic activities and progress heavily dependent on oil. Due to these the international oil market has been experiencing high fluctuations in prices caused by factors such as war, geopolitics, and supply and demand constraints, among others. Such volatility makes the spot market for oil to be unreliable because markets participants are exposed to high risk and uncertainty. As a result, the futures market for oil was introduced to serve as an effective instrument for hedging and speculating on oil prices.

This chapter is organised as follows. Section 2.2 provides a brief review of the history of oil industry. The section discusses the development of the oil industry, from its origins to the modern era. Section 2.3 deals with oil production, multinational firms and producer nations. In this section the contribution to world oil production of the major oil companies (the Seven Sisters), independent oil companies and producer nations are discussed. Section 2.4 covers oil prices, OPEC and the market. This section aims to provide an understanding of different events that have affected oil prices and the international oil market and it also explores the role played by the Organization of Petroleum Exporting Countries (OPEC) in influencing oil prices. Section 2.5 examines the international oil markets, dealing with the growth of the spot market for oil, and the subsequent establishment and development of the oil futures market. Section 2.6 summarize and conclude the chapter.

2.2 History of the Oil Industry

The history of the oil industry can be traced as far back as the period before the industrial revolution. During this era, oil was one of the important commodities required for economic activity. In the West, where it was found in spring and salt wells around oil creeks in North Western Pennsylvania, USA, it was called “Rock oil”, and was used for medicinal purposes. The rock oil was supplied in small quantities and obtained using traditional methods, such as skimming or soaked in rags and blankets in oil water (Yergin, 2008). In the Middle Eastern countries, oil was obtained - as it had been since 3000 BC - through natural seepage of asphalt bitumen, sourced from mountain cracks in what was once Mesopotamia. In this area, oil was used for medicinal poultices and in making weapons and mastic in construction (Giebelhaus, 2004). Although there was only a small market for oil, it was the most highly traded commodity and integrated the people around the area (Giebelhaus, 2004).

As the global population began to grow, the demand for oil outstripped the available supply and as a result, in the West investigation into the other properties of rock oil began. In 1850, George Bissell discovered that rock oil could be used as an illuminative substance. In early 1854, an American named Professor Silliman who was hired by Bissell and other group of businessmen further investigated the properties of rock oil and found that it could serve as an illuminative and lubricating substance (Yergin, 2008). Following his successful experiment, Silliman, along with other investors, formed the Pennsylvanian Rock Oil Company in the United States. At the same time, a small oil industry had already been formed in the Eastern European region where cheaper refined kerosene for lamps was being traded in areas such as Galicia and Romania (Yergin, 2008). Until 1859, these areas had sourced their illuminate from animal and vegetable origins, as well as other petrochemicals; this changed with the discovery, by Dr. Abraham Gesner, of a means to produce kerosene from coal. By the year 1858, the demand for illuminate had also outstripped supply, while rapid industrial growth further increased demand for oil. As results, another oil company was established, the Seneca Oil Company, with the aim of finding oil in large quantities. On 27th August, 1859, Edwin L. Drake, who had been hired by Seneca, discovered oil at approximately 69ft in Titusville, Pennsylvania. As a consequence, the business expanded and oil production in Pennsylvania increased from about 450,000 barrels per day in 1860 to 3 million barrels in 1862 (Yergin, 2008). This rapid growth of the industry was caused by factors such as free entry and exit into the business, the use of small capital and traditional techniques, lack of geological knowledge of oil exploration, expectation of high return and the Pennsylvanian law of capture that gave the owner of the land the right to drill oil without restrictions (Giebelhaus, 2004; Yergin, 2008; Eden, 1981).

In 1865, John D. Rockefeller, a twenty-six-year-old American, joined the business after winning an auction from his partner Maurice Clark in Cleveland, Ohio. This event marked the beginning of the modern oil industry. Rockefeller first started as a refiner, but within five years he had become the world leader in oil refining. By the late 1860s, the oil industry had grown to the extent that increased competition and overproduction had pushed it into depression. As a response, Rockefeller and five other major oil producers met and formed the Standard Oil Company on 10th January 1870. The goal of Standard Oil was to regulate oil prices and therefore protect the industry from further depression. By 1871, production had increased to about 4.8 million barrels a day, which led to the establishment of a formal exchange in Titusville where oil could be traded in three possible ways: either on a regular basis, where the transaction took place within ten days; spot sales, where the oil was traded for immediate delivery; or future sales, where oil was traded at a certain quantity and for delivery at a particular period of time (Yergin, 2008). By the year 1883, Standard Oil had expanded so dramatically that the company now owned the pipelines through which oil was extracted from the Eastern United States (Sampson, 1988). Standard Oil later formed a partnership with the railroad committee, with the result that by the end of the 1870s, Standard Oil had become the leader in the oil industry, and had acquired almost all the refineries in the United States. In 1879 it produced more than 90% of the oil supply in the USA (Eden, 1981) and by 1900 about 86% of crude oil production and 82% of refining capacity was under their control, and also produced about 85% of all the gasoline and kerosene that was sold in the United States (Giebelhaus, 2004).

Despite the fact that oil was discovered in other areas of the country and new oil companies had entered into the business, the Standard Oil Company still dominated oil production, refining, marketing and price setting, and this would continue until 1911, when antitrust legislation, in order to break the company's monopoly, forced Standard Oil to separate into a number of subsidiaries. Among the 38 companies in the group only three - Exxon (formerly Esso or, Standard Oil of New Jersey), Social Standard of California and Mobil (Standard of New York) - expanded and together with four other companies - two from the southern US (Gulf and Texaco) and two from Europe (Shell and British Petroleum) - became the world's major oil companies (Eden, 1981). These seven companies, known as the "Seven Sisters", later dominated and made significant contributions to the development of the modern oil industry.

2.3 Oil Production, Major Oil Companies and Producer Nations

The major oil companies, or "Seven Sisters", are multinational oil companies that once controlled and dominated the world oil production. Prior to 1920s, the majors operated separately, but by the end of 1930s, they had become highly integrated both vertically and horizontally which enabled them to take control of the global oil market (Penrose, 1968), in part because they supplied more than 80% of the world's oil. Until the end of the First World War, the majors had owned and controlled oil production in their own geographical locations. During the war, oil became a necessity because for a country to survive it had to depend on oil (Sampson, 1988). As a result, the oil producer nations had a significant advantage over the non-producer nations, because oil became a sign of status, prestige, power and also a weapon for the countries that produced it. It was not surprising, then, that following the war, the most powerful countries' interest in controlling the world's major oil producing areas rose noticeably; this interest naturally focused on the Middle East, because the area was said to have the world's largest oil reserves. Britain was the first to start exploration in Iraq once called Mesopotamia, followed by France in Baghdad, while later supply shortages in the United States shifted the interest of the Americans towards taking control of Middle Eastern production. The presence of these three developed countries in the same area led to intense competition and conflict between them as each wanted to acquire the largest share and control production. Thus, oil production in the Middle East came under the control and therefore the countries of the majors (Yergin, 2008).

On the other side, the idea of oil equalling power, and the high profit earned by the major oil companies prompted the producer nations to seek nationalization. It also led to the emergence of new oil companies outside the Seven Sisters. By the mid-1920s, a move towards nationalization of oil production had begun in Mexico, the second largest oil producer nation, when the union of oil workers went on strike demanding higher wages; yet due to the United States' intervention to protect their own companies it was unsuccessful. However, the emergence of the new companies and producer nations reduced the dominant power and share of the majors in the international market because oil was being produced and sold at a cheaper price. By 1927, there was an increased flow of cheaper oil from the Soviet Union and other countries such as Venezuela and Rumania, as well as the Middle East region, which caused overproduction, intense competition and increased cost of investment in the oil industry (Yergin, 2008). These industry problems led the major oil companies to establish two different agreements in 1928. The first was the Red Line Agreement, signed between America, France and the Anglo-Dutch Oil Company under which the major oil companies were restricted from operating independently around the

Persian Gulf region. The second was the Achnacarry Agreement (Global Agreement) signed between the three major oil companies of Jersey, Anglo-Persian and Shell and the parent governments of Kuwait and Saudi Arabia. The agreement forced the three major oil companies operating in the areas to have a unified oil price.However, these measures gave the new independent oil companies the opportunity to fix their own oil price above that of the majors so that they could beat the market and acquire a larger share. As a result of this, certain of the majors violated the agreements and sold outside the agreed price in order to maintain their position in the industry. By 1929, the increase in competition between the independent and major companies, together with the discovery of oil in new fields, brought an end to the global agreement.

In the early 1930s, three of the major oil companies (Jersey, Shell and Anglo-Persian) established another local agreement under which the companies would have equal control and shares in the European markets. Yet the agreement failed because of an increased supply from new producer countries (Yergin, 2008). Again in the mid-1930s, the major oil companies signed the Blue Line Agreement which gave them equal share and control over production in Bahrain, Kuwait and Saudi Arabia. Furthermore, the As-Is (Global Agreement) was re-established in 1934 based on Dutch principles, but was only effective for a limited time and finally collapsed with the coming of the Second World War. After the Second World War, the producer nations' interest in nationalization increased, as they felt that the majors had an advantage over them. In 1938, the government of Mexico forced the operating oil companies to nationalize because of their failure to improve the welfare of their workers (Eden, 1981). In the same year, Venezuela, a country in which oil accounted for more than 60% of the national income, increased the royalty payments of the major companies operating in the country (Eden, 1981). In other places the oil producing countries imposed different measures and restrictions on the oil companies so as to regulate their operations, while in some areas, the majors were forced to form cartels with the domestic oil companies, or to divide their market share with the government of the producer states.

The measures taken by these countries began to weaken their relationship with the major oil companies, and in addition gave the new oil companies a greater chance of survival, and acquire larger share in the global oil market. Furthermore, the relationship between the majors and the producer nations had changed; the producer nations now viewed the activities of the majors as exploitative, both retarding economic development and creating political tension (Yergin, 2008). In contrast, the majors felt they should have control of oil exploration because they had been responsible for the economic progress of these nations and, in addition to investing huge amounts of capital, had taken all the risk in production (Yergin, 2008). In March 1943, Venezuela announced a petroleum law called the Fifty-Fifty (50/50) Agreement, under which the oil companies and the Venezuelan government had an equal share in oil profits (Eden, 1981). This agreement forced the oil companies to sell at fixed prices rather than at their so-called "posted price" which was based on how the oil companies sold their oil (Sampson, 1988). The same agreement was established in Saudi Arabia on 30th December, 1950. In the year this agreement was formed, the royalties paid by the major companies to the government of Saudi Arabia increased from $6 million to $110 million (Yergin, 2008). By the mid-1950s, the "fifty-fifty agreement" had reached other Arab nations; it was implemented in Iraq in 1952 and then spread to the rest of the world. Despite the fact that the fifty-fifty agreements gave the governments of the producer nations more power over their oil industry, the majors' share in oil production of non-communist areas outside the United States alone was still more than 70 percent in the 1950s (Adelman, 1972). The fifty-fifty agreement continued until 1957 when the Saudi Arabian government signed the "fifty-six-forty-four" (56/44) agreement with Japan. After a year Iran entered into a 75/25 agreement with Italy. However, the fifty-fifty agreement was later changed to posted price due to a problem with the calculations involved (Cremer and Salehi-Isfahani, 1991). The posted price was based on the cost of production and tax paid by the major oil companies to the governments of producer countries (Eden, 1981).

By the end of the 1950s, increased competition between the newcomers and the majors, alongside the plentiful supply of cheap oil from the Soviet Union, had caused a fall in oil prices. As a result, the major oil companies decided to cut their posted prices so that they could survive the competition. In February 1959, British Petroleum cut their oil price by almost 10%, from $2.04 to $1.84 (Giebelhaus, 2004). On 9th August 1960, Standard Oil of New Jersey also cut their posted price by almost 14 cents per barrel, which reduced about 7% of the Middle Eastern crude oil (Yergin, 2008). These cuts in oil price subsequently caused a serious reduction in the revenues of the producer nations. As a consequence, the five major oil exporting countries (Kuwait, Saudi Arabia, Venezuela, Iran and Iraq) met in Baghdad on 14th September 1960, and formed the Organization of Petroleum Exporting Countries (OPEC). Between them, these countries supply the global economy with more than 80% of the world's crude oil production. The goal of the organization was to restore the price of oil and protect it from further cuts by the major oil companies; it also aimed to protect the revenues of its member countries. It quickly grew as other oil producer nations, such as Libya, Qatar, Indonesia, Abu-Dhabi, Algeria, Nigeria, Angola, Gabon and Ecuador, applied for membership and was accepted. However, the Organization currently consists of 12 Member Countries because Gabon withdraws its membership in 1995 and Indonesia on hold from January 2009.

2.4 Oil Prices, OPEC and the Market

Since the initial development of the oil industry, the global oil price has been controlled by a number of different economic bodies. In the nineteenth centuries, oil prices were set by the Rockefeller Standard Oil Trust; from the 1930s the government of the United States, breaking the agreement, gave the Texas Railroad Commission the right to control oil production and price. By the 1940s, the price of oil was under the control of the major oil companies (the Seven Sisters). The majors set prices based on what was known as the "Gulf Plus": the price paid in the Gulf of Mexico, plus the cost of transporting it to the point of consumption (Chalabi, 2004). This changed to the posted price in the 1950s due to the emergence of new, independent oil companies and oil producer nations. In 1960, OPEC was formed to restore the falling price of oil and to protect the revenues of its member countries; OPEC oil price is based on the maker crude (Saudi Arab Light) for which the members agreed to sell their oil. Although

OPEC does not set the world oil price, its posted price does influence the price of oil because the majors, independent oil firms and non-OPEC producer nations fix their price by looking at the OPEC basket price. Apart from this the organization also makes a significant contribution in regulating the global oil price. During its early years, OPEC was unable to achieve any of its set goals because the major oil companies still owned the concessionaries; furthermore, the increased supply of oil from new producer countries and the import quotas imposed in the United States to protect its domestic producers during the period reduced the power of OPEC to compete in the world oil market. Cremer and Salehi-Isfahani (1991) point out that oil prices reached their lowest point of approximately \$1.29 per barrel in 1969, and therefore, despite the fact that OPEC members produced 90% of globally traded oil, the major companies still controlled about 92% of their production (Foster, 1994).

In spite of this, in its early years OPEC succeeded in shaping the structure of the oil industry in different ways first, OPEC protected oil prices from high volatility and further cuts by the majors. Secondly, the governments of the producer nations were able to participate in oil production and price setting. Thirdly, the organization was able to restructure the tax system in such a way that the taxes paid to producer nations by the operating oil companies were in line with those of the Gulf of Mexico (Chalabi, 2004). These measures helped the major oil companies to maintain their dominant position in the industry and also reduced competition and the ability of the independent oil companies to increase their market share. Thus, between 1960 and 1966 the share of the major oil companies rose from 72% to 76% in the upstream operation, and from 53% to

61% in the downstream operation (Chalabi, 2004). In June 1966, OPEC announced a "Declaratory Statement of Petroleum Policy" by member countries. This marked the first step in giving the organization the rights to fix oil prices independently and to engage in concession agreements with the majors. This policy therefore shifted the attention of the majors to Africa where oil had already been discovered in some areas such as the Sahara in Algeria and the Niger Delta in Nigeria in 1956 and at Zelten in Libya in April 1959 in an attempt to diversify their production. Before the year 1970, the supply of crude oil from these countries, and Libya in particular, had led to a dramatic change in the global oil market. Libyan oil had the advantage of being of high quality, containing less sulphur compared to that of the Persian Gulf, and Libya itself is comparatively close to Europe. In 1969, Libya supplied one quarter of the oil consumed in Western Europe (Sampson, 1988). Between 1960 and 1969, overproduction from Libya caused a drop in world oil prices by more than 22% per barrel (Yergin, 2008). Additionally, the majority of Libyan production was supplied by independent oil companies outside the majors. By the end of 1969, the rise to power of Colonel Qaddafi increased the posted price of Libyan oil, and the share of the government in oil production from 50% to 55%. During this period the world oil prices reached $3 per barrel which is a decline of more than $19 per barrel and $14 per barrel from 1958.

In January 1971, the major oil companies agreed to negotiate price setting with OPEC for the first time in order to break competition with the new oil companies and producer nations; however, the Shah of Iran refused the agreement because he wanted a concession only between the oil companies and the oil price of the

Persian Gulf. As the pressure mounted, on 14th February 1971 OPEC delegates met with the members of the major oil companies in Tehran, and agreed an increase in their oil price of $0.35 and a tax ratio of about 5% (Chalabi, 2004). In April of the same year, OPEC announced the Tripoli agreement under which the posted price of oil for OPEC members in the Mediterranean countries (Saudi Arabia, Libya, Iraq and Algeria) was increased by 90% (Yergin, 2008). After these agreements were established the price of oil was stable at $3 per barrel until the outbreak of war in Vietnam. Although their involvement in South-East Asia was to prove disastrous for the United States, it did succeed in effectively "colonizing" other nations, resulting in its position as one of the two "superpowers". The influence of America meant that Britain had to stop oil exploration in the Middle East; the removal of British influence allowed independence but also gave way, in turn, to the insecurity and geopolitics of the Middle Eastern region. At the same time, there was worsening conflict between the Shah of Iran and Saudi Arabia over who should lead the Persian Gulf region and the devaluation of American dollar also caused great turmoil in the oil industry.

In mid-September of 1973, OPEC met in Vienna to renegotiate the Tehran and Tripoli agreement because they realized that the major companies were profiting at their expense. The negotiation was not successful because OPEC wanted a 100% increase in oil prices, and the major companies would agree to only a 15% increase (Eden, 1981). At the time of this re-negotiation, the Yom Kippur war then broke out between an Arab coalition and Israel, alongside war between Egypt and Syria. The conflict between the Arabs and Israeli had escalated;

Israel's support from the United States and the Netherlands prompted other Arab countries to use their oil as a weapon to protect and support those they saw as their brothers. On 16th October, OPEC members from the Persian Gulf met in Kuwait and unilaterally increased the posted price of oil to $5.40 barrel - an increase of about 70% (Eden, 1981). OPEC members and the Arab countries, with the exception of Iraq, also made the decision to cut oil production by 5% each month to the United States and Netherlands, as well as to any country which supported Israel, until the conflict was resolved. On 18th October, Saudi Arabia announced a 10% cut in oil production to the United States and Netherlands. This unprecedented embargo had a huge impact on the oil industry in particular and the world economy in general, especially in the industrialized countries. It also led to shortages of oil and a doubling of its price (Sampson, 1988). With no sign of an end to the war, OPEC members met again in Tehran and agreed to raise the posted price of oil to $11.65 (Yergin, 2008). This gave the Shah of Iran, whose interest lay in having control over the oil production of the Persian Gulf, the opportunity to increase Iranian oil prices from $5.40 to $10.85 per barrel (Chalabi, 2004). These two phenomena raised the world price of oil to $12 per barrel in 1973 and, in turn, led to the first price shock in the oil industry.

As a consequence, the European countries decided to move to support OPEC and the Arab countries, in order to protect their economies from further disruption. On the other side, the oil consumer countries began to adopt different measures and to establish energy policies that would reduce oil consumption. Yet in June 1979, when the global economy had barely recovered from the first oil price shock, another tremendous rise in oil prices occurred. The second oil price shock was caused by the ascension to power of Ayatollah Khomein in Iran, and the Iranian oil workers' strike. As a consequence, the world oil production reduces by more than 4 million barrels per day as Iranian oil supply was limited to internal consumption until March 1979. This event increased the world oil price from $14 to about $30 per barrel and production reduce by about 10 percent. No sooner had the Iranian production was cut, Saudi Arabia increased production from 8.5 million to 10.5 million barrels per day which reduce the posted price to $24 per barrel; in January 1980 it lowered its daily production ceiling to 8.5 million barrels. In mid-September 1980, OPEC members met in Algeria and agreed to cut production in order to restore oil prices; on 22nd September, as OPEC members were meeting again in Vienna to negotiate, the Qudisiyya war broke out between Iran and Iraq. This reduced global oil production by about 4 million barrels a day and increased oil prices to $42 per barrel. During the war Saudi Arabia increased its supply, and its oil price to about $34 per barrel, while non-OPEC members were selling at less than $30 per barrel in order to capture the market. In October 1981, OPEC members met with Saudi Arabia in an attempt to unify their oil prices, but the meeting was not fruitful because of the failure of the OPEC members to agree concessions. OPEC members agreed to a fixed price of $36 per barrel while Saudi Arabia agreed on $32 per barrel.

By 1983, oil production from the non-OPEC countries was higher than that of the OPEC members, and there was increasing competition in the global oil market. In February 1983, Britain cut the price of North Sea oil from $33 to $30 per barrel, an action which had a serious economic effect on OPEC members, especially those countries whose oil was of the same quality as that of the North

Sea. In March 1983, OPEC also cut its oil price and production from $34 to $29, and agreed on a quota system to protect its members (Aarts, 1999). However, increased production from non-OPEC members had, in 1984, reduced the market share of OPEC by more than 30% from its peak in the 1970s (Aarts, 1999) and as a result, some of the OPEC members violated their quotas and sold their oil at a lower price. In 1985, Saudi Arabia initiated a new oil policy outside OPEC, the focus of which was to restore market share rather than price stability. Suddenly, the price of oil from the United States rose dramatically to $31 per barrel while that of the world oil market crashed to less than $10 per barrel - causing the third oil price shock. By 1986, OPEC's posted price of oil had fallen from $30 to less than $5 per barrel, with that of Saudi Arabia reaching about $8 per barrel; as a result, the global oil price declined to less than $10 per barrel. In 1987, OPEC decided to adopt Saudi Arabia's pricing policy and introduced a new quota system in 1990. As a consequence of this new policy, OPEC's oil price rose to $15 and $22 per barrel in September and December of 1987 respectively (Treat, 2004) while during the same period the world oil price stood at approximately $18 to $20 per barrel. However, with the growth of the oil futures market, oil price came under the control of the market forces of supply and demand and OPEC therefore began to base the posted price of their oil on the total quantity of the global supply and demand for oil.

Oil prices remained stable throughout 1990 until Iraq invaded Kuwait in January 1991, which caused an increase in the price of oil from $26 per barrel to $30 per barrel in the same month. Following Iraq's defeat by the United States and its allies, the oil price stood at $18 and $22 per barrel, although it had declined to about $10 in 1998. Prices began to rise to their previous levels and had reached more than $28 by the end of 1999. This changed after the attacks on Washington and New York by Al-Qaida on September 11th 2001, which was followed by the outbreak of war between the United States - which aimed to remove President Saddam Hussein - and Iraq, in March 2003. These two events caused the new oil price shock in the oil industry. During this period, oil prices rose from $25 per barrel to $50, and reached $70 between 2001 and 2005. Oil price continue to increase and reached about $90 per barrel in 2007 and it highest ever at $145 per barrel in July 2008 from where it again declined to $30 in the same year. This decline pushed the global economy into recession. Since then oil prices have been highly volatile, particularly when compared to events that affected the market before the twentieth century. Oil price began at $70 in 2009 and reached $80 per barrel 2010. The political unset in Arab countries increase the price of crude oil prices to $125 in early 2011 and slightly decline to about $111.1 in December 2011. Some of the factors that contributed to the current oil price increase include weak dollar condition; low spear capacity, rapid economic growth and increase consumption in Asia, military conflict, geopolitical concerns and the U.S refinery problems (WTRG's, 2010). Figure 2.1 shows the fluctuations and events that affected the world crude oil prices from 1861 to 2011.

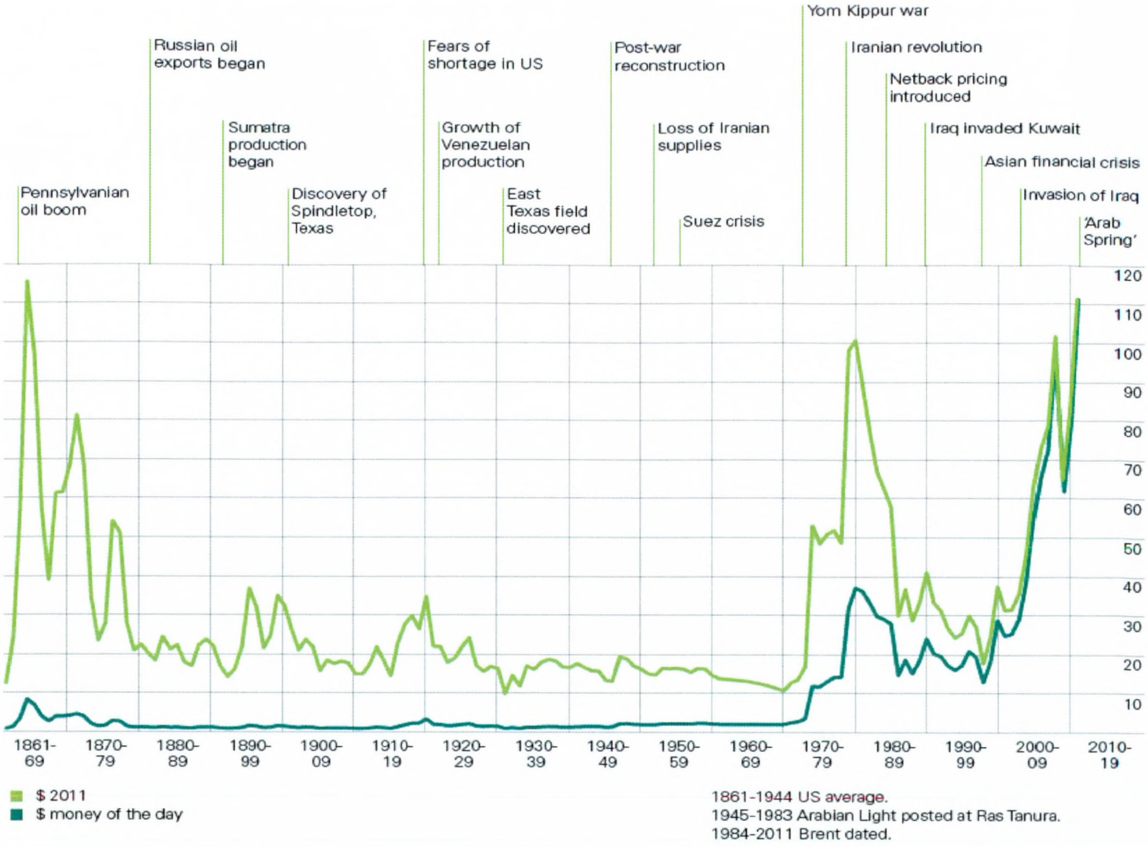


Figure 2. 1: Crude Oil Prices 1861-2011

Source: BP Statistical Review 2012

2.5 The International Oil Markets

The international oil market is comprised of the spot and the futures markets for oil. The spot market for oil deals with short-term contracts where oil is traded for immediate delivery of not more than ten days. On the other hand, the futures market for oil deals with long term contracts where oil is traded at a specific market price for delivery at specific future period from fifteen days long to months and up to a year. Historically, oil has been produced, refined and sold in the international market by the major oil companies in the *spot market* under short term contracts since the 1960s. However, the spot market trading had been relatively small - accounting for not more than 3 to 5 percent of international traded oil (Gulen, 1998). During this period, oil was traded only to local and regional markets because of the high cost of delivery (Adelman and Lynch, 2004); this continued until the 1970s, when the new independent oil companies emerged and began to engage in oil refining. These independent oil companies do not participate in oil production but buy, process and sell their oil to consumers on the spot to make immediate profit (Claudy, 1986). Furthermore, the nationalization of OPEC and non-OPEC countries also contributed to spot market activities, while increased production from the new oil companies and producer nations enlarged the size of the spot market. It also weakened the ties of the major oil companies in both upstream and downstream operations of the industry (Claudy, 1986).

By the early 1980s, spot market trading had increased, and accounted for almost 10 per cent of the international oil trade. Yet participation in spot market trading was still very small, until after the second oil price shock. In 1983, the disruptions in the oil industry and nationalization in Nigeria and other OPEC countries led British Petroleum (BP) to engage in spot market trading (Yergin, 2008). BP began buying and selling oil in large quantities and at a lower cost than its major partners, which prompted the other major oil companies to also start participating in spot market trading. Between the early and mid -1980s, the volume of crude oil traded in the spot market increased from 50% to 65% respectively (Foster, 1994). Before the year 1986, more than half of the internationally traded crude oil was sold in the spot market and the major oil companies had acquired almost 30% to 50% share in oil supply (Yergins, 2008).

Oil was traded in the spot market at five major centres: the Gulf of Mexico, North-West Europe, the Mediterranean, the Caribbean and Singapore (Claudy, 1986). The Gulf of Mexico, based out of Houston, is the world's largest crude oil spot market and is supplied by South America, the United Kingdom and Nigeria, while North-West Europe, based on the cargo market and located out of London, is supplied primarily by gasoline from the USSR. The Mediterranean, based on Italy's west coast, is supplied by local refineries from the west Italian coast and Islands. The Caribbean is the smallest and least active spot market, supplying the United States with gasoline and fuel oil, and Singapore is the fastest growing and supplies oil to South East Asia, Japan and the Persian Gulf (see Claudy, 1986).

Although spot market trading has grown very fast, on the other hand it has led to increase in the oil price volatility and consequently exposes the weakness of the market because participants are faced with high risks and uncertainty (Foster, 1994). As a result the oil companies and independent refiners have developed various measures aimed at stabilizing the fluctuation in crude oil prices. Spot market trading also shifted to an informal forward market where oil was traded for 30 days, and then 60 days and then 90 days (Treat, 2004). However, the forward market was inefficient because it was unable to provide the market participants with the available information regarding market conditions and (Foster, 1994) as result of this ineffectiveness; the futures market for oil was introduced to serve as a more effective tool for hedging on oil prices. The high fluctuation in spot oil prices and the need for hedgers to minimize risk and reduce uncertainty led oil to begin trading in the *futures market* over long term contracts[1]. The crude oil futures market aim was to serve the functions of price discovery, risk management and speculative opportunity. Prior to the lunch of oil contract in the New York Mercantile Exchange (NYMEX), and until the late 1950s, the market engaged in trading agricultural commodities on term contract. This changed in 1960 when financial instruments were introduced. In 1978, the deregulation of the heating oil prices led NYMEX to introduced heating oil futures contract No.2 and fuel-oil contract No.6. In their early stages, the markets for these crude oils were very small with only a few contracts traded per day. By the end of 1984, trading in heating oil alone had risen to about 20,000 lots a day with open interest of around 37,000 marks (Claudy, 1986). This success together with increased uncertainty and high risk in the spot market trading led NYMEX to introduce gasoline contract in 1982.

In 1983, NYMEX introduce the crude oil contract based on West Texas Intermediate. In the year the WTI contract was established the Chicago Board of Trade (CBT) introduced contracts for unleaded gasoline and crude oil based on light Louisiana sweet. However, the markets for the contracts were not able to survive, the exception being West Texas Intermediate crude oil. Before the end of 1983, the NYMEX crude oil contract had attracted more than 80 per cent of the fifty largest oil companies and almost all the major oil exporting and importing countries to future trading. In April 1981, the London International Petroleum Exchange (IPE) launched the gasoline contract and North Sea crude. It introduced the Brent Blend contract in November of 1983 and the unleaded gasoline contract in January of 1992. However, the Brent contract was not

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[1] Long term contract is when oil is traded at a specific market price for delivery at specific future period from fifteen days long to months and up to a year.

successful because of delivery problems. After some modifications the Brent contract was re-launched on 23rd June 1988. This was due to mounting pressure and the failure of the market participants to accept West Texas Intermediate as the only hedging instrument (Claudy, 1986). After several years of re-establishment the Brent futures contract has made remarkable progress, and the volume of the Brent contract traded has increased to approximately $100 billion per day.

This rapid growth of the futures market led the Singapore International Monetary Exchange (SIMEX) to establish futures contracts for Dubai sour crude oil in February 1989 and Gas oil in June 1991. On June 2002, E-mini futures contract on natural gas and light sweet crude oil were lunched by NYMEX and Chicago Mercantile Exchange (CME). These markets are less half the size of their regular futures markets and are traded electronically through CME and their goal was to cater for investors that cannot participate in regular futures trading (Tse, 2005). In August 2004, the Shanghai Futures Exchange (SHFE) also lunched the China's fuel oil futures contract due to the increased fluctuation in oil prices and demand for fuel in China (Chen, 2009). Again, the high volatility in oil prices and need for pricing benchmark crude for the Asian countries which import oil from the Middle East, the Oman crude oil futures market was launched by Dubai Mercantile Exchange (DME) in June 2007. This was because the bulk of the Middle Eastern oil is comprised of sour and heavy crude, therefore the WTI and Brent futures markets would not serve as effective pricing instruments (Fattouh, 2008). The New York Mercantile Exchange (NYMEX), the International Petroleum Exchange (IPE), the Singapore International Monetary Exchange

(SIMEX), the Shanghai Futures Exchange (SHFE) and the Dubai Mercantile Exchange (DME) are the known established oil futures markets. These markets use a variety of instruments in futures trading. Although these crude oil futures markets are related, they each operate independently from one another, which make them to operate efficiently. NYMEX is by far the largest and its light sweet oil contract (West Texas Intermediate) is one of the world's largest traded commodities. The West Texas Intermediate is located in the United States, it has an API gravity of 39.6 degree and contain about 0.24 percent of sulphur. These two properties make it to be light sweet crude oil and have a very good quality. In 1991, NYMEX traded energy futures at the rate of 160 million barrels per day (Roeber, 1993). By 2007, the volume of crude oil traded in NYMEX has reached about 1 billion barrel per day and continue to increase.

The London International Petroleum Exchange (IPE) is the second largest futures exchange because of its deals with the world's most highly traded crude oil contract (Brent). Brent crude oil also serves as a leading global benchmark for Atlantic Basin crude oils and low sulphur crude, particularly grades produced from Nigeria and Angola, as well as Louisiana light sweet from the Gulf coast, and West Texas Intermediate from the United States. Brent crude oil is located in the North Sea in UK and has an API gravity of 38.3 degree and contains 0.37 per cent of sulphur. Brent also has a good quality but is not as light and sweet as WTI. In 1991, the IPE energy futures trading rose to about 45 million barrels per day. During this period NYMEX and IPE traded crude oil at a volume almost three times the world oil consumption (Roeber, 1993). By the year 2000, the volume of energy futures traded in IPE has reached 1,778,142 million per barrel.

It further increased to 199,328,366 million in 2005 and reached 199,328,366 million per barrel in December 2010 with Brent crude accounting for almost 50% of the total volume in each of the years (ICE, 2011). In early 2000s, the London International Petroleum Exchange (IPE) was changed to Intercontinental Exchange (1CE). The Shanghai Futures Exchange is the third largest and its fuel oil contract has attracted many investors. The monthly trading volume of this contract has increase from 34523 Lot in 2004 to 84305 in 2007, and suddenly declined to 46629 in 2008 (Chen, 2009). By mid-2009, the volume of this contract traded has increased to 6.8 trillion Yuan which make it the third largest energy futures contract in the world. Moreover, despite the global financial crisis and the disruptions in the international oil market this futures contract has been successful, thus indicating the effectiveness of the control mechanisms that operates in this market.

Finally, SIMEX and DME are the smallest crude oil futures markets ever. The SIMEX oil futures contract was able to survive for only a few years and collapsed around 1992, due to problems with both delivery and financial instruments. While, the DME is still in operation but has the lowest contract volume. In December 2007, the volume of its contract increased to 27,000 with physical delivery of more than 6,000 (Fattouh, 2008). However, this does not guarantee that the DME futures market will survive in the long term and (Fattouh, 2008) stated that for it to survive and perform its function of price discovery and risk management required the liquidity of the market to increase.

2.6 Summary and Conclusion

This chapter provides background introduction on the oil industry and the development of the oil futures markets. It can be seen that throughout the history, the oil industry has experience disruptions and high volatility in prices caused by different events. The crude oil prices have also been controlled by different economic bodies until the establishment of the futures market for oil, which was the most remarkable change that the oil industry has ever experienced in its history. First, this market serves the functions of risk management, thereby allowing the hedgers to reduce their risk and the uncertainty of price changes. Second, it allows free competition between the oil companies, independent oil refiners, trading companies and producer nations. Third, it provides consumers, producers, distributors and investors with information on oil prices. Finally, it provides speculators the opportunities to make arbitrage profit. This thesis explores the informational efficiency of the crude oil futures markets using different theoretical and methodological approaches.

CHAPTER THREE

The Short-Term and Long-Term Efficiency of the Oil Futures Markets

3.1 Introduction

In recent years, the high volatility in oil prices has attracted the attention of market participants, researchers and policy makers regarding the efficiency of the crude oil futures markets. Market efficiency, or the efficient market hypothesis, refers to the conditions where asset prices fully reflect available and relevant information (Fama, 1970). In an efficient market, neither undervalued nor overvalued assets are traded, and the assets price serves as appropriate tool that can help in capital budgeting and resources allocation (Ortiz-Cruz, 2011; El Hedi Arouri et al, 2010)[2]. Fama (1970) also divide the efficient market hypothesis into three types based on the information set Ω: weak-form, semi-strong and strong-form efficiency. The weak-form efficient hypothesis requires that the asset price should reflect all available information, including past price information; the semi-strong efficient hypothesis asserts that asset price should reflect all publicly available information (e.g. annual reports, announcement on stock splits, interest rates and inflation), and, strong-form efficiency requires that the asset price should reflect private information preventing even stockholders from using inside information to exploit market opportunities.

In the futures market, efficiency refers to the condition where the current futures price responds instantaneously to any information, making it an unbiased predictor of the future spot price. This notion refers to the unbiasedness or simple

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[2] Market efficiency implies that resources are allocated effectively; therefore market participants cannot trade “undervalued stock “in order to beat the market opportunities.

efficiency hypothesis used to test whether the futures market is information efficient (Hansen and Hodrick, 1980). The unbiasedness hypothesis is based on two assumptions: first, that market participants are risk neutral, implying that risk premium does not exists in the futures market, and second, that market participants make rational use of all available information about market conditions. These two assumptions form the joint hypothesis of the futures market efficiency test for risk neutral people. If the joint hypothesis of risk neutrality and rational expectation holds, then the futures market will be efficient, and the reverse is the case of market inefficiency which may lead to one of the following conclusions: (1) inefficiency may exist in the market; (2) the futures market may be efficient but the forecast is biased due to a constant risk premium; or (3) the futures price may be inefficient because a time varying risk premium prevails in the market (McKenzie and Holt, 2002). It can also mean that there are no homogenous expectations.

The objective of this chapter is to examine the short and long term efficiency in the crude oil futures markets by testing the unbiasedness hypothesis[3]. Although there is considerable research in this area, there is no clear consensus as to whether the futures market is efficient or not (see Mamatzakis and Remoundos, 2010; Charles and Darne, 2009; Maslyuk and Smyth, 2008; Switzer and El-Khuory, 2007; Gülen, 1998; Moosa and Al-Loughani, 1994 and Serletis and Banack, 1990). However, majority of these studies have concentrated on the efficiency of the West Texas Intermediary crude oil futures market. Previous

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[3] Short term efficiency refers to the condition where the current future price is an unbiased predictor of the expected sport price within period of intraday to a week depending on the maturity of the contract. On the other hands long term efficiency is where the current future market price is an unbiased predictor of the expected sport price within period of a week to maturity of the futures contract.

research has also been devoted to testing for long-term efficiency; rather less attention has been paid to the market's short-term dynamics. Furthermore, past studies were concerned with the weak-form efficiency and have also ignored the possibility of the existence of a risk premium, while evidence has shown that risk averse investors may bias the futures market (Beck, 1993). This chapter addresses four important research questions: Are the WTI and Brent crude oil futures markets efficient in the long term? Are these markets efficient in the short term? Do time-varying risk premium exists in these markets? Are these oil futures markets multi-market and multi-contract efficient[4]? Finally, are these markets efficient in different maturities? In this chapter, the thesis contributes to the knowledge and understanding of the efficiency in the crude oil futures markets in the following ways:

1. It investigates the unbiasedness hypothesis in two benchmark crude oil futures markets: West Texas Intermediate and Brent crude oil. Knowledge on the behaviour of different crude oil futures markets provides new insight into the efficiency of the international oil markets.
2. It examines the short- and long-term efficiency of the crude oil futures markets, but different from the previous studies, the analysis allows for a constant and a time varying risk premium. The Engle-Granger (1987) and the Johansen and Juselius (1988) cointegration tests are applied to test the long-term efficiency, while the Error Correction Model (ECM) is used to explore the short-term dynamics.

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[4] Multi-contract efficiency is the market condition where the current futures price is an unbiased predictor of the expected spot price with the addition of another contract from the same market. The multi-market efficiency is the market condition where the current futures contract prices is an unbiased predictor of the expected spot price with addition of another contract from different market.

3. It also examines the multi-contract and multi-market efficiency hypothesis, which, to the best of my knowledge no previous study has done. As Otto (2011) pointed out, the multi-market and multi-contract perspective would provide additional information about market efficiency because investors take into account these interrelationships before making investment decisions.
4. It differs from previous studies as this chapter tests both the weak-form and semi-strong form efficient hypothesis in the oil markets at different maturities.
5. It provides new evidence on the unbiasedness behaviour of the crude oil futures markets using a data set that covers the most recent fluctuations in oil prices between January 2000 and May 2011.

The chapter is structured as follows: Section 3.2 summarises the relevant empirical literature on the efficiency of both these markets and other non-oil commodities in order to ensure a better understanding of previous studies' findings. Section 3.3 discusses the theoretical framework, providing an understanding of the theoretical basis of the efficiency of the futures market. Section 3.4 discusses the methods employed, while section 3.5 discusses the sources and type of data. Section 3.6 presents the empirical results that were obtained from the analysis and the final section 3.7 summarise the findings and presents conclusions.

3.2 Literature Review

There is considerable literature that investigates the efficiency of the oil futures markets using the unbiasedness hypothesis, and what has been done has offered mixed conclusions. This section is divided into two parts. The first part discusses the literature on the oil futures market, while the second explores the literature on non-oil commodity futures markets where the same theoretical and methodological approach has been applied, in order to have a greater understanding of the area.

3.2.1 The Oil Futures Market

Among the first studies to investigate the unbiasedness hypothesis; that is, the joint assumptions of risk neutrality ($\alpha = 0$) and rational expectations ($\beta = 1$) of the market participants in the oil futures market by applying the cointegration approach is Serletis and Banack (1990). The authors investigated the efficiency of three petroleum futures contracts traded in the NYMEX: crude oil, heating oil and unleaded gasoline using the Engle-Granger cointegration test. The data used in their analysis were daily spot and second-month futures contracts and they used the spot month futures as proxy for current spot prices while the second-month futures were used as current futures prices. The results show that the prices are cointegrated in all the three oil markets; the coefficients of α and β were nearly 0 and 1, respectively. From this the authors conclude that there is strong evidence of market efficiency in NYMEX petroleum futures contracts. However, they failed to examine the joint restriction hypothesis test ($\alpha = 0 \text{ and } \beta = 1$) which is the sufficient condition for market efficiency. Again, the analysis in this study was based on the Engle-Granger cointegration test, known to have less power in efficiency testing. Crowder and Hamed (1993), continuing the research in this field, examined the simple efficiency and arbitrage equilibrium hypotheses in the NYMEXWTI crude oil futures market by employing the Johansen cointegration test, to avoid the weakness of the Engle-Granger approach. The authors argued that the rejection of the simple efficient hypothesis does not imply that risk premium prevails in the market, but instead results from the need for compensation by investors for the risk they have taken. Using monthly futures price, spot price and US 3-month interest rate, they found that the oil prices are cointegrated. Furthermore, they could not reject the null of the joint restriction hypothesis test ($\alpha = 0, \beta = 1$) and therefore support the unbiasedness hypothesis in the WTI market. They also found that the arbitrage equilibrium hypothesis is rejected because the returns on risk-free rate are not equal to the returns on speculation which violates the semi-strong form efficient hypothesis. According to the authors opinion these is caused either from lack of interest on the risk-free returns that can be earn by traders or there is cointegration between the unobserved convenient yield and the risk-free rate.

In their study, Moosa and Al-Loughani (1994) tested the speculative efficient hypothesis in the WTI market using monthly spot and futures prices at three and six- month contracts. The authors argued against the ideas of Crowder and Hamed (1993), as they proposed that the unbiasedness hypothesis is rejected may be because of the irrational expectations of participants or a time varying premium exists in the market. However, they pointed out that the former is difficult to test without survey data and there is a lack of theoretical support regarding assumptions that market participants can differ, so as a result they focused on investigating the existence of the time varying risk premium. To avoid the problem of data overlapping, they favour the Engle-Granger cointegration test based on Phillips and Ouliaris' residual tests, rather than the Johansen cointegration approach, because the latter is based on VAR dynamics. In testing efficiency they addressed three important issues: firstly, whether the expected spot price can be predicted with current futures price; secondly, whether it can provide good prediction for the spot price and finally, the existence or absence of a time-varying risk premium. They found that prices are cointegrated, supporting the first condition for market efficiency. Their results also show that the joint restriction hypothesis is rejected; implying that the expected spot prices can be predicted using the futures price at the different maturities. Finally, by applying the ARCH model, they established presence of a time-varying risk premium. According to the authors, the rejection of the unbiasedness hypothesis was because of the varying risk premium, but they also cautioned that the results cannot be generalized for all energy products and suggests that it should be compared with that obtained from other oil markets.

In contrast to these previous studies, Foster (1994) investigated the unbiasedness hypothesis among international oil markets in order to reach a generalized conclusion on oil futures market efficiency. The author tested the unbiasedness hypothesis in two benchmark crude oil futures markets: WTI and Brent crude, as well as examining the short-term efficiency using the error correction model. The data are monthly spot and futures prices at one, two- and three-month contracts to maturities. Using the Johansen cointegration test the results show cointegration between the prices in all, except Brent market at three-month contracts; likewise, the joint restriction hypothesis test was rejected only in Brent at one and three-month maturities. In the short-term analysis, the results only support the unbiasedness hypothesis for WTI one-month contracts, while Brent was inefficient in all the maturities. The author presents a number of interesting findings: first, that market efficiency varies in the short- and long-term, and across maturities. Secondly, the international oil futures markets behave differently; as he points out, the WTI futures market is more efficient because its size and trading volume is larger than that of the Brent market. He concludes that only the WTI futures market is long-term efficient, and both are short-term inefficient. However, a criticism that can be made of this study is that Foster does not go further in testing the reasons for the rejection of the unbiasedness hypothesis, unlike previous studies Moosa and Al-Loughani (1994) and Crowder and Hamed (1993), which have shown the possibility of a time-varying risk premium.

Gulen (1998) extended previous studies and re-examined the simple efficient hypothesis in the NYMEXWTI monthly spot and futures prices for 1, 3 and 6-month contracts. His study is based on the Engle-Granger approach and the Perron (1989) ADF unit root test that accounts for the existence of structural changes. The author argued that the use of conventional unit root tests is inappropriate and will produce spurious results when dealing with oil price series. He examined three different types of relationship in the oil price series: spot-contract, spot-futures and spot-contract-futures. He chose February 1986 as the period when the largest structural changes occurred. He found that the oil prices are cointegrated and the joint restriction of $\alpha = 0$ and $\beta = 1$ holds in the three maturities. Furthermore, the results indicate that the posted prices have less power in explaining the expected spot prices. He observed that the difference between his results and that of Moosa and Al-Loughani (1994) was that he account for structural changes and the data covers a longer period. Peroni and McNown (1998) applied the informative and non-informative tests to NYMEXWTI crude oil, heating oil and unleaded gasoline, again using monthly data. The results of the informative test based on the Phillips-Lorenten cointegration estimate support the unbiasedness hypothesis in all three oil futures markets. However, the results of the non-informative test indicate that while the markets for unleaded gasoline and heating oil are predictable, the WTI market is not. Observing that, after correcting for the specification of the model, the result of the data generating process shows efficiency in all three futures markets, they further examined the predictability of the forecast error and found that the semi-strong form efficient hypothesis is supported in unleaded gasoline and heating oil markets while only the weak-form efficient hypothesis hold in the WTI crude oil. They then argued that the mixed conclusions on the oil futures efficiency were due to the use of different approaches, and suggested that the stochastic properties of the variables should be accounted for as part of a valid test of market efficiency.

Kellard et al (1999), building on the literature of market efficiency, developed a measure of relative efficiency for the commodity futures markets. The authors argued that previous studies are concerned with either market efficiency or inefficiency, but have failed to look at the degree to which the efficiency exists. They pointed out that the test for market efficiency would not provide exact information regarding market inefficiencies because the former has different ranges. Using monthly data for two oil (Brent crude and gas oil) and four non-oil commodity futures markets, they found that in the Brent market the prices are cointegrated and the joint restriction hypothesis could not be rejected in the long-term. To measure the relative efficiency, they used the quasi-error correction model based on a 28-day and 56-day forecast horizon, and consequently found that the unbiasedness hypothesis cannot be supported in the short term, thus confirming market inefficiency. They concluded that the oil futures markets are long-term efficient, but arbitrage possibilities exist in the short run. However, they fail to detail reasons for this short-term inefficiency.

Abosedra (2005) re-examined the simple efficient hypothesis in the NYMEXWTI crude oil futures market, using the ordinary least square and Phillips and Lorentan cointegration tests; in contrast to previous studies, the monthly spot and futures prices are proxies of their average daily prices. The empirical results indicate that cointegration exist between the prices and the joint restriction hypothesis of $(\alpha, \beta = 0,1)$ cannot be rejected in both models, and therefore the future spot price cannot be predicted with the current futures price, supporting the weak-form efficient hypothesis. He also examined the predictability of the forecasting error in order to establish whether lagged futures prices can improve univariate forecast. The results show that past information on the univariate forecast cannot improve the futures market forecast, while the lagged futures price can be used to improve the univariate forecast, leading him to conclude that the univariate forecast is weakly efficient while the futures market forecast is semi-strong form efficient. Additionally, Switzer and El-Khoury (2007) tested the unbiasedness hypothesis in NYMEX light sweet using daily and monthly data during the period of extreme conditional volatility. They employed the Fama (1984) regression approach and the Johansen (1988) cointegration test and found that in the Fama approach the results support the unbiasedness hypothesis and the presence of risk premium. These results are also confirmed by the Johansen cointegration, which supports the weak-form efficient hypothesis in the long term for all the frequencies. Their study also examined hedging effectiveness. Thus, both Kellard et al (1999), Abosedra (2005) and Switzer and El-Khoury (2007) studies have the limitation of restricting their analysis to only weak form efficiency test.

Shuping et al (2007), using a modified model, examined the simple efficiency in the NYMEXWTI, heating oil and unleaded gasoline futures markets. They introduced convenience yield and risk premium as lagged spot prices in the analysis, arguing that risk premium exists only in spot markets because only small portion is provided by investors to the total margin when trading futures contracts. The data used in their analysis were monthly spot prices, futures prices and interest rates, and by applying the Engle-Granger test, the results in the WTI market support the existence of cointegration between the variables. However, they observed that the joint hypothesis of simple efficiency test does not hold, implying that the market is biased in the long term. According to the author the unbiasedness hypothesis is rejected because of the presence of a risk premium. In order to confirm their results they further divided the study into three sub-periods, leading them to observe that the hypotheses of simple efficiency and arbitrage equilibrium do not hold in the first stage, while only simple efficiency holds in the second and the third stage supported both hypotheses. They therefore concluded weak-form efficiency in the second stage and semi-strong efficient in the third. Maslyuk and Smyth (2009) also applied the Gregory and Hansen cointegration test to daily spot and futures prices at one and three-month contracts for the WTI and Brent crude oil markets, and the results indicates that the oil prices are cointegrated in all maturities, thus supporting the weak-form efficient hypothesis in both markets in the long run. But they also do not go further to investigate the joint restriction of the market efficiency test.

Extending previous work, Kawamoto and Hamori (2010) considered the efficiency of the NYMEXWTI futures market in the short- and long-term within 8 different contracts, allowing the risk premium to vary in the short-term dynamic analysis. They argued that market participants may be risk-averse which leads to bias in the futures markets. By employing the Stock and Watson dynamic OLS approach and GARCH-M error correction model their results indicate the following: first, that all the prices are cointegrated within the maturities and the joint hypothesis test cannot be rejected except at one and two-month maturities. They also observed that when the hypothesis $(\beta = 1)$ is tested separately the null could not be rejected in the 8 maturities, and finally, they found that the estimates of the short term efficiency test using the GARCH-M error correction model fail to reject the joint hypothesis in all the maturities. It is clear from the findings that weak-form efficiency holds in the market in both the short-and long-term, and, furthermore, the results do not support that the risk premium is time varying in all the maturities, in contrast to the research of Moosa and Al-Loughani (1994). Finally, Lee and Zeng (2012) applied the quantile cointegration regression to investigate the efficiency of NYMEXWTI under the expectation and no arbitrage rule hypotheses. They used monthly interest rate, spot and futures prices at 1 to 4-month contracts. First, the results indicate that the spot and futures prices at three-month and four-month contract shows that quantile cointegration exist between the prices. They observed that the joint restriction of the expectation hypothesis test does not hold except at one-month contract, implying that the market is inefficient in the rest of the three maturities in the long term. According to the author the hypothesis is rejected because the futures contract with longer maturity impound less information than short term contract. In contrast, the results of the no arbitrage rule do not support the effect of quantile cointegration in all contracts and also the joint restriction hypothesis indicates market efficiency except at four-month maturities.

Table 3.1 Summary of Previous Results on Market Efficiency in the Oil Futures Market

Author(s) and Year	Data and Market	Methods	Results
Serletis & Banack (1990)	WTI monthly spot and futures prices for 1-month contract from 1983-1988	Engel-Granger cointegration test	Weak-form efficient in the long term.
Crowder & Hamed (1993)	WTI monthly spot price, 1-month futures contract price and interest rate from 1983-1996	Johansen cointegration test	Weak-form efficient but not semi-strong form efficient in the long term.
Moosa & Al-Ghouni (1994)	WTI monthly spot and futures prices for 3 and 6- month contracts from 1986-1990	Engel-Granger cointegration test	Weak form inefficient in the long term in all maturities and there is evidence of a time varying risk premium.
Foster (1994)	WTI and Brent monthly spot and futures prices for 1, 2 and 3-month contracts from 1983-1993	Johansen cointegration test/ ECM	WTI is weak-form efficient at 1-month maturity while Brent market is inefficient all maturities in the long term. Both markets are also short term inefficient.
Gulen (1998)	WTI monthly spot and futures prices for 1, 3 and 6-month contracts from 1983-1996	Engel-Granger cointegration test	Weak-form efficient in the long term in all maturities.
Peroni & McNown (1998)	WTI monthly spot and futures prices for 1-month contract from1979-1996	Phillips-Lorenten cointegration test/Ordinary Least Square	Weak-form efficient but not semi-strong form efficient in the long term.

Kellard et al (1999)	Brent monthly spot and futures prices for 1-month contract from 1991- 1996	Johansen cointegration test	Weak-form efficient in the long term but not in the short term.
Abodesra (2005)	WTI monthly spot and futures prices for 1-month from 1991-2002	Phillips-Lorenten cointegration test	Weak-form and semi-strong efficient in the long term.
Switzer & El-Khoury(2007)	WTI daily and monthly spot and futures for 1-month contract from 1986-2005	Fama regression approach and Johansen cointegration test	Weak-form efficient in the long term.
Shuping et al (2007)	WTI monthly spot price, 1-month futures price and interest rate from 1986 to 2004	Engle-Granger cointegration test	WTI is inefficient in the first stage, weak form efficient in the second stage and also semi-strong form efficient in the third stage.
Masyluk & Smyth (2009)	WTI and Brent daily and monthly spot and futures prices for 1 and 3-month contracts from 1991-2008	Gregory-Hansen cointegration test	All markets are weak-form efficient in the long term.
Kawomoto & Hamori (2010)	WTI monthly spot and futures prices for 1 to 8-month contracts from 1991-2008	Dynamic Ordinary Least Square and GARCH-M-ECM	Weak-form efficient in both the long term and short-term within the maturities and there is no evidence of time varying risk premium.
Lee and Zeng (2012)	WTI monthly spot price, 1 to 4-month futures contract prices and interest rate from 1986 to 2009	Quantile cointegration regression	Weak-form efficient at only one-month contract in the long term.

Table 3.1 presents a summary of the results obtained from these previous studies, from which it can be seen that most of these studies support the unbiasedness hypothesis in the long term while few fail to reject it in the short term. Most of these studies used monthly data, especially for one-month futures contracts, in their analyses and have been conducted on weak-form efficiency in the WTI crude oil futures market in the long-term. Finally, it can be observed that majority of these studies failed to take into account the possibility that the oil futures market can comprise of participants that may demand a risk premium; which can also be time varying.

3.2.2 The Non-oil Commodity Futures Markets

This section reviews the relevant empirical literature examining the unbiasedness hypothesis in the non-oil commodity futures market, in order to demonstrate knowledge of the area. It also helps in understanding what other markets have found in relation to market efficiency. In metal commodities, Chowdhury (1991) tested the simple efficient hypothesis in the futures market for four nonferrous metals (copper, lead, tin and zinc) using the Engle-Granger approach. The data employed were monthly average spot and three-month futures contract prices. The author argued that most of the previous studies rejected the market efficient hypothesis because they do not account for the stochastic properties of the time series. The empirical results show cointegration between the spot and futures prices, with the exception of the copper market, and rejected the joint restriction hypothesis test of $(\alpha, \beta = 0,1)$ in all markets, suggesting market inefficiency. His analysis supports the view that the presence of long run relationship between the spot and futures prices does not imply market efficiency. Chowdhury further applied the cointegration test to examine the multi-market efficient hypothesis and found long run relationship between the spot and futures prices for different metals. These results imply that the price of each market can help predict the other, confirming the rejection of the efficient market hypothesis between the markets. Building on previous studies, Chow (2001) examined the efficiency of four precious metal (gold, silver, palladium and platinum) futures markets, accounting for the existence of a risk premium. The author conducted his analysis employing the Phillips and Ouliaris cointegration test using monthly spot price, futures prices and interest rates (used as proxy to the risk premium). The results indicated that the prices in each market are cointegrated; however, the joint restriction test rejects market efficiency in the gold and platinum markets. Furthermore, the author developed a model for testing multi-market efficiency extending the unbiasedness hypothesis. In contrast with Chowdhury (1991), his investigation of the multi-market efficiency between the silver and gold futures markets resulted in the conclusion that the prices of the different markets do not form cointegration relationship, consistent with the semi-strong form hypothesis. To confirm the findings, the author tested the joint restriction hypothesis on the cointegrating vectors, with identical results, as well as investigating efficiency in the cost-of carry framework, where he found consistent estimates.

Additionally, Kenourgies and Samitas (2004) examined the efficiency in copper market using daily spot and futures prices for three- and fifteen-month contracts. They conducted their analysis using Johansen's cointegration test and error correction model. The results were consistent with Chowdhury (1991), in that they rejected the unbiasedness hypothesis in both the short- and long-term for all the maturities, resulting in the conclusion that a positive time-varying risk premium may be the caused for the rejection of the simple efficient hypothesis. However, they do not test whether the risk premium exists and varies over time. Otto (2011) took a different perspective in his study of the speculative efficiency in the metals futures market, from a multi-contract and multi-market framework. Relying on the ARMA procedure, he used monthly spot and futures prices for copper, nickel, aluminium, tin, zinc and lead three-month and fifteen-month contracts. The author argued that the study of metal futures markets' efficiency should focus on the multi-market perspective because market participants base their trading decisions on the interrelation of different markets. In contrast to Chowdhury (1991) and Kenourgies and Samitas (2004), he found that all markets with the exception of tin fail to reject the unbiasedness hypothesis in single-market analysis, suggesting that the different strategies implemented have improved the metal markets' efficiency. He also found that the unbiasedness hypothesis is rejected in both the multi-contract and multi-market analyses, with the exception of aluminium and lead at three-month contracts. The author's conclusions, that the metal markets are neither multi-contract nor multi-market efficient, are consistent with Chowdhury (1991), although he studied different sample periods.

In the agricultural market, Yang and Leatham (1998) investigated market efficiency across the US grains market for wheat, corn, oat, and soybeans using Johansen's cointegration test. They argued that the existence of cointegration among the grain spot prices violates the weak-form efficient hypothesis and found that the spot prices for the different grains are not cointegrated in both the bivariate and multivariate analysis, thus supporting that all the commodity markets are efficient but without testing the joint restriction of the unbiasedness hypothesis. They suggest that little arbitrage profit can be exploited across the grain markets. In contrast, McKenzie et al (2002) examined the short-term and long-term unbiasedness in US rice futures market using two-month spot and daily futures price for 6 different maturities, where they found the all the prices are cointegrated although the joint hypothesis test was rejected in all maturities. However, they also observed that when the hypothesis is tested separately, β=1 could not be rejected in all maturities, leading them to suggest that either the market exhibits some degree of inefficiency, or the risk premium is not constant. The results of the short-term efficiency test support the unbiasedness hypothesis in all maturities and therefore they re-estimated the ECM by allowing for a risk premium. They found that the results confirm the presence of long- term inefficiency. They also applied the ARIMA and Random walk models but the results continued to support the weak form efficiency and so they suggest that, given the nature of the sample size, the market is efficient in both the short- and long-term.

Mckenzie and Holt (2002) extended this work by developing the GARCH-M-ECM model which allows a non-linear and time-varying risk premium in the regression equation and applying this model to examine the unbiasedness hypothesis in four agricultural commodity futures markets. The empirical results show that all the commodities spot and future prices are cointegrated and also fail to reject the joint hypothesis in all the commodity markets. However, the results of the short-term efficiency test using standard (ECM) contrast with those of McKenzie et al (2002), while those of the GARCH-M-ECM model confirm the inefficiency. Their analysis does not support the existence of the time varying risk premium, except in two commodities markets. In a similar vein, He and Holt (2004) also tested the unbiasedness hypothesis in three commodity futures markets, in this case for softwood lumber, Northern bleached softwood Kraft and oriented strand board, using the GARCH-M-ECM. They applied the Johansen cointegration test and weekly future and three-months-five-days average futures prices for the nearby contract as a proxy to spot prices. As well as supporting the unbiasedness hypothesis in all three commodity markets, their analysis also found that the time-varying risk premium is insignificant in explaining market inefficiency, but the presence of volatility affects all commodities markets. They suggest that the persistence of the GARCH effect plays a significant role in explaining changes in spot prices over time and should be considered when testing market efficiency.

In the financial market, Chan et al (1992) examined the efficiency of daily futures prices for the British pound, Japanese yen, Deutschemark and Swiss franc foreign exchange markets. By using the unit root test, they found weak form efficiency in all the markets. They also found that the pairwise cointegration test rejected market efficiency, apart from in Deutschemark and Swiss franc futures, while the higher order system ADF cointegration test rejected the hypothesis that the foreign exchange markets are multi-market efficient in the long run. However, their findings are unreliable because the unit root test was used to support the weak form efficient hypothesis. Crowder and Phengis (2003) investigated the simple efficient hypothesis in S&P 500 and Nikkie 225 using daily spot and futures prices, favouring the Hodgson adaptive estimator against the Johansen cointegration tests because they argued that the former takes into account the underlying error distribution. They found that the prices are cointegrated but the joint hypothesis of the unbiasedness test is rejected in both markets. The authors noted that the estimates of the Johansen test are even closer to unity than the Hodgson test and therefore their study was inconclusive on the efficiency of the two index markets. Laws and Thompson (2004) also studied short term and long term efficiency in the Eurodollar, short sterling and yen foreign exchange markets using the Johansen cointegration test. The data used in their analysis were three-month spot interest rates and daily futures price for one-, two- and three-month contracts. They found that all the prices were cointegrated, with the exception of three-month Eurodollar and dollar/yen, but the joint hypothesis is rejected in all the futures markets. Furthermore, in the short-term analysis only sterling contracts at one and two months are unbiased. They support market efficiency in all three foreign exchange futures markets, even though the results are ambiguous. An important finding of this study is that the foreign exchange markets behave differently and across maturity, findings similar to those of Foster (1994) in oil markets. A short-coming of the study is that it fails to account for the possibility that the risk premium can change over time, which may be the reason for the rejection of the joint hypothesis.

In contrast to previous studies, Villanueva (2007) applied the Gregory and Hansen cointegration test to examine efficiency of the Deutschemark, yen and pound sterling foreign exchange futures markets. His study utilized monthly spot and forward rates. The empirical results indicate the existence of cointegration in all markets and that the coefficients of the residuals, slope and trend were stationary centred to zero, cross zero and more frequency, and had less persistence than no breaks. The author also found that the short-run unbiasedness held strongly although not over the entire sample periods. He further argued that the lack of uniform results on the foreign exchange market efficiency was due to structural breaks, rather than fractional integration relied upon by the previous studies, but he failed to test the joint restriction hypothesis implied by the simple efficiency test.

Table 3.2 Summary of Previous Results on Market Efficiency in the Non-Oil Commodity Futures Markets

Author(s) and Year	Data and Market	Methods	Results
Chowdhury (1991)	Four metals: copper, lead, zinc and tin monthly spot and futures prices for 1-month contract from 1971-1988	Engel-Granger cointegration test	All the markets reject the weak-form efficient and multi-market efficient hypotheses in the long term.
Chan et al (1992)	Four currencies: British pound, Japanese yen, Deutschemark and Swiss franc daily aggregate futures prices from 1977 to 1987	Phillips-Perron unit root test and Engle-Granger cointegration test	All the markets are weak form efficient but reject the multimarket efficient hypothesis in the long term.
Yang and Leatham (1995)	Four US grains: wheat, corn, oat and soybean daily spot prices from 1992 to 1995	Johansen cointegration test	All the markets are weak-form efficient in the long term.
Chow (2001)	Four precious metals: gold, platinum, silver and palladium monthly spot and futures prices from 1970-2000	Phillips-Ouliaris cointegration test	The market for platinum and gold are weak form inefficient, while the silver and gold markets are multimarket efficient.
Kenourgies & Samitas (2004)	Copper spot and futures prices for 3 and 15-month contracts from 1989-2000	Johansen cointegration test/ ECM	Weak form inefficient in both the short term and long term.
Mekenzie et al (2002)	US rice daily spot and futures for 1-6 month contracts from 1986-1999	Johansen cointegration test/ ECM	Weak-form efficient in the long-term and

			short-term inefficient in all maturities.
Mekenzie & Holt (2002)	Four agriculture: live cattle, hogs, corn and soybean meal monthly spot and futures prices for 1-month contracts from 1959-2000	Johansen cointegration test/ GQARCH-M-ECM	All the markets are weak-form efficient in the long term, inefficient in the short term except live cattle and time-varying risk premium exist in cattle and hog futures markets.
He & Holt (2004)	Three wood: soft lumber, Northern bleached softwood Kraft and oriented strand board weekly spot and futures prices for 1-month contract from 1997-2001	Johansen cointegration test/ GARCH-M-ECM	All the markets are inefficient in both the long term and short term and there is no evidence of time-varying risk premium.
Crowder & Phengis (2003)	S&P and Nikkei index daily spot and futures prices for 1-month contract from 1997-2003	Johansen cointegration/Hodgson estimator	All the two markets are weak-form inefficient in the long term.
Law & Thompson (2004)	Three currencies: Eurodollar, short sterling and yen daily spot and futures prices for 1, 2 and 3 month contracts from 1987-2000	Johansen cointegration test/ECM	There is mixed conclusion on weak-form efficiency among the markets in both short-term and long-term.
Villanueva (2007)	Three currencies: deutschemark, yen and pound sterling daily spot and futures prices for 1 and 3-month contracts from 1991-2008	Gregory-Hansen cointegration test	All the markets are weak-form efficient in the long term
		ARIMA procedure	

Otto (2011)	Six metals: copper, nickel, aluminium, tin, zinc and lead monthly average spot and futures prices for 3 and 15-month contracts from 1991 to 2008		All the markets are weak form efficient except one and they are neither multi-contract nor multi-markets efficient in the long term.

The above review provides an insight into the efficiency of the oil and non-oil commodities futures markets. Table 3.2 reports the results obtained from previous research in non-oil commodity markets. Overall, however, reviewing the existing literature in both the oil and non-oil commodity futures markets indicates a lack of consensus on market efficiency. There are a number of general similarities in these studies: first, the cointegration approach was applied to test the unbiasedness hypothesis in the long-term, while the error correction model was employed in the short-term analysis. Second, the studies concentrated on testing the weak-form efficient hypothesis in the long-term. Third, they used data for monthly observation and finally, they neglect the possibility of the existence of the risk premium. On the other hand, the major difference between these studies is that in non-oil markets, market efficiency is investigated from multi-contract and multi-market perspectives. In this chapter, the thesis adds to the literature by investigating the short- and long-term efficiency in the West Texas Intermediate (NYMEX) and Brent (ICE) crude oil futures markets, using recent data from 2000 to 2011. The short-term efficiency is also examined by assuming the risk premium to be constant and time-varying in the oil futures markets, and this chapter also tests the multi-market and multi-contract efficient hypothesis among the crude oil futures markets.

3.3 Theoretical Framework of Market Efficiency

In theory, market efficiency refers to the condition where a price incorporates available information so that resources are allocated effectively. There are different views regarding market efficiency (see Samuelson, 1965; Robert, 1959; Fama, 1965, 1970), but the most widely accepted is the Efficient Market Hypothesis (EHM) proposed by Fama in 1970. The Efficient Market Hypothesis argues that the asset price P_t at any given time t should react instantaneously to the arrival of the new information set Ω_t. This new information should be independent of any past information making the market unpredictable. If asset price P_t adjusts slowly to new information set Ω_t, inefficiency may exist in the market because rational investors can use this as an opportunity to make profit above average returns consistently. Lo (2007) described the concept of informational efficiency in the following terms: "the more efficient the market, the more random the sequence of price changes generated by such a market, and the most efficient market of all is the one in which price change is completely random and unpredictable".

The Efficiency market hypothesis requires the current futures price F_t to be "martingale" with respect to any information set Ω_t available on expected spot price S_t at a given maturity time t. This means that the current futures price must be an unbiased predictor of the expected spot price at any given time t; otherwise the market will be inefficient. This relationship refers to the simple efficiency or unbiasedness hypothesis that was used to test the efficiency in commodities futures markets. The unbiasedness hypothesis can be expressed as:

$$E(S_t) = F_{t-1} \tag{3.1}$$

where S_t is the expected spot price at t and F_{t-1} is the futures price for contract at time $t-1$ maturity at time t. Equation (3.1) shows that the current futures price will equal the expected spot prices of a contract at maturity if the market participants are risk neutral. Assuming rational expectation in the market, we obtain:

$$S_t = E(S_t / \Omega_{t-1}) + \varepsilon_t \tag{3.2}$$

where Ω_{t-1} is the total available information set at time $t-1$ and ε_t is the error for rational expectation. If equation (3.1) and (3.2) are combined we obtain:

$$S_t = F_{t-1} + \varepsilon_t \tag{3.3}$$

The above equation forms the basis for testing the unbiasedness relationship between the spot and the futures prices. The relationship can be expressed in linear regression form as:

$$S_t = \alpha + \beta F_{t-1} + \varepsilon_t \tag{3.4}$$

where S_t is the expected spot price at time t, F_{t-1} is the futures price for contract at time $t-1$ maturity at time t, α is the constant risk premium, β is the rational expectation of the market participants and ε_t is the disturbance term which incorporates all available information about the futures contract at time t. Equation (3.4) is the general and valid model used to investigate the unbiasedness hypothesis of the commodity futures market. The model is tested using the natural logarithm of the spot and futures prices (see Serletis and Banack, 1990; Chowdhury, 1991; Foster, 1994; Villanueva, 2007; Switzer and El-Khuory, 2007). Yet the futures market would not be efficient unless equation (3.4) satisfies the following two conditions: The first is the necessary condition, requiring the current futures price and expected spot price for any given contract to have a long run equilibrium relationship[5]. Hence, both prices move together in the long term, implying that they are cointegrated. The second is the

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[5] The long run equilibrium means that the prices attained optimal position and do not move far from each other so that investors would obtain normal profit.

sufficient condition, which requires the joint restriction hypothesis of the coefficients of the risk premium to be equal to zero ($\alpha = 0$) and rational expectation to be unity ($\beta = 1$). If the null hypothesis of the joint restriction $\alpha = 0$ and $\beta = 1$ is rejected, the futures market may be biased in the long term. The techniques used to examine the long term efficiency of the futures market are the ordinary least square regression (OLS) or the cointegration test. Earlier studies applied the ordinary least square regression to test equation (3.4) because it provides a simple way of testing efficiency where the spot price is regress on the lag of the futures price, and then testing the joint restrictions for $\alpha = 0$ and $\beta = 1$ using the Wald test. However, the OLS approach was found to yield inconsistent results for the joint hypothesis of $\alpha = 0$ and $\beta = 1$ because its T- test and F - test do not follow a standard normal distribution process (Haigh, 1998)[6]. Due to these limitations more recent studies have employed the cointegration test (see Moosa and Al-Loughani, 1994; Gülen, 1998; Kellard et al., 1999; Shuping et al., 2007; Switzer and El-Khuory, 2007) which deals with non-stationary series and is more powerful in examining the long-run relationship between economic variables. Consequently this chapter uses Engle-Granger and Johansen's cointegration approaches.

Nevertheless, previous studies on commodity markets have found that the presence of long-term efficiency cannot confirm that the futures market is overall efficient, because there is strong evidence that the market may be biased in the short term (see Foster, 1994; McKenzie and Holt, 2002; Laws and Thompson, 2004; Kenourgies & Samitas, 2004; Kawomoto & Hamori, 2010) . To understand the overall efficiency of

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[6] Nelson and Plosner (1982) show that the used of standard statistical techniques that assume a stationary model will lead to an invalid inference because the stochastic trend affects the modelling of the economic relationships.

the crude oil futures market, it is important to examine both short-term and long-term efficiency. The latter is tested with Beck's (1994) error correction model approach (ECM), based on equation (3.4) which can be specified as:

$$\Delta S_t = \alpha_0 + \beta \Delta F_{t-1} + \sum_{i=1}^{k} \lambda_i \Delta S_{t-i} + \sum_{i=1}^{l} \gamma_i \Delta F_{t-i} - \rho[S_{t-1} + \delta F_{t-2}] + \varepsilon_t \qquad (3.5)$$

where α_0 is the constant term, ΔF_{t-1} is the changes in futures price at time $t-1$, ΔS_{t-i} is changes in spot price, ΔF_{t-i} is the changes in futures price, $[S_{t-1} + \delta F_{t-2}]$ is the error correction term, and ε_t is the disturbance term. The parameters β, λ_i, γ_i, ρ are to be estimated while k and l are the number of lags. Cointegration exists if the coefficient ρ is greater than zero because the spot prices react to movement from the long-run equilibrium position. Beck (1994) showed that the unbiasedness of the futures market can be tested by imposing the restrictions: $\rho = 1$, $\beta = 1$ and $\lambda_i = \gamma_i = 0$ on equation (3.5)[7]. The coefficients λ_i and γ_i are expected to be zero because the current futures and spot prices should incorporate all historical information. The parameter β is expected to be nonzero because new information is expected to affect changes in both spot and futures prices (see Beck,1994). The condition $\rho = 1, \beta = 1$ and $\lambda_i = \gamma_i = 0$ implies that the futures market will be unbiased and efficient. On the other hand, the condition $\rho \leq 1, \beta = 0$ and $\lambda_i \neq \gamma_i \neq 0$ implies that the futures price is biased and inefficient. Kawamoto and Hamori (2010) have pointed out that testing equations (3.4) and (3.5) would provide a more strong result regarding the efficient market hypothesis, while Mckenzie and Holt (2002) proposed GARCH-in-

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[7] If we imposed the restrictions $\lambda_i = \gamma_i = 0$ on equation (3.5) we obtain: $\Delta S_t = \alpha_0 - \rho[S_{t-1} + \delta F_{t-2}] + \beta \Delta F_{t-1} + \varepsilon_t$. Again if the restrictions $\rho = 1$ and $\beta = 1$ are imposed the equilibrium condition for the spot and futures prices is attained: $S_t = F_t$

mean error correction model by extending Beck's (1994) model, which allows the risk premium to be time varying. They argued that their model has three important advantages over Beck: first, it assumes that the risk premium is time varying in the market; second, the conditional variance of spot price changes accounts for both the linear and non-linear changes, and third, they stated that when the data is characterized by GARCH process the model provides better estimates than OLS. Their model can be specified as follows:

$$\Delta S_t = \alpha_0 + \beta \Delta F_{t-1} + \sum_{i=1}^{k} \lambda_i \Delta S_{t-i} + \sum_{i=1}^{l} \gamma_i \Delta F_{t-i} + \rho [S_{t-1} + \delta F_{t-2}] + \theta \sqrt{h_t} + \varepsilon_t \qquad (3.6a)$$

$$\varepsilon_t = e_t \sqrt{h_t}, \quad e_t \sim IN\,(0,1)$$

$$h_t = w + \sum_{i=1}^{r} \gamma_i h_{t-i} + \sum_{j=1}^{s} \alpha_{jj} \varepsilon_{t-j}^2 + \sum_{j=1}^{s} \alpha_j \varepsilon_{t-j} + \sum_{j \neq k}^{s} \alpha_{jk} \varepsilon_{t-j} \varepsilon_{t-k} \qquad (3.6b)$$

where h_t represents the changes in the conditional variance of the spot price for period t and $\theta\sqrt{h_t}$ denotes the time-varying risk premium. As with Beck (1994), the short-term unbiasedness is tested by imposing the joint restrictions $\rho = 1, \beta = 1$, $\lambda_i = \gamma_i = 0$ and $\theta = 0$ in equation (3.6a). Following both studies this chapter tests long-term efficiency using equation (3.4), and short-term efficiency with equations (3.5) and (3.6). However, the tests discussed above provide evidence for the weak-form efficient hypothesis; Granger (1986) argued that the existence of cointegration between the prices of two different speculative markets (or a multi-market) implies inefficiency because past information about their forecast errors can help predict each other. Following this Chowdhury (1991), Chan et al (1992), Chow (2001) among others investigated the multi-market efficient hypothesis. Extending Granger (1986), Chow (2001) argued that the multi-market efficiency test can be used as a semi-strong form hypothesis test, which can be express as in equation (3.4):

$$S_{t+1}^{i} = \beta_0 + \beta_1 F_{t,t+1}^{i} + \beta_2 F_{t,t+1}^{j} + \varepsilon_t \tag{3.7}$$

where i, j represents market i and j, respectively. S_{t+1}^{i} represents market i expected spot price at time $t+1$, $F_{t,t+1}^{i}$ and $F_{t,t+1}^{j}$ represents the futures price contract for i and j that matures at time $t+1$, respectively. As in equation 3.4, market efficiency requires the joint restriction hypothesis of $\beta_1 = 1$ and $\beta_2 = 0$ to hold. This chapter extend this analysis to a multi-contract framework where i, j can also represent contract a, b as follows:

$$S_{t+1}^{a} = \beta_0 + \beta_1 F_{t,t+1}^{a} + \beta_2 F_{t,t+1}^{b} + \varepsilon_t \tag{3.8}$$

where a, b represents contract a and b, respectively. S_{t+1}^{a} is the expected spot price for a contract at time $t+1$, $F_{t,t+1}^{a}$ is the futures price for contract a that matures at time $t+1$ and $F_{t,t+1}^{b}$ is the futures price for contract b that matures at time $t+1$. The joint restriction $\beta_1 = 1$ and $\beta_2 = 0$ is imposed so that the futures price for a contract is unbiased predictor of its expected spot price with the addition of another futures contract price. Equation (3.7) and (3.8) are used to examine the multi-market and multi-contract efficiency in the crude oil futures markets to test for the semi-strong form efficient hypothesis.

3.4 Empirical Methodology

This section briefly examined the econometric techniques used in the data analysis. These techniques include the unit root tests (with and without structural break), the cointegration test and the error correction model (ECM). Firstly, the unit root test and its use in determining the stochastic properties of the oil price series is discuss. Secondly, the use of the cointegration tests to investigate the long run relationship between the crude oil spot and futures prices are considered, and finally, the application of error correction model tests in determining the crude oil spot and futures prices in the short run is discussed.

3.4.1 Unit Root Test

The unit root test is the econometric technique used to investigate whether the time series is stationary or otherwise. It is important when dealing with time series analysis to understand the stochastic properties (order of integration) of a series because it can strongly influence its behaviour (Brooks, 2008). There are a large number of unit root tests with different power and functions, but in this chapter the three most common tests, along with one with structural break test, have been chosen in order to ensure the robustness of the results. These unit root tests include the Augmented Dickey and Fuller test (1979), the Phillips-Perron (1988), the Kwiatkowski, Phillips, Schmidt and Shin (1992) and the Zivot and Andrews (1992) test. First, the Dickey and Fuller (1979) unit root test examines the null hypothesis H_0: $\gamma_1 = 1$ that the series x_t is non-stationary against H_1: $\gamma_1 < 1$ and that the series is stationary in the following regression equation[8].

$$\Delta x_t = \gamma x_{t-1} + \varepsilon_t \tag{3.9}$$

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[8] Dickey and Fuller test the null hypothesis H_0: $\alpha = 1$ in the model $x_t = \alpha x_{t-1} + \varepsilon_t$. If we rearrange the model by subtracting x_{t-1} from each side in order to make it easier to compute we obtain: $\Delta x_t = \gamma x_{t_{-1}} + \varepsilon_t$, where $\gamma = \alpha_1 - 1$, the test for $\alpha_1 = 1$ is the same as the test for $\gamma = 0$.

The Dickey and Fuller (DF) tests examine the presence of the unit root test in equation (3.9) by allowing for an intercept, intercept and deterministic trends and none. However, the test statistics of the Dickey Fuller test do not follow the standard t-distribution and the critical values are obtained from simulation (Brooks, 2008); as a result, the Augmented Dickey and Fuller test (ADF), which uses the lag of the dependent variable Δx_t to make sure that ε_t is not autocorrelated, was introduced

$$\Delta x_t = \gamma x_{t-1} + \sum_{i=1}^{p} \beta_i \Delta x_{t-i} + \varepsilon_t \tag{3.10}$$

The ADF tests also examine the null hypothesis $\gamma = 0$ with an intercept, intercept and deterministic trend, or none in equation (3.10). Phillips and Perron (PP) (1988) also developed a more comprehensive alternative unit root test that uses non-parametric adjustment for higher order serial correlation. The Phillips-Perron method is an extension of the Augmented Dickey Fuller test where the t-ratio of γ coefficient is modified to prevent serial correlation in affecting the asymptotic distribution of the test statistic (Agung, 2009). It also assumes that the error term is weakly dependent and heterogeneously distributed. Both the ADF and PP tests yield the same conclusions and have low power especially when the process is stationary but with a root close to the non-stationary boundary (Xu, 2009). Kwiatkowski, Phillips, Schmidt and Shin (KPSS) (1992) proposed an alternative test of the unit root that assumes the time series to be trend stationary under the null, as:

$$x_t = x_t + \varepsilon_t \tag{3.11}$$

where x_t represents a random walk and ε_t represents a stationary process. The KPSS test investigates the null hypothesis H$_0$: $\sigma_v^2 = 0$, that the variance of x_t is stationary against the alternative H$_1$: $\sigma_v^2 > 0$, that x_t is not stationary. The main limitation of these standard unit root tests discussed is that the presence of structural changes in the time series data is not accounted. To overcome this problem is to perform the unit root test that deals with structural break. Zivot and Andrews (1992), building on Perron's (1989) procedure, proposed a unit root test that accounts for one change in the intercept (model A), one change in the slope of the trend (model B) and one change in both intercept and trend function (model C)[9]. The endogenous break in the test can be written in three forms:

$$\text{Model A: } \Delta y_t = \mu + \beta_t + \theta DU_t + \alpha y_{t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + e_t \quad (3.12a)$$

$$\text{Model B: } \Delta y_t = \mu + \beta_t + \gamma DT_t + \alpha y_{t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + e_t \quad (3.12b)$$

$$\text{Model C: } \Delta y_t = \mu + \beta_t + \theta DU_t + \gamma DT_t + \alpha y_{t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + e_t \quad (3.12c)$$

where Δy_t is the change is the series, μ is the intercept, β_t is the slope of the trend, DU is the dummy for the intercept, DT is the dummy for trend, y_{t-1} is value of the series at time $t-1$, Δy_{t-j} is the changes in the series up to period j, k is the number of lags determined for each possible breakpoint, e_t is the error term and T_B is the chosen break date[10]. This procedure investigates the null hypothesis H$_0$: $\alpha = 0$, implying that the series y_t contain a unit root and excludes any structural breakpoint

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[9] Enders (1995) showed that when conducting a unit root test care should be taken due to the possibility of structural change because (Perron, 1989) when a time series contains structural breaks the various Dickey-Fuller and Phillip-Perron unit root test statistics will be biased by supporting non-stationarity.

[10] The Zivot and Andrews test assumes that $DU_t = 1$ if $t > T_B$, 0 otherwise and $DT = t - T_B$ if $t > T_B$, 0 otherwise.

against alternative H$_1$: $\alpha > 1$, meaning that the y_t is a trend stationary process with one break that take place at unknown period (see Zivot and Andrews, 1992).

3.4.2 Cointegration Test

This chapter applied the Engle-Granger (1987) and the Johansen (1988) cointegration approaches to examine long run relationship between the oil spot and futures prices[11]. These cointegration tests, discussed below, were selected because evidence from existing literature has shown that they are powerful in studying the futures market efficiency.

3.4.2.1 The Engle- Granger Cointegration Test

Engle and Granger (1987) proposed that when two or more variables are non-stationary, for example the spot (S_t) and futures prices (F_t) are both I(1), then their linear combination $Z_t = S_t - \alpha F_t$ will be I(0). The Engle and Granger cointegration approach can be explain in the following regression equation:

$$S_t = \alpha + \beta F_{t-1} + \varepsilon_t \tag{3.13}$$

where S_t is the spot price at time t and F_{t-1} is the futures price for contract at time $t-1$ maturity at time t. The cointegration test is a two-step procedure. First, the

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[11] When two or more non-stationary variables are estimated using the regression analysis, we will have the non-dynamic version of spurious regression. Granger and Newbold (1974) shows that such a regression will produce parameters that is highly statistically significant even if there is no relationship among the variables. However, the alternative of using the difference form of the time series will be undesirable because it only models the short-run relationship of the variables. In this case, the cointegration techniques will provide an alternative method for examining the relationship between variables in both the short-run and long-run. Cointegration means that if two variables are non-stationary together they form a stable linear combination, even if they deviate from each other in the short run.

variable S_t is regressed on F_t. Second, the unit root test can be used to examine the hypothesis $H_0 : \varepsilon_t = I(1)$ (containing a unit root and therefore non-stationary) against the alternative $H_1 : \varepsilon_t = I(0)$ (not containing a unit root and therefore stationary). Accordingly, rejecting the null hypothesis of the test implies that the prices are cointegrated and therefore there is long run relationship between them.

3.4.2.2 The Johansen Cointegration Test

Johansen (1988) introduced a cointegration test based on a maximum likelihood estimator. The Johansen procedure has advantage over the Engle- Granger approach because it allows for testing of long-term equilibrium and short-term dynamic relationships among variables. It also allows for testing restrictions on the coefficients of the cointegrating vectors using the likelihood ratio test. Generally, the Johansen cointegration approach is a multivariate generalization of the Augmented Dickey-Fuller test, based on vector auto regression framework (VAR). The model can be written in levels as follows:

$$x_t = \mu + \sum_{i=1}^{p} \Pi_i x_{t-i} + \varepsilon_t \tag{3.14}$$

where x_t is the N×1 vector of I(1) variables, Π is the N x N matrix parameter, μ is a vector of constant and ε_t is a vector of mean-zero error with covariance matrix Λ. Johansen (1991) states that the term μ contains information on component of x_t, that is, whether it has a constant or linear trend. Johansen and Juselius (1990) suggest that equation (3.14) can be expanded by examining the cointegrating matrix in order to give its equivalent error correction representation as follows:

$$\Delta x_t \ = \mu + \sum_{i=1}^{p-1} \Gamma_i \Delta x_{t-i} \ + \Pi x_{t-p} + \varepsilon_t \tag{3.15}$$

where $\Gamma = (-1 + \Pi_1 + \Pi_2 + \dots\dots\dots \Pi_j)$ and $(i = 1,2 \dots\dots\dots p-1)$

From equation (3.15) all the variables in difference form contain short-run information and those in levels contain long-run information. The coefficient Π is the only source of long-run information and therefore represents the stationary linear combination of the I(1) variable. If the long run equilibrium is attained, Δx_{t-p} and ε_t will be zero. The Johansen procedure centres on the examination of the rank of the Π matrix. The rank of Π ranges from G to zero and takes three possible forms: (a) If rank $\Pi = 0$, then the variables in x_t are not cointegrated. (b) If rank $\Pi = G$, then the variables in x_t are not cointegrated. (c) If $0 <$ rank $\Pi < G$, then the variables in x_t are cointegrated. The rank of matrix Π indicates whether cointegration exists between the variables in x_t[12]. The Johansen procedure allows further testing for restrictions on

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[12] The rank Π is equal to its characteristic roots (Eigen value) which are different from zero (Brooks, 2008). The order of the characteristic roots is represented by λ such that $\lambda_1 > \lambda_2 > \dots\dots\dots > \lambda_g$; if the rank of Π is zero its characteristic roots will also be zero and vice versa. The Johansen approach offers two test statistics for cointegration. However, in the test statistics, $\ln(1-\lambda)$ is used instead of λ, but the two carry the same value. The approach offers the following test statistics for calculating cointegration:

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{g} \ln(1 - \hat{\lambda}_i)$$

$$\lambda_{\max}(r, r+1) = -T \ln(1 - \hat{\lambda}_{r+1})$$

where r is the number of cointegration that exist between the variables, $\hat{\lambda}$ is the estimated value of the characteristic root and T = number of variables. The first formula for λ_{trace} investigates the null hypothesis that (r) is less than or equal to the number of cointegrating vectors from the estimated equation against the alternative of more than (r) cointegrating vectors. The second formula for $\lambda_{\max}$ tests the null hypothesis that (r) is equals to the number of cointegrating vectors from the estimated equation against the alternative of $(r+1)$ (see Enders, 1995). The test statistics are estimated the cointegrating vectors. In order to do this, Johansen shows that the Π matrix can be decomposed into two matrices α and β, each with the dimension $(n \times r)$, where r is the rank of Π.

$$\Pi = \alpha\beta' \tag{3.16}$$

where β represents the matrix of the cointegrating vectors and the matrix α is that of the error correction term (or speed of adjustment coefficient). However, the parameters of β and α cannot be identified; only their spanned space can be determined in the Π matrix. The space spanned for the coefficient β is the row space and the coefficient α is the column space (Johansen, 1991). This procedure tests the hypothesis of whether the non-stationary variables in x_t together form a linear combination relationship $\beta' X_t$. The restriction can be tested by imposing a given value on either α or β coefficient. Given that $\beta' X_t$ is defined as:

$$\beta' X_t = 0 \tag{3.17}$$

where $X_t = (S_t, F_t, 1)$ and $\beta' = (1, -\beta, -\alpha)$. To test for market efficiency the restriction $\beta' = (1, -1, 0)$ is imposed, normalizing the variable S_t to unity and give the joint restriction of $\alpha = 0$ and $\beta = 1$. The test statistic is asymptotically χ^2 distributed and the number of restrictions imposed on the parameters is equal to the degrees of freedom (Enders, 1995). Johansen proposed the following test statistic for testing restriction:

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by critical values given by Johansen and Juselius (1990). If the null hypothesis of λ_{trace} and $\lambda_{\max}$ is rejected, there is no cointegration between the variables in x_t.

$$= T\sum_{i=1}^{r}\left[\ln(1-\lambda_i) - \ln(1-\overset{*}{\lambda}_i)\right] \qquad \sim x^2(n) \tag{3.18}$$

where the characteristic roots of the restricted and unrestricted models are represented by λ_i and $\overset{*}{\lambda}_i$, respectively, and n is the number of restrictions. The restriction will be binding when the calculated value of the χ^2 table is greater than the test statistics (see Brooks, 2008; Enders, 1995; Lutkepohl and Kratzig, 2004).

3.4.3 Error Correction Model Approach

The error correction model (ECM) was developed by Granger (1981), which, Engle and Granger (1987) then connected to their test for cointegration. The authors proposed that when two or more variables that are I (1) have a linear combination, their short-run dynamic equilibrium relationship can be estimated with the error correction model[13]. The error correction model measures how much disequilibrium is eliminated in each period until the variables reach their long-run equilibrium value. To describe how the mechanism works and assuming our variables S_t and F_t in equation (3.13) are cointegrated, their error correction model can be specified as:

$$\Delta S_t = \alpha_0 + \rho[S_{t-1} + \delta F_{t-2}] + \beta\Delta F_t + \sum_{i=1}^{k}\lambda_i \Delta S_{t-i} + \sum_{i=1}^{l}\gamma_i \Delta F_{t-i} + \varepsilon_t \tag{3.19}$$

where ε_t is the stationary disturbance term with mean equals to zero, and $\rho[S_{t-1} + \delta F_{t-2}]$ is the error correction term measuring the rate of convergence to long-term equilibrium position. The coefficient ρ will be greater than zero if the variables are cointegrated and less than zero if otherwise.

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[13] This implies that if two non-stationary variables are cointegrated they must have an error correction model.

3.5 Data and its Properties

The data used to examine the efficiency of the crude oil futures markets are West Texas Intermediary and Brent monthly crude oil spot and futures prices for one, two and three-month contracts to maturities. These two benchmark crudes were chosen because they are the world's most liquid and heavily traded crude oils, and also have well established spot and futures markets (Maslyuk and Smyth, 2009). WTI futures contract is traded in the New York Mercantile Exchange (NYMEX), while the London Intercontinental Exchange (ICE) traded Brent futures contract. Data for WTI were obtained from the Energy Information Administration and NYMEX, while that of Brent were sourced from the Data Stream. The data covers the sample period from January 2, 2000 to May 15, 2011. Data for both WTI and Brent have been adjusted for weekends and holidays. A total number of 136 observations are obtained in each crude oil market; all the price series are transformed into natural logarithm forms to reduce the problem of heteroskedasticity and to obtain consistent estimates.

The futures price is the closing price of a particular contract thirty days before the end day of its trading (see Crowder and Hamed, 1993). Trading for the WTI crude oil futures contract ends on the third business day before the 25th calendar day of the month and therefore if the day is a non-business day then trading on that contract ends on the third business day before the one preceding it. For the Brent contract, trading ends on the business day preceding the 15th calendar day of the month and if it is a non-business day then trading ends on the business day before that day. Both WTI and Brent futures contracts are delivered one month prior to their maturity day. The expected spot price of a particular futures contract is its closing cash price on its last trading day. Following Crowder and Hamed (1993), and Kawamoto and Hamori

(2010) and others the closing futures price of every month is used as a proxy to the expected spot price. This chapter uses the closing futures price for one-month as expected spot price for one-month futures contract because it has zero maturity and two-month futures contract price is used as the expected spot price for three-month futures contract. The futures price rather than the spot price are used because they provide more information about market behaviour. This chapter used the following notations: WTI-S1, WTI-S3 to denote WTI expected spot prices for one-and three-month contract and WTI-C1, WTI-C3 are futures prices at one- and three-month maturities, respectively, while for the Brent market, Brent-S1, Brent-S3, Brent-C1, Brent-C3 are used to denote Brent crude oil spot and futures prices for one-and three-month maturities, respectively.

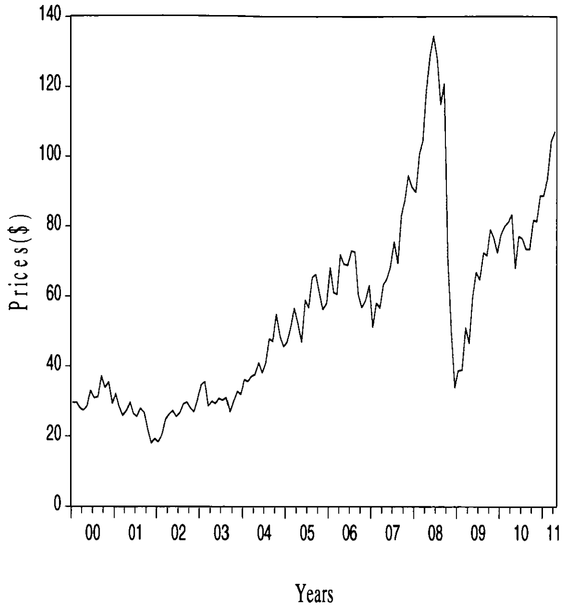
Table 3.3 Descriptive Statistics for Crude Oil Prices

Statistic	**WTI-S1**	**WTI-C1**	**WTI-S3**	**WTI-C3**
Maximum	4.9025	4.8980	4.9017	4.9036
Minimum	2.8920	2.9653	2.9811	2.9907
Mean	3.8889	3.8901	3.8930	3.8931
Std.Deviation	0.49165	0.4907	0.4979	0.5055
Kurtosis	1.9427	1.8426	1.7752	1.7201
Skewness	0.0289	0.0187	-0.005	-0.0208
Jarque-Bera prob	6.353(0.0)	7.599(0.0)	8.502(0.0)	9.293(0.0)

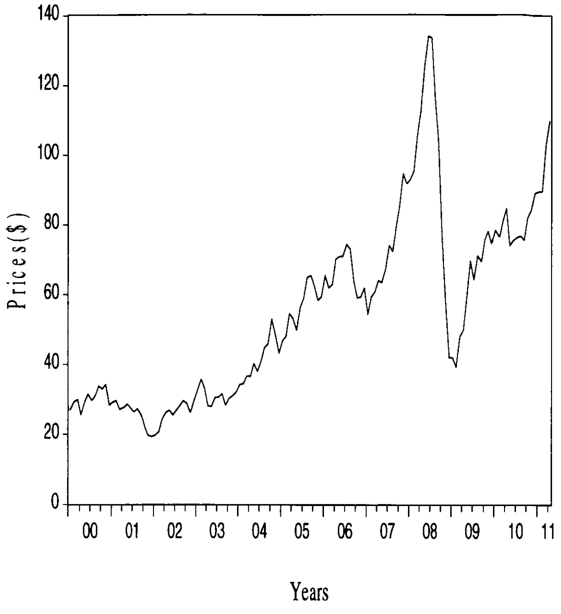
Statistic	**Brent-S1**	**Brent-C1**	**Brent-S3**	**Brent-C3**
Maximum	4.9589	4.9404	4.9459	4.9507
Minimum	2.9199	2.9518	2.9585	2.9575
Mean	3.8531	3.8715	3.8723	3.8723
Std.Deviation	0.5102	0.5262	0.5326	0.5392
Kurtosis	1.8342	1.7320	1.6948	1.6602
Skewness	0.0432	0.0211	0.0036	-0.0115
Jarque-Bera prob	7.743(0.0)	9.121(0.0)	9.654(0.0)	10.18(0.0)

Note: Figures in brackets are probability values for the normality test.

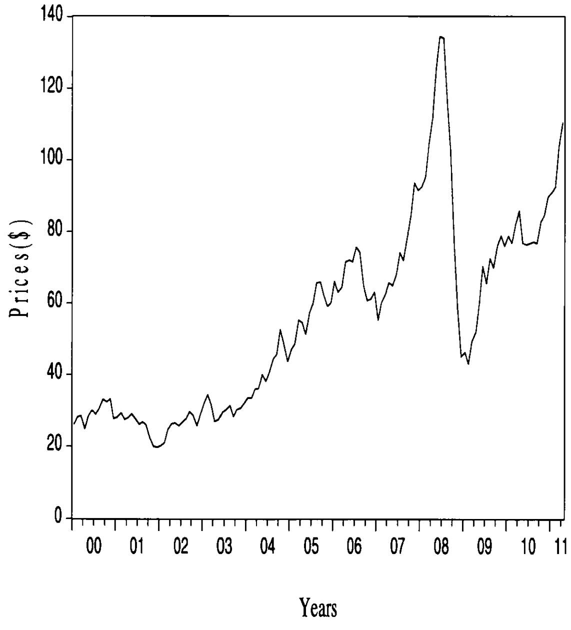
WTI-S



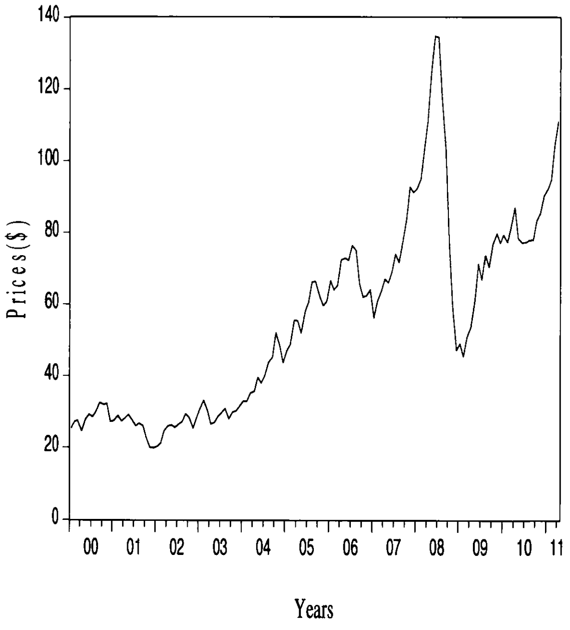
WTI-C1



WTI-C2



WTI-C3



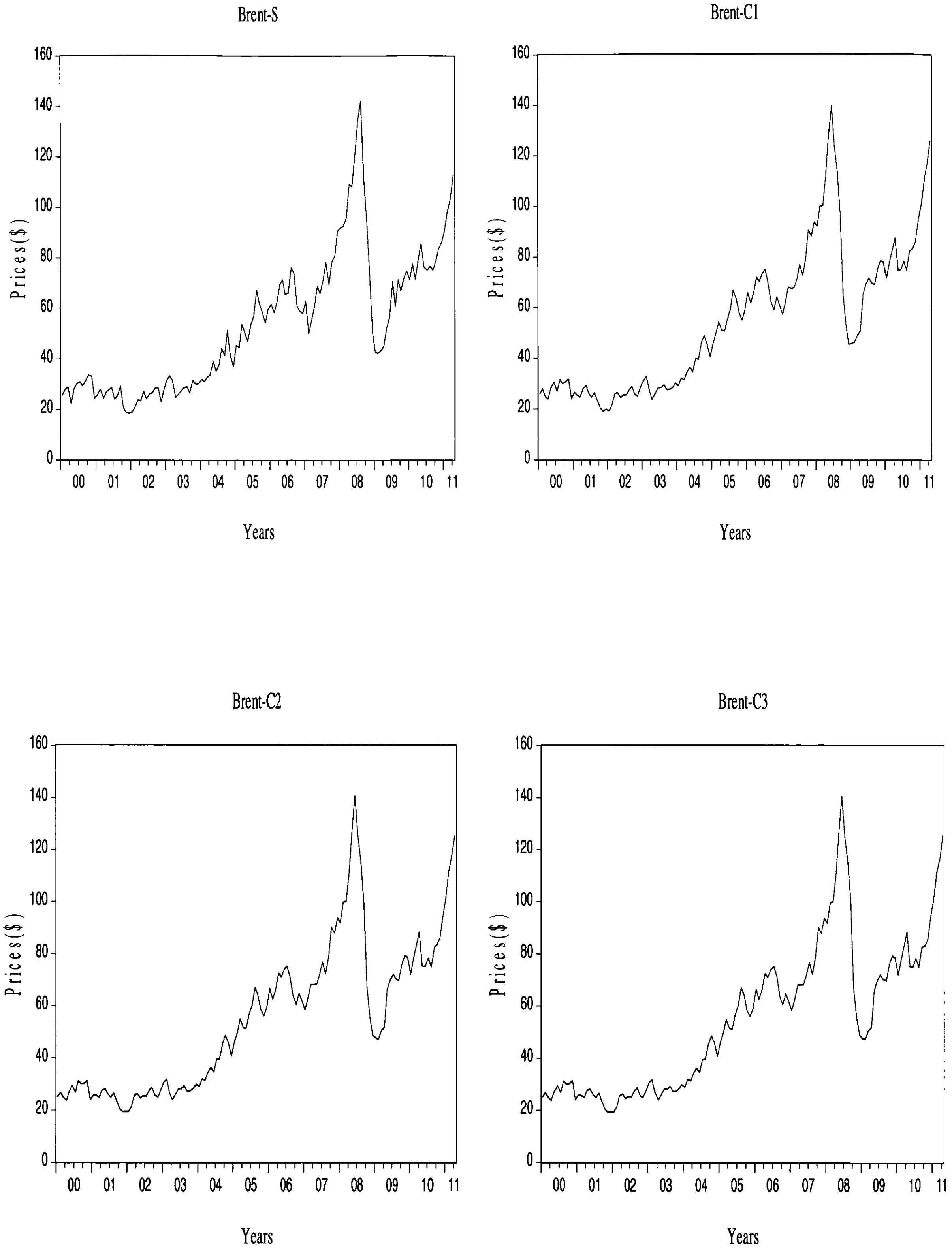


Figure 3.1: Monthly Spot and Futures Prices for WTI and Brent, January 2000 - May 2011

Table 3.3 reports the summary statistics of the monthly spot and futures prices for WTI and Brent markets. This reports the mean, maximum, minimum, standard deviation, skewness; Kurtosis and Jarque-Bera probability and shows that WTI and Brent have similar features in all maturities. The mean is higher than the standard deviation in each price series; the prices in both markets also increase in longer futures contracts. Almost all the prices show evidence of positive skewness, and Kurtosis is lower than 3. The Jarque-Bera test shows that the oil prices reject the normality test at 5% significant level. Fig 1 plots the monthly spot and futures prices for one and three-month contracts to maturities from January 2000 to May 2011, showing that the prices series in all markets are characterised with upward and downward trends. The prices are also highly volatile and move in the same direction, indicating that the crude oil futures markets respond to new information simultaneously at almost the same time. The plots suggest that all the oil price series might have one or more structural breaks over the sample period.

3.6 Empirical Results

This section applies the econometrics methodologies discussed in section (3.4). First, the unit root test is used to examine the properties of the crude oil spot and futures prices. Second, the Engle-Granger cointegration test is apply to investigate the long run relationship between the crude oil spot and futures prices, then the Wald test is used to estimate the joint restriction hypothesis implied by the long-term efficiency test. Third, long-term efficiency is re-examined with the Johansen approach. Fourth, an error correction model for each market is constructed using their spot and futures prices, then restrictions are imposed to examine the short-term efficiency in each market with and without a time varying risk premium. Finally, the Johansen cointegration approach is employ to test the multi-contract and multi-markets efficient hypothesis in these oil markets.

3.6.1 Unit Root Test

This chapter used four unit root tests to examine the properties of the oil spot and futures prices series: the Augmented Dickey-Fuller; Phillips-Perron, Kwiatkowski, Phillips, Schmidt and Shin, and Zivot and Andrews. The results of the first three tests are presented in Table 3.4. Both were undertaken using two specifications: with constant and with constant and trend. The Schwarz Information Criterion (SIC) is used to choose the order of the estimated auto-regression for the ADF, while the PP and KPSS tests are selected with Bartlett kernel. The ADF and PP tests results for the two specifications show that all the price series contain a unit root at both 5% significant levels, implying that the series are non-stationary. However, the results also indicate that each of the price series is stationary in their first difference, suggesting that they are integrated of order 1 and they are all I (1). On the other hand, the KPSS test show that each of the oil price series rejects non stationarity in both specifications.

To confirm the results the Zivot and Andrews (1992) unit root test, which allows for an unknown structural break in the slope and intercept, is carried out (Model C). The results of this unit root test reports that the spot and futures prices in all markets are non-stationary at the 5% level, suggesting that they all have a unit root as in Panel C of Table 3.4. However, the results indicate that the oil prices reject a unit root in their first difference; they are I (1). The Zivot-Andrews test also identifies the single period in which the most substantial changes (structural break) occur in the prices series over the sample period. The break date for each time series is reported in panel C. For the WTI crude oil market, the break point occurred in August 2008, with the exception of the spot price which shows July 2008. In the Brent market, the results show July 2008 apart from the spot price which indicates September 2008. It can be concluded that July 2008 has the most significant break in both markets because when estimating an endogenous break point the tests may not show the exact date of an event (Maslyuk and Smyth, 2008). This coincides with the period when oil prices increased to $145 per barrel, from which point they had crashed to $33 by December 2008. In sum, the four different unit root tests support non-stationarity in all the oil price series.

Table 3.4 Unit Root Test

Panel A. Unit root test with intercept

Variables	**ADF**		**PP**		**KPSS**	
	(i)	(ii)	(i)	(ii)	(i)	(ii)
WTI-S1	-1.116	-11.05*	-1.268	-11.07*	1.237*	0.042
WTI-C1	-1.059	-8.786*	-1.129	-8.756*	1.260*	0.042
WTI-S3	-0.982	-8.750*	-1.047	-8.727*	1.278*	0.043
WTI-C3	-0.949	-8.589*	-1.001	-8.568*	1.290*	0.043
Brent-S1	-1.091	-11.99*	1.070	-11.99*	1.274*	0.042
Brent-C1	-0.785	-9.690*	-0.757	-9.680*	1.296*	0.059
Brent-S3	-0.788	-9.250*	-0.732	-9.254*	1.304*	0.058
Brent-C3	-0.773	-9.078*	-0.710	-9.083*	1.310*	0.058

Note: * denote statistical significance at the 5% level. The specifications (i) and (ii) represent level and first difference of the unit root test, respectively.

Panel B. Unit root with constant and trend

Variables	ADF		PP		KPSS	
	(i)	(ii)	(i)	(ii)	(i)	(ii)
WTI-S1	-2.719	-11.02*	-3.096	-11.05*	0.122*	0.037
WTI-C1	-2.937	-8.766*	-2.791	-8.736*	0.129*	0.039
WTI-S3	-2.842	-8.728*	-2.691	-8.705*	0.137*	0.042
WTI-C3	-2.795	-8.566*	-2.621	-8.544*	0.141*	0.042
Brent-S1	-2.820	-11.96*	-3.001	-11.96*	0.128*	0.037
Brent-C1	-2.870	-9.681*	-2.686	-9.671*	0.133*	0.047
Brent-S3	-2.817	-9.238*	-2.604	-9.240*	0.138*	0.049
Brent-C3	-2.748	-9.062*	-2.536	-9.067*	0.142*	0.050

Note: * denote statistical significance at the 5% level. The specifications (i) and (ii) represent level and first difference of the unit root test, respectively.

Panel C. The Zivot and Andrews's unit root test

Variables	T-statistics (i)	Break date	T-statistics (ii)	Break date
WTI-S1	-5.341	2008M10	-7.514*	2008M07
WTI-C1	-5.011	2008M10	-9.594*	2008M08
WTI-S3	-4.732	2008M10	-9.625*	2008M08
WTI-C3	-4.568	2008M10	-9.492*	2008M08
Brent-S1	-4.498	2008M11	-12.958*	2008M09
Brent-C1	-4.682	2008M10	-10.653*	2008M07
Brent-S3	-4.526	2008M10	-10.251*	2008M07
Brent-C3	-4.375	2008M10	-10.119*	2008M07

Note: * and ** denote significance at the 1% and 5% levels. The asymptotic critical values for model Care:-5.57(1%), -5.08(5%) and -4.82(10%). The specifications (i) and (ii) represent the t-statistics in level and first difference of the unit root test, respectively.

3.6.2 Test of Long-term Efficiency

Given that the spot and futures prices in both the WTI and Brent crude oil markets have a unit root, they are I (1); the long term efficiency is then investigated in these markets. First, the Engle and Granger (1987) cointegration test is applied to examine market efficiency in each of the crude oil futures markets; Table 3.5 reports the results of this approach. The results indicate that the prices of the two crude oil futures markets are cointegrated at different maturities, and the residuals were not different from white noise. These suggest that there is long run relationship between the spot and futures prices in both markets, thus the prices move together in the long term even if they deviate in the short run. The results show that the coefficients for α and β are nearly 0 and 1, respectively, in each market at different maturities.

The joint restrictions hypothesis of $\alpha = 0$ and $\beta = 1$ is then examine using the Wald test in each market. Table 3.5 presents the results of the joint restriction tests. The estimated results indicate that the WTI and Brent markets do not reject the joint restriction test at the 1% significant level, meaning that the futures price in each of the oil markets is unbiased within the maturities. These results suggest that the current future price can predict the expected spot price and arbitrage opportunities do not exist between the two markets, findings which are consistent with Serletis and Banack (1990), Gulen (1998) and Peroni and McNown (1998) who have examined the WTI market. However, they contrast with Moosa and Al-Loughani (1994), who found that the WTI market was inefficient at the different maturities. Overall, these analyses provide evidence that support the unbiasedness and weak-form efficient hypothesis in both the WTI and Brent crude oil markets in the long term.

Table 3.5 Engle and Granger Cointegration Test for Long term Efficiency

Dependent Variable	α	β	DF-test	$\alpha=0,\beta=1$
WTI-C1	0.089 (1.087)	0.979 (46.95)	-8.560* (0.000)	0.842 (0.433)
WTI-C3	0.109 (1.924)	0.975 (67.32)	-8.321* (0.000)	2.597 (0.078)
Brent-C1	0.126 (2.542)	0.966 (75.82)	-12.48* (0.000)	4.180 (0.017)
Brent-C3	0.092 (1.591)	0.979 (66.81)	-8.781* (0.000)	2.146 (0.121)

Note: * and ** indicate that the null hypothesis is rejected at the 1% and 5% significance levels. α and β denote the coefficients of the OLS estimates of equation (3.4) and the numbers in parentheses below are their t-ratios. DF is a test of the unit root for the OLS estimates and its p-values shown below in parentheses. $\alpha=0,\beta=1$ is the joint hypothesis and p-values shown below in parentheses.

Although there is a large body of literature that has investigated the efficiency of the commodity markets using the Engle and Granger cointegration test, this approach has been proven to have some limitations. First, the approach assumes that the cointegrating vector is unique (Foster, 1994). Second, the intercept (α) and slope (β) coefficients which form the basis of the efficiency testing cannot provide a strong statistical inference (Haigh, 1998) because the T and F- statistics used to estimate the parameters are not normally distributed, which may lead to incorrect hypothesis testing. Finally, the method relies on two steps; therefore errors that occur in the first step are transferred to the analysis in the second step (Enders, 1995). These drawbacks give the Engle and Granger approach less power in testing market efficiency.

Table 3.6 Johansen Cointegration Test for Long term Efficiency

Variables	λ trace r=0	λ trace r≤1	λ Max r=0	λ Max r≤1
WTI-S1 vs WTI-C1	23.74* [15.49]	0.586 [3.841]	23.15* [14.26]	0.586 [3.841]
WTI-S3 vs WTI-C3	17.88* [15.49]	1.022 [3.841]	16.86* [14.26]	1.022 [3.841]
Brent-S1 vs -Brent-C1	14.75* [15.49]	0.356 [3.841]	14.39* [14.26]	0.356 [3.841]
Brent-S3 vs Brent-C3	25.30* [15.49]	0.718 [3.841]	24.59* [3.841]	0.718 [3.841]

Note: * indicates that the null hypothesis is rejected at 5% level of significance. The critical values at 5% level are taken from λ trace and λ max tables, MacKinnon-Haug-Michelis (1999) and are shown in parentheses below the test statistics.

Table 3.7 Johansen Cointegration Restriction Test for Long-term Efficiency

Variables	Restricted log-likelihood	LR -statistics	$\alpha = 0, \beta = 1$
WTI-S1 vs WTI-C1	384.89	4.368	0.037
WTI-S3 vs WTI-C3	636.94	5.820	0.016
Brent-S1 vs -Brent-C1	306.08	4.362	0.037
Brent-S3 vs Brent-C3	638.59	13.21	0.000*

Note: * indicates that the null hypothesis is rejected at the 1% significance level. The null hypothesis of $\alpha = 0, \beta = 1$ and their p-values are shown in this table. The likelihood ratio test statistics for the various restrictions is shown and has a x^2 distribution with the degree of freedom equal to the number of restrictions placed on the parameters.

The Johansen (1988) cointegration approach is therefore applied to re-examine the oil futures markets efficiency because it provide solutions to some of these problems. (This approach and its advantages were discussed in section 3.4.2.2). It is conducted with an intercept and no trend specified for the cointegrating equations. The optimal lag lengths of the VAR specification range from one to six lags, and in each case are selected by Akaike Information criterion (AIC), Sequential Modified LR statistics (LR) and Final Prediction Error (FPE) criterions[14], except Brent one-month which is not selected by second criterion. Table 3.6 reported the results of the Johansen cointegration test. The estimates of the trace and maximum eigen value statistics indicate that the spot and futures prices are cointegrated in both the WTI and Brent crude oil markets at the different maturities. These results illustrate that the spot and futures price series have a long-run relationship in both markets at different maturities and thus support the Engle–Granger approach. The second condition for market efficiency is then investigated by testing the joint hypothesis restrictions of risk neutrality and rational expectation implied on the coefficients α and β in equation (3.4). The test is undertaken using the Johansen likelihood ratio test statistic. Table 3.7 shows that the WTI market cannot reject the joint hypothesis of the market efficiency test in all maturities, confirming the Engle-Granger approach. These results show that the futures price is an unbiased predictor of the expected spot price at the different contracts, findings consistent with Crowder and Hamed (1993), Abosedra (2005) and Switzer and El-Khoury (2007) at one-month maturity, and with Foster (1994) and Kawamoto and Hamori (2010) at three-month maturity.

For the Brent market, Table 3.7 reports that the null of the joint restriction test cannot be rejected at the 1% significant level at only one-month maturity. In contrast to Engle-Granger approach, Brent market fails the test of the weak-form efficiency at three-month maturity. These results show that the three-month futures price is biased

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[14] These different criterions are used to select the optimal lag length of the VAR.

predictor of the future spot price in the long term and therefore arbitrage can be exploited. These findings are consistent with Kellard et al(1999) at one- month maturity and Foster (1994) at three-month contract. The results of the long term efficiency test using the Johansen approach show that each of the crude oil futures market supports the unbiasedness hypothesis, except Brent at three-month maturity. These results are consistent with the previous studies that cointegration between the spot and three-month futures contract prices does not imply efficiency because the Brent market fails the test of the joint restriction hypothesis at this maturity. Hence, the thesis supports the results of the Johansen cointegration test in the Brent market at three-month contract given its power over the Engle-Granger approach.

The implications of the results are firstly, that market participants can benefit more from investment diversification across the markets at one month contract and across the contracts in the WTI, but not in the Brent market because the efficiency in this market varies in different maturities. Secondly, hedgers can minimise unsystematic risk by trading in the WTI and Brent markets in all and at one-month contracts, respectively, because these futures prices contain all available information about market conditions. Therefore hedgers can avoid adopting expensive hedging strategies, since the markets operate efficiently at these maturities. Thirdly, speculative opportunities can be exploited in the Brent market at three-month contract because the market is inefficient and thus by using past information about futures prices speculators can generate excess returns. Finally, the analysis of long-term efficiency supports the weak-form efficient market hypothesis in each market except Brent at three-month maturity.

3.6.3 Test of Short-Term Efficiency

To understand the overall efficiency of these markets, the third condition for market efficiency requires the futures price to be unbiased in the short term. In this section, the short-term efficiency of the oil futures markets is examined using the error correction model. At first, the crude oil futures markets efficiency is estimated in the short-term using the standard ECM as specified in equation (3.5). The standard error correction model for each market was estimated with zero to three lags of the spot and futures prices. However, following Engle-Granger (1987) only the lags with significant coefficients are used in the analysis. The results of the diagnostic test on the residuals, conducted using the Ljung-Box Q-statistics with up to 36 lags, indicate no evidence of autocorrelation in both markets at different maturities. Table 3.8 presents the results of the short-term efficiency test, assuming a constant risk premium; panel A reports the estimated parameters of the error correction model. The estimated results of the error correction coefficients are significant in all the markets, implying that there is co-movement between their spot and futures prices in the long term. The second lagged futures price is also significant in these markets, indicating that the futures price adjust instantaneously to the long-run equilibrium position. Furthermore, the results show the significant of the coefficients of the lagged spot and futures prices in each case except for the WTI at one-month contracts. These results indicate that information about past spot and futures prices for the different maturities in each market are reflected in the current futures price.

The results of the joint restriction hypothesis for short-term efficiency using the Wald test are reported in Panel B and indicate that the WTI and Brent oil markets reject the unbiasedness hypothesis in the short-term at the different maturities, as can be seen from their p-value of (0.00). However, when the restrictions are tested individually the hypothesis $\beta = 1$ is cannot be rejected in each market at the 5% significant level, suggesting that the futures markets are unbiased in all maturities. Both markets fail the weak-form efficiency test in the short term because the individual hypothesis test on the error correction coefficient is rejected in each case, implying that they do not converge together. The results show that futures price is biased predictor of the future spot price in each market in the short term. The results are consistent with Foster (1994) in both markets, but contradict Kawomato and Hamori (2010) for the WTI market in all the maturities.

Table 3.8 Error Correction Model Test for Short-Term Efficiency with Constant Risk Premium

Panel A. Estimated Coefficients for the ECM with Constant Risk Premium

Coefficients	WTI-C1	WTI-C3	Brent-C1	Brent-C3
ρ	-1.168 (-4.212)	-1.017 (2.629)	-1.165 (8.804)	-0.968 (2.055)
β	0.967 (3.439)	1.916 (1.733)	0.894 (11.23)	1.253 (2.586)
λ_i	0.446 (2.061)	-0.604 (0.564)	0.108 (1.101)	1.498 (1.156)
γ_i	0.273 (2.259)	0.118 (1.293)	-0.124 (1.342)	-1.502 (1.115)

Note: t-statistics are shown in parentheses below the parameters.

Panel B. Estimates of the Joint Restriction Hypothesis Test with Constant Risk Premium

Coefficients	WTI-C1	WTI-C3	Brent-C1	Brent-C3
$H_o : \rho = 1$	61.14 (0.000)*	27.18 (0.000)*	267.6 (0.000)*	104.7 (0.000)*
$H_o : \beta = 1$	0.014 (0.906)	0.687 (0.409)	1.769 (0.186)	0.273 (0.273)
$H_o : \lambda_i = 0$	4.249 (0.041)	0.317 (0.573)	1.212 (0.273)	1.338 (0.250)
$H_o : \gamma_i = 0$	5.105 (0.026)	1.673 (0.198)	1.710 (0.182)	1.242 (0.267)
$H_o = \rho = 1, \beta = 1,$ $\gamma_i = \lambda_i = 0$	112.2 (0.000)*	107.3 (0.000)*	146.9 (0.000)*	17.45 (0.000)*

Note: * Indicates reject the null at 5% significance level; p-values are shown in parentheses below the F-test statistics; H_o: $\rho = 1, \beta = 1, \gamma_i = \lambda_i = 0$ are Wald test for short-term market unbiasedness and efficiency with associated p-values shown in parentheses.

Since all the crude oil futures markets reject the unbiasedness hypothesis in the short run, the efficiency of the oil futures markets is re-examined with error correction model that allow the risk premium to be time-varying as specified in equation (3.6). Table 3.9 reports the estimated coefficients of the error correction model and the joint restrictions test, assuming that the risk premium is time-varying. The results of the estimated coefficients in panel A are consistent with the previous analysis in all the oil markets at the different maturities and support the rejection of the unbiasedness hypothesis in both markets in the short run. Additionally, the estimated coefficient of the lagged spot and futures prices in the error correction model are similar in each market with that in panel A, 3.8 in values and significant in all maturities. The results in panel B also show that the coefficient of the time-varying risk premium is insignificant in the markets within the maturities, suggesting that the change in the risk premium over time is not the cause of inefficiency. The joint restriction hypothesis of short-term efficiency test is also rejected at 1% significant level in the markets, confirming that the futures prices are biased in both the WTI and Brent markets, and therefore implying market inefficiency. In summary, the analysis of the short-term efficiency indicates that both WTI and Brent crude oil futures reject the weak-form efficient hypothesis in all the maturities with or without the existence of risk premium. The implication of the findings is that arbitrage profit can be exploited in all the markets at the different maturities in the short run. Secondly, investors who hold positions in oil futures for the short term would not profit because at this stage the market faces high risk. Finally, investment diversification would be ineffective across the contracts because the markets do not incorporate all the necessary information in these maturities.

Table 3.9 Error Correction Model Test for Short-Term Efficiency with Time-varying Risk Premium

Panel A. Estimated Coefficients for the ECM with Time-varying Risk Premium

Coefficients	WTI-C1	WTI-C3	Brent-C1	Brent-C3
ρ	-1.311	-1.459	-1.164	-1.309
	(-4.301)	(2.966)	(-8.752)	(-1.866)
β	1.061	2.311	0.893	1.601
	(3.620)	(2.037)	(11.13)	(2.229)
λ_i	0.510	-0.562	0.108	1.530
	(2.369)	(-0.528)	(1.095)	(1.178)
γ_i	0.288	0.137	-0.124	-1.533
	(2.369)	(1.489)	(1.334)	(-1.133)
θ	-0.106	-0.158	-0.014	-0.619
	(-1.125)	(1.445)	(0.200)	(-0.657)

Note: t-statistics are shown in parentheses below the parameters.

Panel B. Estimates of the Joint Restriction Hypothesis Test with Time-varying Risk Premium

Parameters	WTI-C1	WTI-C3	Brent-C1	Brent-C3
$H_o : \rho = 1$	57.51 (0.000)*	24.99 (0.000)*	264.7 (0.000)*	10.84 (0.001)*
$H_o : \beta = 1$	0.044 (0.835)	1.336 (0.250)	1.788 (0.184)	0.700 (0.404)
$H_o : \lambda_i = 0$	5.214 (0.024)	0.279 (0.599)	1.200 (0.275)	1.387 (0.241)
$H_o : \gamma_i = 0$	5.612 (0.019)	2.217 (0.139)	1.778 (0.185)	1.285 (0.259)
$H_o : \theta = 0$	1.266 (0.263)	2.088 (0.151)	0.040 (0.842)	0.432 (0.512)
$H_o = \rho = 1, \beta = 1,$ $\gamma_i = \lambda_i = 0$	90.18 (0.000)*	86.95 (0.000)*	116.5 (0.000)*	83.50 (0.000)*

Note: P-values are shown in parentheses below the F-test statistics; * Indicates reject the null at 5% significance level, H_o: $\rho = 1, \beta = 1, \gamma_i = \lambda_i = 0$ and $\theta = 0$ are Wald test for short-term market unbiasedness and associated p-values are shown in parentheses below t-statistics.

3.6.4 Test of Multi-contract Efficiency

In this section, the multi-contract efficient hypothesis is examined to test whether different oil contract are biased predictor of each other in the long term. As discussed earlier, the multi-contract (or multi-market) efficiency test can also be used to provide evidence for the semi-strong form efficiency test in the crude oil futures markets. The tests is conducted using Johansen's cointegration procedure; the optimal lag lengths of the VAR specification range from one to five lags, and in each case are selected by Akaike Information Criterion (AIC). Table 3.10 presents the results of the multi-contract analysis and shows that the null hypothesis of no cointegration between spot, one-month and three-month futures prices is rejected both by the trace and maximal eigenvalue statistics at the 5% level in all markets. However, the results indicate that the hypothesis of that is at least one cointegrating vector between the prices cannot be rejected in both markets. The results show that the spot, one-month and three-month contract futures prices in each market move together, implying that past forecast error across contracts can be used to predict errors of each other in the long run. Table 3.11 reports the results of the joint restriction ($\beta_1 = 1, \beta_2 = 0$) for the multi-contract efficiency. The results show that the hypothesis cannot be rejected at the 1% significant level in the WTI and Brent markets in the analysis for one-month contract. For the three-month contract, the markets reject the joint restriction test at the 1% level indicating that with the addition of one-month futures price, the expected spot price can be predicted with this price in all markets. The findings suggest that the two crude oil markets support the multi-contract efficient hypothesis at only one-month maturity in the long term. Therefore, the co-movement between the spot and three-month futures prices at one-month maturity does not have any significant impact on each other, and in line with (Chow 2001) it can be spurious.

Table 3.10 Johansen Cointegration Test for Multi-contract Efficiency

Dependent variable	**λ trace r=0**	**λ trace r≤1**	**λ Max r=0**	**λ Max r≤1**
WTI-S1,WTI-C1 and WTI-C3	64.43** [29.71]	15.85 [15.49]	48.58** [21.13]	15.43 [14.26]
WTI-S3, WTI-C3 and WTI-C1	64.11** [29.71]	17.56 [15.49]	46.56** [21.13]	16.58 [14.26]
Brent-S1, Brent-C1 and Brent-C3	81.74** [29.71]	22.49 [15.49]	59.25** [21.13]	21.73 [14.26]
Brent-S3, Brent-C3 and Brent-C1	88.81** [29.71]	25.53 [15.49]	63.28** [21.13]	24.97 [14.26]

Note: * and ** indicate that the null hypothesis is rejected at 1% and 5% significance levels, respectively. The critical values at 5% level are taken from λ trace and λ max tables, MacKinnon-Haug-Michelis (1999) and are shown in parentheses below the test statistics.

Table 3.11 Johansen Cointegration Restriction Test for Multi-contract Efficiency

Dependent variable	Restricted log-likelihood	LR -statistics	$H_0 : \beta_1 = 1, \beta_2 = 0$
WTI-S1,WTI-C1 and WTI-C3	783.35	0.396	0.529
WTI-S3, WTI-C3 and WTI-C1	1133.1	22.95	0.000*
Brent-S1, Brent-C1 and Brent-C3	694.94	5.215	0.022
Brent-S3, Brent-C3 and Brent-C1	1143.5	38.29	0.000*

Note: * indicates that the null hypothesis is rejected at the 1% significance level. $H_0 : \beta_1 = 1, \beta_2 = 0$, is null of the joint restriction hypothesis of the multi-contract efficiency test.

When compared with Table 3.7 in page 82, the results also provide evidence that a market which is weak form inefficient cannot be semi-strong form efficient as in the case of Brent market at three-month maturity. Again, it can be seen that with addition of one-month contract, WTI market reject the efficient market hypothesis at three-month maturity in this frame work. Thus, both crude oil markets reject the semi-strong form efficient hypothesis at three-month maturity in the multi-contract framework. The implication of the results is that arbitrage opportunities can be exploited by speculating in three-month contract and in fact, the increase in speculative activities in this contract may be the reason for the markets' inefficiency. Another reason is that may be market participant prefer to trade oil at one-month contract which make it more liquid and therefore speculators used this price to predict the three-month contract. Finally, portfolio diversification across the two contracts in either market would not reduce price risk because efficiency varies across maturities.

3.6.5 Test of Multi-market Efficiency

Turning to the multi-market analysis, the results of the test using the Johansen's cointegration procedure for each oil market is reported in Table 3.12. The optimal lag lengths of the VAR specification range from one to seven lags, and in each case are selected by Akaike Information Criterion (AIC). The results of the trace and maximal Eigenvalue statistics show rejection of the null hypothesis of no cointegration between the spot and one-month futures prices at the 5% significance level in each oil market. Instead, the results indicate that there is at least one cointegrating vector between the prices in each case. These results are identical in case of analysis for three-month maturity in all the oil markets. These results show that there is cointegration between the spot and futures prices at the different maturity in all markets, implying they form long run relationship. The results suggest that past information about futures prices of the different markets can provide good forecasts for each other's movement in the long run which violates the efficient market hypothesis following Granger (1969).

On the other hand, the results of the joint restriction hypothesis $(\beta_1 = 1, \beta_2 = 0)$ for the multi-market efficiency test reported in Table 3.13 indicates that WTI market is unbiased at three-month maturity at the 5% level, while within one-month the market can be predicted using information about Brent futures price of the same maturity. For the Brent market, the results cannot reject the joint restriction test at the 1% level of significant within one- and three-month maturities, respectively, implying that futures price is unbiased in all maturities even with addition of WTI futures price in all maturities.

Table 3.12 Johansen Cointegration Test for Multi-market Efficiency

Variables	λ trace r=0	λ trace r≤1	λ Max r=0	λ Max r≤1
WTI-S1,WTI-C1 and Brent-C1	65.45**	9.147	56.31**	7.554
	[24.28]	[12.32]	[17.71]	[11.22]
WTI-S3, WTI-C3 and Brent-C3	36.92**	10.49	26.43**	9.775
	[29.71]	[15.49]	[21.13]	[14.26]
Brent-S1, Brent-C1 and WTI-C1	96.01**	19.43	76.58**	17.47
	[35.19]	[20.26]	[22.21]	[15.89]
Brent-S3, Brent-C3 and WTI-C3	56.21**	22.49	33.72**	21.79
	[29.71]	[15.49]	[21.13]	[14.26]

Note: * and ** indicate that the null hypothesis is rejected at 1% and 5% significance levels, respectively. The critical values at 5% level are taken from λ trace and λ max tables, MacKinnon-Haug-Michelis (1999) and are shown in parentheses below the test statistics. $H_0: \beta_1 = 1, \beta_2 = 0$, is null of the joint restriction hypothesis of the multi-contract efficiency test.

Table 3.13 Johansen Cointegration Restriction Test for Multi-market Efficiency

Dependent variable	Restricted log-likelihood	LR -statistics	$H_0: \beta_1 = 1, \beta_2 = 0$
WTI-S1,WTI-C1 and Brent-C1	783.35	0.396	0.000*
WTI-S3, WTI-C3 and Brent-C3	1133.1	22.95	0.121
Brent-S1, Brent-C1 and Brent-C3	694.94	5.215	0.017
Brent-S3, Brent-C3 and Brent-C1	1143.5	38.29	0.226

Note: * indicates that the null hypothesis is rejected at the 1% significance level. $H_0: \beta_1 = 1, \beta_2 = 0$, is the null of the joint restriction hypothesis of the multi-contract efficiency test. The likelihood ratio test statistics for the various restrictions is shown and has a x^2 distribution with the degree of freedom equal to the number of restrictions placed on the parameters.

It can be seen that while Brent market support the multi-market efficient hypothesis in all the maturities, WTI reject market efficiency at one-month maturity. The results suggest that WTI market is semi-strong form efficient at three-month maturity while

Brent in all maturities, results which contradict the multi-contract analysis. The implication of the findings is that there is strong evidence to suggest that speculators can exploit arbitrage profit by trading across the two oil markets by using Brent futures price to forecast WTI at one-month maturity. Another point is that hedger who trades in oil futures would reduce their risk by portfolio diversification across the two markets because the Brent market indicates efficiency in all the maturity. Overall, it is clear that the oil futures markets support the multi-market and multi-contract efficient hypothesis but not in all maturities.

3.7 Summary and Conclusion

This chapter examined the long-term and short-term efficiency in the WTI and Brent crude oil futures markets. The data used in analysis are monthly spot and futures prices at one, two- and three-month contracts to maturities from January 2000 to March 2011, a period of recent fluctuations in crude oil prices. This chapter applies the Engle-Granger and Johansen cointegration tests to investigate long-term efficiency, while the error correction model (ECM) is utilized to test for short-term efficiency; market efficiency is estimated allowing the risk premium to be constant and time varying. The multi-market and multi-contract efficiency are also investigated as evidence for semi-strong form efficient hypothesis.

Empirical results support the weak form efficient hypothesis in both the WTI and Brent oil markets in the long term. The results from the Engle-Granger and Johansen cointegration test are contradictory: both methods indicate the presence of cointegration relationship between the spot and futures prices at different contracts in the long-term but the results of the joint restriction hypothesis test are rejected by the

Johansen test in the Brent market at three-month contracts to maturity. Given that the Johansen approach is more powerful, the thesis supports the unbiasedness hypothesis in Brent at only one-month maturity and specifically the rejection of the joint restriction hypothesis in this market at three-month maturity which proves that the existence of cointegration does not imply efficiency. The results therefore suggest that the WTI at one- and three-month contract futures price are unbiased in the long term. In the Brent markets, the results show weak form efficiency at only one-month contract. The analysis provides evidence that the WTI market is more efficient in the long term, possibly because the NYMEXWTI futures market is more liquid and has a larger trading volume attracting more investors. In the short-term, the results reject the unbiasedness hypothesis in all the markets at the different maturities, and in particular, the markets reject the weak-form efficient hypothesis test with and without the existence of a time varying risk premium. Interestingly, it appears from the research that both markets indicate that the short term inefficiency was not caused by the time-varying risk premium. These results support the usefulness of the futures price in predicting the expected spot price in all the markets at different maturities. While this contradicts Kawomoto and Hamori (2010) in the WTI market in all the maturities, it is consistent with Foster (1994) in both markets within the maturities but in the absence of risk premium (see Table 3.1). The results suggest that arbitrage opportunities can be exploited in all the oil markets in the short term.

Furthermore, the results of the multi-market and multi-contract analyses show mixed conclusions. First, the two crude oil futures markets support the multi-contract hypothesis at one-month but not at three-month contract, suggesting that the markets are semi-strong form efficient in the long term and contradicting Peroni and

McKnown (1998) and Crowder and Hamed (1993) while being consistent with Abodesra (2005) and Shuping et al (2007), who used a different approach in the WTI market. These suggest that hedgers should be concerned with one-month contracts because they will reduce price risk, while speculative activities will be profitable at three-month maturity in both markets. The results of the multi-market analysis support efficient market hypothesis in WTI at three-month while Brent in all the maturities, implying that information about the futures price of the latter can help predict the former at one-month contract in the WTI market. These findings suggest that portfolio diversification would be profitable across the markets particularly at three-month contract because at the one-month contract the WTI market fails the efficiency test.

This chapter concludes that both the WTI and Brent crude oil futures markets are weak form efficiency in the long term, and inefficient in the short term within the maturities. It is observed that the time varying risk premium is not responsible for the inefficiencies in all markets. The multi-contract analysis supports semi-strong form efficiency in all the markets at only one-month contract while the multi-market test indicates efficiency in all except WTI at one-month maturity. Thus, it can be suggested that the prices of these markets (and contracts) are tied together, and therefore in line with Otto (2011), hedgers and speculators should take the interaction of these markets (and contracts) into account in order to have efficient strategies. Finally, policy makers should focus not only on single-market (or contract) analysis but also considered these interactions when developing measures that aims to increase the efficiency of the international oil futures markets.

CHAPTER FOUR

Price Discovery in the Oil Futures Markets

4.1 Introduction

The primary role of the oil futures market is to serve as an efficient mechanism for price discovery and risk management. Price discovery can be defined as the use of futures market price to determine the expected spot price (Working, 1948; Schroeder and Goodwin, 1991; Yang and Zhou, 2010) and is also interpreted as the process through which markets which trade closely related commodities incorporate all necessary information in order to reach equilibrium price (Schreiber and Schwartz, 1986; Arto, 2009). For these reasons producers, marketing and processing firms all use spot and futures prices when making consumption, production and inventory decisions (Figuerola-Ferretti and Gonzalo, 2010), and moreover, these prices also provide traders, investors, hedgers and speculators with information about the market condition. Therefore the degree to which the oil futures market performs its price discovery function is of crucial importance to both market participants and policy makers.

The price discovery process depends on the relationship between the spot and futures prices; this shows how fast each market responds to new information and thus influences price change in another market. The price discovery process can be generally described in two ways: first, if the spot and future prices respond to new pricing information simultaneously, then neither the spot nor the futures market dominates the price discovery process. This implies that both markets make an equal contribution to the process of price discovery, and arbitrage opportunities cannot be exploited. Second, if either market responds to new pricing information first, that market dominates the other in price discovery, implying that arbitrage may exist from the deviation of the two prices before they reach their long-run equilibrium position. In general, price dominance does not exist in perfectly integrated market (Foster, 1994).

However, most empirical studies in this area support the theory that the futures market dominates the price discovery process (Moosa, 2002; Schwarz and Szakmary 1994, Traub; Rosenberg, 2009; Figuerola-Ferretti and Gonzalo, 2010; Huang et al., 2009), arguing that it has lower transaction costs and flexibility of short selling (Bekiros and Diks, 2008), relatively less friction and is more liquid compared to the spot market (Foster, 1994). Opponents of this view have demonstrated that the lower transaction costs of the futures market may lead to high speculation, which in turn causes deviation between the spot and futures prices (Ng and Pirrong, 1996)[15]. As identified by Moosa (1996, cited in Bekiros and Diks, 2008), due to unreliable futures prices arbitrageurs and speculators will react to this difference by shifting their interest to spot market trading. The spot market therefore impounds new information faster than the futures market.

Many studies have examined price discovery in the crude oil market using different methodologies, data sets and time frames, yet there is no clear consensus as to which market lead the price discovery process. However, most of these studies examine

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[15] This action will allow the spot market to acquire more information and therefore dominate in price discovery (Moosa, 1996).

price discovery using the lead-lag return regression approach[16]; Hasbrouck (1995) argued that the limitation of these type of models is that they have been misspecified because they assume convergent representations in situations where they do not even exist. More recent studies in this field are now examining price discovery from the microstructure perspective, using as their main methodologies the Hasbrouck (1995) information share and the Gonzalo and Granger (1995) common factor weight approaches. The two approaches are built on the vector error correction model and assume that prices have a common factor (implicit price) which influences changes in the price of all markets (Baillie et al., 2002). The Hasbrouck approach measures price discovery from the proportion of innovation that each market contributes to the variance of the common factor, while the Gonzalo-Granger measures the contribution of each market to the common factor. Initially, the approaches were introduced to examine the contribution to price discovery for a single security traded in multiple markets[17]; recent empirical evidence, however, supports the effectiveness of this method in investigating price discovery in commodity futures markets (see Figuerola-Ferretti and Gonzalo, 2010; Fricke and Menkhoff, 2010; Chen and Gau, 2010).

The objective of this chapter is to examine price discovery in the West Texas Intermediate and Brent crude oil futures markets. Kaufmann and Ullman (2009) pointed out that knowledge of how the oil markets incorporate information is important because it can help in understanding some of the causes of recent

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[16] See for example Quan (1992), Silvapulle and Moosa (1999), and Moosa (2002).

[17] For more discussion on this see Hasbrouck (1995).

fluctuations in oil prices[18] and that furthermore, with the continuous rise in prices, investors want to know whether the crude oil futures markets are performing their price discovery function. At the same time, it is also very important for policy-making, as alternative strategies may be introduced to improve the performance of the crude oil markets. This chapter addresses four important research questions: Do WTI and Brent crude oil futures markets perform their price discovery role in the long term? Do these markets perform their price discovery role in the short term? Do futures contracts of different maturity lead each other in the price discovery process in these markets? Finally, do the international crude oil futures markets share a similar pattern in performing their price discovery role? This chapter also contributes to the existing literature on price discovery as follows:

1. It provides a broad analysis of price discovery in the WTI and Brent crude oil futures markets. Despite the fact that Brent Blend is the second world marker crude, few studies have examined the price discovery function of this contract and therefore it is important to establish if these two contracts exhibit similar characteristics in term of price discovery, because market participants want alternatives for risk diversification.
2. It also examines price discovery in these futures markets across different maturities. Although this has been examined in previous studies, only Hammaudeh et al (2003) and Kim (2010) have investigated price discovery in the WTI across different contracts, and there is no study of this kind in the Brent market. Hammaudeh et al (2003) pointed out that, when compared with trading in the long term on the spot contract alone, cross-contract analysis

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[18] For instance, when the futures market impounds new pricing information first, speculation may be the driving factor, while the spot market possesses more information when market fundamentals are the cause (Kaufmann and Ullman, 2009).

provides investors with information on whether trading in different maturities of the same underlying asset adds more diversification benefits.

3. It used three standard measures to investigate price discovery in the crude oil futures markets: the vector error correction model (VECM), the Gonzalo-Granger common factor weight and the Garbade-Silber dynamic approach. To my knowledge there is no study that has been conducted in the Brent market using the second model.
4. Finally, it provides new insights on price discovery in the international crude oil futures markets over the period of recent fluctuations in prices, based on the above contributions.

The remainder of the chapter is organized as follows. Section 4.2 provides a brief review of the literature on price discovery between the two different markets, as well as that on price discovery in the non-oil commodity futures markets. Section 4.3 presents theoretical framework of price discovery relationship between the oil spot and futures markets, while section 4.4 discusses the empirical methodology used to investigate price discovery in these markets. Section 4.5 describes the data used to analyse price discovery; empirical results and discussion are provided in section 4.6, and section 4.7 summarizes and presents the conclusions drawn from the findings of this chapter.

4.2 Literature Review

This section, which is divided into two parts, reviews related empirical studies that investigate the contribution to price discovery of the oil spot and futures markets. Part one reviews the empirical studies concerned with price discovery (or price dominance) in the oil market, and the second part reviews relevant studies on price discovery in other commodity futures markets in order to shed more light on the area.

4.2.1 The Oil Futures Market

Several studies have investigated price discovery in the crude oil futures market with a view to establishing whether or not the market performs its function. Silvapulle and Moosa (1991) using the linear and non-linear causality test, and daily spot and futures prices at one-, three- and six-month contracts examine price discovery in the WTI crude oil market. Before conducting the causality test, the authors carried out the cointegration test and found that all the prices contain a unit root and are not cointegrated, with the exception of contracts at three-months maturity: as a result the authors limit their analysis to three-month futures contracts. The result of the linear causality test indicates that the spot prices is cause by futures prices, while the non-linear causality test indicate strong evidence in support of bi-directional causality between the two oil prices in price discovery process. They observed that after accounting for the presence of the ARCH effect, the non-linear causality test shows non-linear non-bi-direction causality between the oil spot to futures prices. Without considering the volatility persistence in the price series, the presence of bi-directional non-linear causality will be supported; the authors also note that the simple volatility effect associated with information flow may cause non-linear causality or lead to spurious causality. They argued that the real price discovery relationship between the spot and future prices cannot be captured with low frequency data and conclude that both markets perform the price discovery role in the WTI market. In contrast to their work, Quan (1992) applied monthly data to analysed the role of the WTI crude oil futures market in price discovery using the Granger causality and Garbade- Silber approach. He argued that the study of price discovery should be based on a two-step testing procedure: first, establishing whether the spot and futures prices have cointegration relationship, and secondly, testing the causal relationship between the prices. Data for the study are spot and futures prices at one-, three-, six- and nine-month contracts. He found that the prices are cointegrated and the spot price leads price discovery in all the contracts under investigation; furthermore, the results of the Garbade-Silber approach and error correction model also confirmed this. He concludes that because the spot and the futures markets converge quickly, market participants do not observe the difference and therefore assume that they move together in the long term.

Extending on Quan's study, Schwarz and Szakmary (1994) examine price discovery in energy commodities – specifically, crude oil, unleaded gasoline, heating oil futures markets. In the WTI crude oil market, the estimated results of the Granger causality and Garbade-Silber approach indicate that the futures market leads price discovery, contradicting Quan (1992). Schwarz and Szakmary argued that the monthly data on which Quan's analysis is based cannot capture the dynamic relationship that may exist within a short interval of time, and also suggest that if the contribution made by the futures market in the process of price formation is insignificant, this raises the question of why the market for petroleum is unique and still exists. Building on the literature, Foster (1996) developed a generalized dominance model to study price discovery in the Brent and West Texas Intermediate crude oil futures markets. His model analyses price discovery within a time-varying framework and examine daily data that covers the period before and after the Persian Gulf War from 1990 to 1991. The results show that price is discovered in the futures market during the pre-conflict era, but in the post-conflict the nature of the relationship changes, with the spot market weakly dominating price discovery in all markets. The author suggests that because of the high fluctuations in oil prices during the study period the pattern of the dominance relationship should not be considered as permanent. He also reports that the dominance relationship between the markets can be explain in terms of investors' behaviour and the type of information that enters into the oil markets, and therefore concludes that generalizations should not be made even if the futures market performs its price discovery role.

Moosa (2002) re-investigated the role of the WTI crude oil futures market in price discovery and risk transfer using the Garbade-Silber model. Following Foster (1994), he estimated the model using the seemingly unrelated time series equation in order to allow time varying in the coefficients of the regression equation, arguing that, due to the non-stationarity of the variables and assumption that the regression coefficients are fixed, the estimates of the OLS method can be bias. In contrast to Silvapulle and Moosa (1999), Moosa found that the share of the futures markets in price formation is higher than the spot market. He reports that the two markets do not converge quickly because they react to new information with one day interval. Bekiros and Diks (2008) examined price discovery relationship in WTI daily spot and futures prices at one, two, three and four months to maturity, using the linear and non-linear causality tests and dividing the study into two sample periods from 1991-1999 and 1999-2007. They found evidence of strong linear causality between the prices in either direction in the vector error correction model, while the five-variate implementation showed unidirectional causality in all contracts and for both subsamples. However, the non-linear causality test indicates non-linear bi-directional causality from spot to futures in the first sample, and unidirectional causality in the second sample. As a consequence of these mixed results the authors conducted VECM filtering and found that the linear causal relationship had disappeared, while the non-linear test continued to show bi-directional causality in the first sample. Finally, they also accounted for the volatility effect to see whether the results changed, finding non-linear bi-directional causality still exists in the second sample while the linear causality test indicate support for bi-directional causality from oil spot to futures prices. They reported that when new information flows into the market, participants filter it according to their position, and as a result, there may be bi-directional causality from spot to futures and vice-versa. In line with Silvapulle and Moosa (1991) they concluded that the spot market also make an equal contribution to the process of price discovery.

In a similar vein, Huang et al (2009), using the Granger causality test, and multivariate threshold autoregressive model, studied the relationship between the WTI spot and futures prices in the short run. In order to account for the most important events that affect world oil prices, data for the study covered 1986 to 2007. Contrary to the work of Bekiros and Diks (2008), both the linear and non-linear causality tests indicate that the futures market leads price discovery over the whole sample. When they divided the data into three sample periods – 1990, the most volatile period, a relatively stable period, and 2001, the major volatile period - the results still support that the dominant role of the futures market in price formation is higher in all the subsamples, except the linear model in the first sample. Differing from previous studies, Lean, McAleer and Wong (2010) investigated price dominance from investors' perspectives. In their study, price discovery is assumed to depend on the behaviour of investors who based on the type of information they assimilate about the market condition, switch their assets between the spot and futures markets. They applied the mean-variance and the stochastic dominance approach to analyse the relationship between daily data for closing spot and futures prices at one to four-month contracts in the WTI market: their results indicate that both markets play the price discovery role consistent with Silvapulle and Moosa (1999) and Bekiros and Diks (2008). They observed that even after dividing the study period into three subsamples the results are still consistent and also found that if price dominance is investigated using portfolio diversification both markets contribute to the process.

Other studies have investigated price discovery across different maturities. Hammoudeh et al (2003) studied whether investment in different contracts or markets reduces price risk or increases benefits among three energy products: crude oil, gasoline and heating oil exchange within and outside the United States. They applied the error correction and GARCH models to daily spot and futures prices at one- and three-month contracts, and found that in the WTI market, one-month futures lead spot and three-month futures, while the same contributions was make by the markets in price discovery among the gasoline and heating oil markets. They therefore suggest that the WTI one-month contract should be the main focused of investors and traders because is more efficient. Kim (2010), expanding the previous researches, proposed the Adjustment share approach which can be used to examine price discovery for non-unitary cointegrating vectors. He uses five different approaches to investigate this across the WTI daily spot and futures prices for one to four-month contracts and found mixed results across the models: the Garbade-Silber and Price discovery efficiency loss methods indicate that the spot markets perform the price discovery role in the different maturities while the common share approach shows that the futures market dominates at one-month maturity. Furthermore, the Hasbrouck approach reveals contradictory results in different maturities while the Adjustment share approach support that futures with longer maturities perform the highest role in price discovery. The author argues that the mixed findings was because the models based on permanent shock, and those on structural shock offer a different conclusion because each takes different factors into account, leading him to conclude that price discovery varies across the measures of analysis. Table 4.1 discussed the summary of previous findings on price discovery in the oil futures markets.

Table 4.1 Summary of Previous Results on Price Discovery in the Oil Future Markets

Author(s) and Year	Data and Market	Methods	Results
Silvapulle & Moosa (1991)	WTI daily spot and futures prices at 1, 3 and 6-month contracts from 1985 to 1996	Linear and non-linear Granger causality tests	Futures and spot markets make equal contribution to price discovery.
Quan (1992)	WTI monthly spot and futures prices at 1, 3,6 and 9-month contract from 1984 to 1989	Linear Granger causality and Garbade-Silber approach	Spot market leads price discovery.
Swchwatz & Szakmary (1994)	WTI daily spot and 1- month futures prices from 1984 to 1991	Linear Granger causality and Garbade-Silber approach	Futures market leads price discovery.
Foster (1996)	WTI and Brent daily spot and futures at 1-month from 1990 to 1991	Generalize dominance model	Futures market leads price discovery before the Gulf War, while the relationship changes with spot been the price leader after the War.
Moosa (2002)	WTI daily spot and futures prices at 1-month contract from 1985 to 1999	Garbade-Silber approach	Futures market leads price discovery.
Hammoudeh et al (2003)	WTI daily spot and futures prices at 1, and 3-month contracts from 1986-2001	Error correction and GARCH models	Futures contract for one-months leads three-month and spot in price discovery process.

Bekiros & Diks(2008)	WTI daily spot and futures prices at 1, 2, 3 and 4-month contract from 1991 to 1999	Linear and non-Linear causality tests	Futures and spot markets play equal role in the process of price discovery.
Nung-Hung et al (2009)	WTI daily spot and 1-month futures prices from 1991 to 2007	Linear Granger causality test	Futures market leads price discovery.
Lean et al (2010)	WTI daily spot and futures prices at 1 , 2, and 3 month contracts from 1986 to 2008	Mean variance and Stochastic dominance approach	Futures and spot markets make an equal contribution in price discovery in all maturities.
Kim (2011)	WTI daily spot and futures prices at 1, 2, 3, and 4-month contracts from 1986 to 2010	Garbade-Silber (GS), Common factor weight (CFW), Information share (IS), Adjustment share (AS) & price discovery efficiency loss (PDLE) approaches	Spot market leads price discovery in all maturities in the GS and PDEL while the CFW show that the futures market at one-month maturity. Hasbrouck model show contradictory results across the maturities and AS support that futures contract with longer maturity leads price discovery.

Form the above review, it can be seen that most of the previous studies support the hypothesis that the futures market leads price discovery in the crude oil markets. They also applied either the Granger causality or the Garbade-Silber approach, and that they have focused primarily on the WTI futures market and the price discovery role of the spot and futures markets. Finally, most of these studies have utilized daily data because it is believed to capture all the available information that flows into the market.

4.2.2 The Non-oil Commodity Futures Markets

This section reviews previous studies on other commodity markets, in order to develop a deeper understanding of the area. The bulk of earlier studies in this area have focused on price discovery in agricultural commodities because they have well-established futures markets, some of which have been in operation since the 18th century. Ollermann et al (1989) applied the Granger causality test and the Garbade-Silber model to study price discovery in the US feeder cattle market, using as data daily spot and futures prices over two periods, from 1979 to 1982 and from 1983 to 1986, in order to capture the structural changes in the market. They found that the feeder futures led price discovery in both periods, but the dominance was stronger in the first subperiod and very weak in the second. These results are confirmed by the Garbade-Silber model. Oellermann et al conclude that the role of futures market in price discovery is greater because market participants use the futures prices in decision-making, given the low cost of obtaining information. In a similar vein, Schroeder and Goodwin (1991) applied the Garbade-Silber approach to examined the short-term dominance in the US live hog spot and futures markets. They found that live hog futures market leads price discovery with approximately 65% of new information over the fifteen year period; they noted that the magnitude of the dominance changes over the years and no general trend was discovered over the time period. They also observe that if the study is divided into subperiods, the spot market dominate the process in five out of the fifteen years. As results they suggest that the live hog spot market leads price discovery and this occurs during large cash movements that are not necessarily known in the futures market. In contrast to previous studies, Liu and An (2011) applied the M-GARCH and information share approach to investigate price discovery in the markets for Chinese soybean and copper futures. They found that the share of the futures market in price formation is higher in all the commodities and also observed that the contribution of the soybean futures in the process of price discovery is larger than that of copper. This study also examined information transmission between these commodity markets and the US.

In the financial markets, Abhyankar (1998) investigated the UK stock index futures market using minute-by-minute spot prices and intraday futures at one to four different maturities in 1992. He found that both the linear and non-linear causality tests support that the index futures market perform the function of price discovery, and that after volatility filtering the non-linear causality test indicates non-linear causality running from futures to spot price, leading the author to conclude that price discovery is carried in the futures market. Rosenberg and Traub (2007) studied short- and long-term price discovery in four currencies futures markets, namely, pound, euro, yen and deutschemark. Using as data daily prices for three-month periods in 1996 and in 2006 and the correlation analysis, they found that futures returns led price discovery by up to twelve minutes in 1996, while in 2006 the relationship changed, with spot return leading futures return for all the markets. The author pointed out that the change in the pattern of dominance may be due to changes in the market structure which allow spot traders to have more information on market conditions. He found that in the long term both the Hasbrouck information share and Gonzalo-Granger approach support the theory that the futures market dominated in 1996, with more than 75% information, while the spot market dominated in 2006 in all the currency markets. He concludes that the higher level of transparency in the futures market leads to its key role in price discovery. The problem with this finding is that it cannot be generalized because the sample covers short time period. In line with the previous study, Mizrach and Neely (2008) applied the Hasbrouck information share and Harris-McInish-Wood permanent-transitory weight measures to examine price discovery in the US treasury futures market. They used daily closing spot and futures prices at on-the-run two-year, five-year and ten-year notes. The results indicate that more than 50% of the new pricing information is contributed by the futures market in all except two-year notes, where spot market trading is more active. They show that the growth of the bond futures market around 1996 increased its information share, while the spot market responded less to new information during its period of high volatility.

Theissen (2010) using the Hasbrouck information share and the Gonzalo–Granger common factor weight approach analysed the contribution of the German index futures market in price discovery. He used high frequency data for fifteen-second interval prices and quote midpoints of the thirty most liquid German stocks futures; in contrast to previous studies in these markets, he found that the role played by the futures market in this process is greater, with approximately 93% and 72% of information share and common factor weight, respectively. The author suggest that the dominant role of the futures market occurs when arbitrage prevails in the market but that the spot market adjusts rather quickly to the future market when the deviation between them is large.

Building on these previous studies, Chen and Gau (2010) re-examined price discovery around new macroeconomic announcements in the European and Japanese foreign exchange futures markets. Their analysis was carried out with the Hasbrouck information share and the Gonzalo–Granger common factor weight approach and they found strong evidence that support the spot market leading price discovery in euro and yen foreign exchange, both with and without a macroeconomic announcement. Their results are consistent with those of Rosenberg and Traub (2007) and Cabrera et al (2009), who argued that even though the futures market contributes more during macroeconomic announcements, it is because rational investors who are well informed about the market conditions prefer to trade during this period in order to exploit leverage benefits.

Fricke and Menkhoff (2010) analysed the contribution of the ten-year European bond futures markets to German sovereign debt versus two futures contracts for two years and five years maturity. They found that the ten-year bond accounts for 60% of the information share but there are many days when the two other contracts impound more information. The results remain the same when price discovery is re-examined under a macroeconomic announcement, leading them to conclude that although the ten-year bond is the most important contract it does not dominate price discovery in the European bond futures market. Furthermore, most of the studies on metal commodities also support that the futures markets leads price discovery. For example, Pavaburt and Chaihetphon (2010) investigated price discovery in futures market for Indian gold using the VECM. The short-term dynamic analysis shows that changes in futures return do not influence changes in past spot returns, while changes in previous futures prices have significant influence on spot returns. They also found that the long term price discovery is performed by futures market; these results were consistent when they investigated dominance in the Indian gold mini futures contract. Figuerola-Ferretti and Gonzalo (2010), building on the Garbade-Silber model, developed an equilibrium model of commodity spot and futures prices to examine whether the U.S metals futures markets carry out their price discovery function. However, in contrast to the Garbade-Silber model, they assumed that the elasticity of arbitrage service is finite and the existence of endogenous convenient yield. Their study used daily spot and fifteen-month forward prices for aluminium, copper, lead, zinc and neon, and found that the futures market perform the price discovery function, except in the lead and copper commodity markets; they also observed that the process of price formation occurred in all the commodities that have highly liquid futures markets. In line with most studies they generalized their conclusion showing that the futures market is the price leader. Table 4.2 presents a summary of the results obtained from this review of non-oil commodity futures markets.

Table 4.2 Summary of Previous Results on Price Discovery in the Non-Oil Commodity Future Markets

Author(s) and Year	Data and Market	Methods	Results
Ollermann et al (1989)	US feeder cattle daily spot and futures prices from 1979 to 1986	Linear Granger causality and Garbade-Silber approaches	Futures market leads price discovery in all the periods, but the dominance was stronger in the first subperiod and very weak in the second subperiod.
Schroeder& Goodwin (1991)	US live Hog daily spot and futures prices from 1975 to 1989	Garbade-Silber approach	Futures market leads price discovery.
Abyankar (1998)	UK stock index minute-by-minute spot and futures for at 1 to 4-month maturities for 1992	Linear and non-linear Granger causality test	Futures market leads price discovery in all maturities.
Rosenberg & Traub (2007)	Four currencies: euro, pound, yen and deutschemark foreign exchange daily spot and futures prices for markets in 1996 and 2006	Gonzalo-Granger common factor weight and information share approach	Futures market dominates in 1996 in both the short term and long term while the relationship changes with spot market been the price leader in 2006 in both markets.
Mizrach & Neely (2008)	US treasury bond daily spot and futures prices for 2, 5 and 10 years from 1995 to 2001	Hasbrouck information share and Harris-McInish-Wood permanent transitory weight measures	Futures market leads price discovery.
Theissen (2010)	German stocks index 15 second interval and quote mid-points of 30 spot and futures prices for the year	Hasbrouck information share and Gonzalo-Granger approach.	Futures market leads price discovery.

	1991		
Chen & Gau (2010)	Two currencies: euro and Japanese yen foreign exchange intraday spot and futures prices from 2004 to 2005	Hasbrouck information share and Gonzalo-Granger approach	Spot market leads price discovery in all the markets.
Frick & Menkhoff (2010)	European bond daily futures prices for 2, 5 and 10 years from 2004 to 2007	Hasbrouck information share and Gonzalo-Granger approach	Futures markets for all the contracts play important role in price discovery.
Pavaburt & Chaihetphon (2010)	Indian Gold daily spot and futures prices from 2003 to 2007	Vector error correction model	Futures market leads price discovery.
Figuerola-Ferretti and Gonzalo (2010)	Five UK non-ferrous metals: aluminium, lead, zinc, copper and neon daily spot and 15- month futures prices from 1989 to 2006	Equilibrium model of commodity spot and futures prices	Futures market leads price discovery in all the markets except copper.
Lin & An (2011)	Chinese soybean and copper daily spot and futures prices from 2004 to 2009	M-GARCH and Information share approach	Futures market leads price discovery in all markets.

The review shows that the studies in both the oil and non-oil commodity markets are similar, in that they concentrated on price discovery between the spot and futures markets at either one or more maturities. They also examine price discovery using daily data, and apply the Granger causality approach. Their results support that the function of price discovery is carried out by the futures market. However, in contrast to the studies of oil, the recent studies in the non-oil commodity markets are more concerned with microstructure models, especially the common factor weight and information share approach. In addition, studies of non-oil commodity markets use high frequency data such as tick-by-tick, intraday and minute-by-minute to examine price discovery.

4.3 Theoretical Framework of Price Discovery

In theory, the futures and spot prices reflect the same commodity, so their prices are expected to react simultaneously to new information (Bekiros and Diks, 2008) and therefore in perfectly integrated market neither market leads the process of price discovery (Foster, 1994). Although market conditions such as noise trading, investors psychology and market frictions may sometimes cause deviations between the prices (Kurov and Lasser, 2004), such differences should not allow for arbitrage. The spot and futures prices relationship was initially described in the cost-of-carry model which considered the futures price to have a fair value (Working 1948), a model which can be expressed in the following form:

$$F_t = S_t e^{(r+w-\delta)(T-t)} \tag{4.1}$$

where F_t represents the futures price of a contract at period t, S_t represents the spot price at period t, r represents the risk free interest rate, w represents the storage cost, δ represents the convenient yield in case of commodity, the maturity period T represents the futures contract while T-t denotes the period at which the contract matures. In this model, the futures contract price that matures at time t should equal the spot price at time t plus the storage cost (or holding the spot position less the convenient yield). The model argues that at the time of maturity of the futures contract the storage cost of carrying a security is expected to be zero so that the spot and futures prices are equated; otherwise opportunities for arbitrage would prevail in the market[19]. Most studies of price discovery in commodity futures have used the cost-of-carry model; however, this approach is rarely applied to the oil market due to the difficulty in testing convenient yield and storage costs (Switzer and El-Khuory, 2007). As a consequence, studies in the oil futures market have employed either a modification of the cost-of-carry model such as the Garbade and Silber (1983) approach, or have used the Granger causality approach. In this chapter, price discovery is also examined using the Gonzalo-Granger common factor weight, discussed in the next section.

4.4 Empirical Methodology

This chapter provide explanation of the standard econometric approaches that will be used to examine price discovery in the crude oil markets: the Vector Error Correction Model (VECM), Gonzalo-Granger common factor weights (CFW)

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[19] Equation 4.1 is called the equilibrium and no arbitrage position; at this point neither the seller nor buyer of futures will earn an above-average profit.

and Garbade and Silber short-run dynamic model (GS) approaches. These measures are briefly discussed below.

4.4.1 Vector Error Correction Approach

Engle and Granger (1987) proposed the error correction approach which can estimate the short-term deviations between the futures and spot prices changes (arbitrage) to the long-run equilibrium position[20]. Continuous arbitrage moves the two prices together in the long term. The error correction relationship between the prices can be described in the following equation:

$$\Delta S_t = \delta_0 + \sum_{i=1}^{k} \delta_1 \Delta S_{t-i} + \sum_{i=1}^{k} \delta_2 \Delta F_{t-i} + \alpha_s (S_{t-1} - F_{t-1}) + \varepsilon_{st}$$

$$\Delta F_t = \beta_0 + \sum_{i=1}^{k} \beta_1 \Delta S_{t-i} + \sum_{i=1}^{k} \beta_2 \Delta F_{t-i} + \alpha_f (S_{t-1} - F_{t-1}) + \varepsilon_{ft} \qquad (4.2)$$

where ΔS_t and ΔF_t are the spot and futures prices changes, respectively. α_s and α_f are the error correction terms (speed of adjustment coefficient) for the spot and futures prices and ε_{st} and ε_{ft} are the residuals, respectively. Therefore the error correction term can be used to estimate each markets contribution to price discovery (see Cabrera et al, 2009; Eun and Sabherwal, 2003). For instance, the spot market is the price leader if α_s is insignificant while α_f is positive and significant, whereas, the futures market is the price leader if α_f is insignificant and α_s is significant and negative. When α_s and α_f have correct signs and are both significant, then neither market leads. Rather, the market with smaller value of the adjustment coefficient (in absolute value) is the price leader because that

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[20] The deviation between the spot and the futures prices is the arbitrage relationship.

market impounds more information and therefore adjusts faster to the long-run equilibrium position. Among others, Cabrera et al (2009), Schlusche (2009), Floros (2009) and Thiessin (2010) have estimated price discovery using this approach. This chapter also used equation (4.2) to examined price discovery across different crude oil futures contracts.

4.4.2 Gonzalo-Granger Common Factor Weights Approach

Gonzalo and Granger (1995) built this model based on the work of Schwarz and Szakmary (1994). It assumes that when two non-stationary variables together form a linear combination, there must be a common factor which results in them being cointegrated[21]. The model assumes that the common factor of the price P_t in equation (4.3) can be divided into a permanent component f_t and a transitory component z_t. The permanent-transitory (PT) process can be described as follows:

$$P_t = A_1 f_t + A_2 z_t \tag{4.3}$$

where f_t is the vector of common factor and z_t is error correction vector which are both linear combinations of price P_t . $f_t = \alpha'_\perp P_t$ and $z_t = \beta' P_t$, β' is the cointegrating vectors and $\alpha'_\perp$ is a vector. Gonzalo and Granger pointed out that one can identified the common factor weight by imposing that in the long run the error correction term does not cause the common factor. The PT decomposition suggests that the weight of each market in the permanent

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[21] Granger and Gonzalo (1995) shows that the common factor is unobservable and form a linear combination among I (1) variables.

component determines its share in price discovery, which can be calculated as follows:

$$CFW_i = \frac{\alpha_{\perp i}}{\alpha_{\perp 1} + \alpha_{\perp 2}}, \quad i = 1,2..........n \tag{4.4}$$

where $\alpha'_{\perp i}$ is the ith element of $\alpha'_{\perp}$ and can be negative. The value of CFW_i shows market i contribution to price discovery (Figuerola-Ferretti and Gonzalo, 2010)[22]. Baillie et al (2002) argued that because the error correction vector is related to the coefficient $\alpha'_{\perp}$ in orthogonal form, then $\alpha'_{\perp 1} = \alpha_2$ and $\alpha'_{\perp 2} = -\alpha_1$, the common factor of two variables with unitary cointegrating vector $\beta = (1 \ \ -1)$ can easily be computed from equation (4.2) as follows:

$$CFW_f = {}^{\alpha_f}\!\big/\!(\alpha_f - \alpha_s), \qquad CFW_s = {}^{-\alpha_s}\!\big/\!(\alpha_f - \alpha_s) \tag{4.5}$$

where α_f and α_s are the adjustment coefficients for the futures and spot markets, respectively. The ratio of the error correction term $\alpha = (s, f)$ indicates the contribution of each market in price discovery (Schlusche, 2009; Chen and Gau, 2010; Theissen, 2010). The market that contributes more to price discovery adjusts faster to the long-run equilibrium price and thus each market contribution is determined by the value of its common factor weights. For example, the futures market leads in price formation when $CFW_f > CFW_S$ and the reverse is the case when the spot market dominates the process. Both CFW_f and CFW_S will be 0.5 when the two markets make an equal contribution to price discovery.

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[22] Equation (4.4) is related to Granger and Gonzalo's permanent component where higher (lower) values of the common share are the same with higher (lower) contribution of a variable to the common factor (Yang et al, 2010).

4.4.3 Garbade-Silber Short Run Dynamic Approach

Garbade and Silber (1983) proposed the simultaneous price dynamic model, based on elasticity of supply of arbitrage services. In this model, the proportion contributed by a market in price formation can be measured from the share of its adjustment coefficient in the error correction model, and that this contribution is determines by the number of its participants[23]. Garbade and Silber (GS) model show that the market with the largest number of participants impounds new information faster, and therefore leads the price discovery process. The matrix form of the GS model can be described as follows[24]:

$$\begin{bmatrix} S_t \\ F_t \end{bmatrix} = \begin{bmatrix} \alpha_s \\ \alpha_f \end{bmatrix} + \begin{bmatrix} 1-\beta_s & \beta_s \\ \beta_f & 1-\beta_f \end{bmatrix} \begin{bmatrix} S_{t-1} \\ F_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{ts} \\ \varepsilon_{tf} \end{bmatrix} \qquad (4.10)$$

where S_t represents the spot price at time t and F_t represents the futures contract price at time t. The parameters β_s and β_f reflect the current price of each market that is influenced by the past price changes in the other market. The Garbade-Silber model includes the constant term α_s and α_f to reflect the secular price trends and any persistence disparity between the futures and spot prices that results from changes in the quotations. From equation (4.10) changes in price for each market depend on the amount of mispricing $(F_{t-1} - S_{t-1})$ that occurs between the markets, and the price discovery role is performed by the market in

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[23] According to Garbade and Silber (1983) the number of participants determines the sizes of the market.

[24] The Garbade- Silber model can be estimated via ordinary least square as: $\begin{bmatrix} S_t - S_{t-1} \\ F_t - F_{t-1} \end{bmatrix} = \begin{bmatrix} \alpha_s \\ \alpha_f \end{bmatrix} + \begin{bmatrix} \beta_s \\ -\beta_f \end{bmatrix} [S_{t-1} - F_{t-1}] + \begin{bmatrix} \varepsilon_{ts} \\ \varepsilon_{tf} \end{bmatrix}$

which the mispricing begins (Schwarz and Szakmary, 1994). Garbade and Silber proposed that the spot and futures markets share in price discovery is measured by the ratio $\theta = {}^{\beta_s}\!/_{\beta_s} + \beta_f$; where θ must be positive and sum to one[25]. When the coefficient $\beta_f = 0$, the ratio would be unity and the futures market perform price discovery, in this case the spot market become the pure satellite because it received new pricing information from the futures market. Whereas, if the coefficient $\beta_s = 0$, the ratio will be zero and; therefore the reverse is the case, with the futures market becoming the pure satellite of the spot market. However, if θ has its value between 1 and 0, a bi-directional (feedback effect) relationship would exist between the markets in price discovery. Furthermore, Garbade and Silber also proposed that the mispricing ($F_{t-1} - S_{t-1}$) between the markets in equation (4.10) can be solved to estimate the role of the futures market in risk transfer:

$$F_t - S_t = \alpha + \delta(F_{t-1} - S_{t-1}) + \varepsilon_t \tag{4.11}$$

where $\alpha = \alpha_f - \alpha_s, \delta = 1 - \beta_f - \beta_s$ and $\varepsilon_t = \varepsilon_{tf} - \varepsilon_{ts}$. The coefficient δ is the magnitude at which the spot and futures prices adjust to long run equilibrium, and has an inverse relationship with the supply of arbitrage services (Schwartz and Sazkmary, 1994)[26]. If the value of the coefficient is lower the convergence

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[25] $\theta_1 + \theta_2 = 1$

[26] Arbitrage service refers to any activity that allows the spot and futures price to serve as close substitutes for each other (see Schwartz and Sazkmary, 1994).

between the two prices occurs more rapidly because small proportion of the price difference on day $t-1$persists on day t and vice versa[27].

4.5 Data and its Properties

This chapter employs daily closing prices for West Texas Intermediate and Brent crude oil spot and futures at one and three-month contracts to maturities. WTI futures contract are traded in the New York Mercantile Exchange (NYMEX) while Brent futures contract are traded in the Intercontinental Exchange (ICE). Both contracts serve as world benchmarks used in oil pricing and also determine other commodity prices. Daily data is used to fully capture the information flow that brought about innovation in prices during the study period, which the low-frequency monthly data cannot do. The data series covers the sample period from January 2, 2000 to May 15, 2011: those for West Texas Intermediate are source from the U.S Energy Information Administration. Brent prices from January 2000 to November 2008 are sourced from Maslyuk and Smyth (2008), while those from December 2008 to May 2011 are obtained from the Data stream. NYMEX WTI contracts are traded from 09:45 EST (14:45 GMT) to 14:30 EST (20:10 GMT) while spot market close at 18:00. Brent futures were initially traded in the International Petroleum Exchange (IPE) until April 2005, when it became electronic trading in ICE London. The IPE trades Brent contracts from 10:02 GMT to 20:13 GMT while ICE trades start at 01:00 GMT (23.00 on Sundays) to 23:00 GMT and the spot market close trading at 18:30. All the contracts prices are in dollars and cents per barrel in both markets. To deal

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[27] Moosa (2002) pointed out that if the coefficient is estimated for daily data, it means that for short-run periods there is no high correlation among daily price change and the conclusion may be different in the case of monthly or quarterly data.

with the problem of nonsynchronous trading between the spot and futures markets caused by day effect this chapter uses the matching process to adjust for public holidays and other non-trading days, and thus observations with missing information are deleted in all the oil price series. A total number of 2838 observations are obtained for each of the oil prices series, all of which are then transformed into natural logarithm form to reduce the problem of heteroskedascity. This chapter used the following notations: WTI-S, WTI-C1and WTI-C3 to denote WTI spot and futures prices at one- and three-month maturities, respectively, while for the Brent market, Brent-S, Brent-C1 and Brent-C3 are used to denote spot and futures prices for one and three-month maturities, respectively.

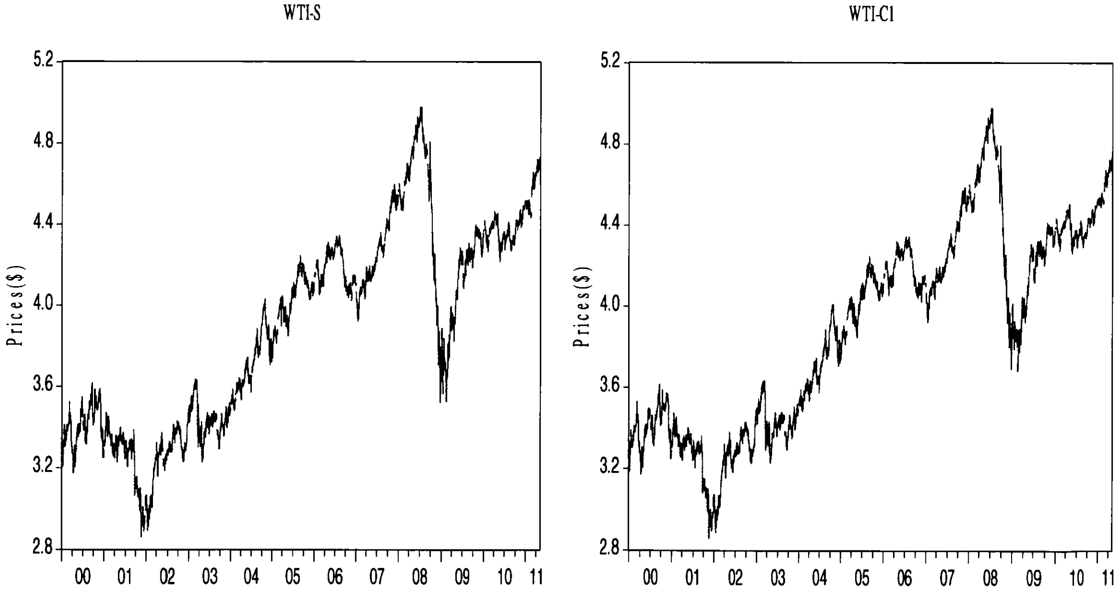
Table 4.3 Descriptive Statistics for Crude Oil Prices

Variables	Mean	Median	Max	Min
WTI-S	3.8939	3.9718	4.9789	2.8622
WTI-C1	3.9019	3.9896	4.9787	2.8593
WTI-C3	3.8880	3.9833	4.9845	2.8937
Brent-S	3.8695	3.9533	4.9695	2.804
Brent-C1	3.8650	3.9469	4.9842	2.8724
Brent-C3	3.8648	3.9665	4.9908	2.8628

Variables	Std.Dev	Skewness	Kurtosis	Jarque-Bera-prob
WTI-S	0.4905	0.0124	1.8643	152.6(0.0)
WTI-C1	0.4942	-0.0136	1.8422	158.6(0.0)
WTI-C3	0.5022	0.0004	1.7471	185.6(0.0)
Brent-S	0.5206	0.0026	1.7778	176.6(0.0)
Brent-C1	0.5184	0.0451	1.7676	180.5(0.0)
Brent-C3	0.5305	0.0210	1.7010	199.7(0.0)

Note: Figure in brackets is the probabilities for the normality test.

Table 4.3 presents the descriptive statistics of the crude oil prices. The sample means are almost the same in all markets, but higher in the WTI at one-month maturity. The standard deviation of the three-month futures contract is the largest in both markets and those for futures increase with maturity. Furthermore, with the exception of WTI at one-month futures contract, the results show evidence of positive skewness, and kurtosis is less in all prices. The Jarque-Bera test shows that the hypothesis of normality is rejected in all the oil prices, indicating that the crude oil prices are not normally distributed. Figure 4.1 plots the daily data for WTI and Brent spot and futures prices at different maturities and shows that all the price series are highly volatile and exhibit a mixed trend. All prices show similar upward and downward trend, implying that they respond to the same shock. The plot also shows that the oil prices exhibits one or more structural breaks.



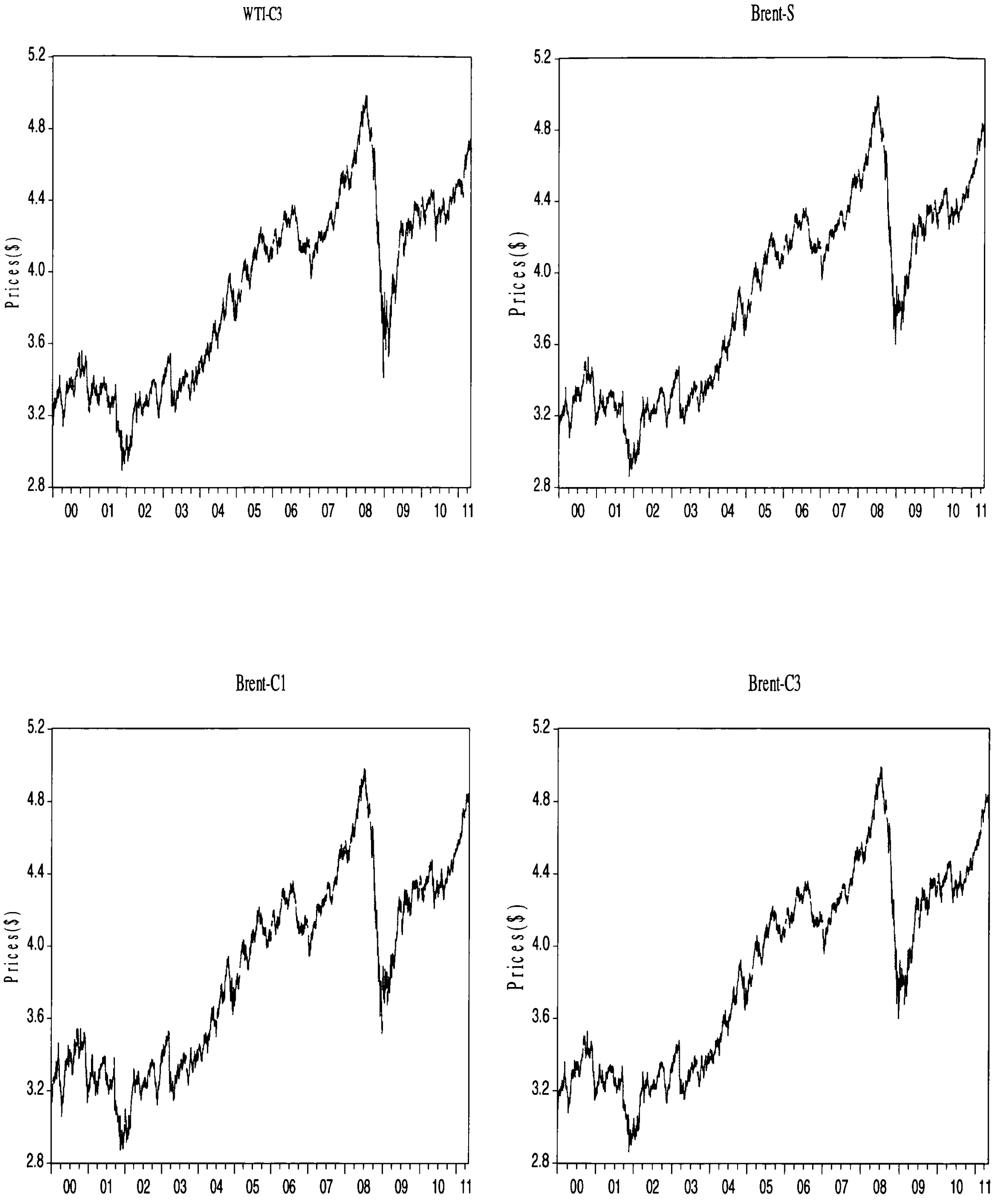


Figure 4.1: Daily Spot and Futures Prices for WTI and Brent, January 2000 - May 2011

4.6 Empirical Results

This section presents the results obtained from the data analysis. First, the properties of the oil prices are examined using the unit root test; second, the

Johansen (1988) and Johansen and Juselius (1990) approach is employed to estimate whether there is cointegration relationship among the prices. Third, the vector error correction model (VECM) and the Gonzalo-Granger (1995) common factor weights are used to examine price discovery in the long term, and finally, the short-term relationship is examined using the Garbade-Silber (1983) approach.

4.6.1 Unit Root Test

The unit root test is used to verify the properties of the oil price series. This chapter applied four types of unit root tests: the Augmented Dickey Fuller (ADF), Phillips-Perron (PP), Kwiatkowski, Phillips, Schmidt and Shin (KPSS) and the Zivot-Andrews (ZA) unit root tests. These are conducted using two specifications: with constant and with constant and trend in the oil price series. The optimal lag length for the ADF test is selected by the Schwartz information criterion (SIC) while the PP and KPSS test were chosen based on Bartlett kernel. The results are reported in Table 4.4, where panels A and B present the results of the tests with constant and with constant and trend, respectively. The results of the Augmented Dickey Fuller and Phillips-Perron tests indicate that each of the oil price have a unit root for the specifications. However, all prices series appear to be stationary I (0) in difference. The Kwiatkowski, Phillips, Schmidt and Shin also support stationary series in each of the price series, and the results are confirmed by the Zivot and Andrew unit root test reported in Panel C. The Zivot and Andrews test also identified the month of July 2008 as the break point period, coinciding with the period when oil reached $145 per barrel prior to its crash to $33 in December of the same year. All the unit root tests therefore show non-stationarity in all the crude oil price series.

Table 4.4 Unit Root Test

Panel A: Unit root test with intercept

Variables	ADF		PP		KPSS	
	(i)	(ii)	(i)	(ii)	(i)	(ii)
WTI-S	-1.368	-55.22*	-1.232	-55.49*	5.463*	0.039
WTI-C1	-1.272	-54.32*	-1.172	-54.49*	5.633*	0.040
WTI-C3	-1.216	-52.63*	-1.220	-52.63*	5.509*	0.042
Brent-S	-1.023	-52.84*	-1.031	-52.85*	5.742*	0.040
Brent-C1	-0.983	-55.41*	-0.910	-55.40*	5.570*	0.050
Brent-C3	-0.876	-56.04*	-0.899	-56.01*	5.661*	0.052

Note: * denotes statistical significance at the 5% level. The specifications (i) and (ii) represent the levels and first difference of the unit root test, respectively.

Panel B: Unit root tests with constant and trend

Variables	ADF		PP		KPSS	
	(i)	(ii)	(i)	(ii)	(i)	(ii)
WTI-S	-2.857	-55.21*	-2.666	-55.48*	0.432*	0.040
WTI-C1	-2.775	-54.31*	-2.637	-54.48*	0.447*	0.041
WTI-C3	-2.482	-52.63*	-2.544	-52.62*	0.487*	0.042
Brent-S	-2.710	-52.84*	-2.758	-52.84*	0.443*	0.038
Brent-C1	-2.544	-55.40*	-2.512	-55.39*	0.440*	0.046
Brent-C3	-2.203	-56.03*	-2.276	-56.00*	0.479*	0.052

Note: * denotes statistical significance at the 5% level. The specifications (i) and (ii) represent levels and first difference of the unit root test, respectively.

Panel C: Zivot and Andrew unit root test

Variables	T-statistics (i)	Break date	T-statistics (ii)	Break date
WTI-S	-4.906	23/09/2008	-25.001**	15/07/2008
WTI-C1	-4.684	23/09/2008	-24.992**	15/07/2008
WTI-C3	-4.726	29/09/2008	-24.559**	15/07/2008
Brent-S	-4.462	29/09/2008	-53.002**	14/07/2008
Brent-C1	-4.524	26/09/2008	-55.618**	7/07/2008
Brent-C3	-4.339	29/09/2008	-24.330**	15/07/2008

Note: * and ** denote significance at the 1% and 5% levels. The asymptotic critical values for model C are:-5.57(1%), -5.08(5%) and -4.82(10%). The specifications (i) and (ii) represent the t-statistics in level and first difference of the unit root test, respectively.

4.6.2 Cointegration Test

This section investigate whether the oil prices are cointegrated, meaning that they have one common stochastic trend. Having I (1) price series, the Johansen cointegration approach described in chapter 3, section 3.4 is used to determine whether there is long run relationship among the crude oil futures and spot prices, and the different futures contract prices series. First, a VAR at level is run to determine the lag length. The optimal lag lengths ranges between one and six lags for all prices and were selected by the Akaike information criterion (AIC) and Schwartz information criterion (SIC). Table 4.5 presents the results for the Johansen cointegration test and shows that for both markets the trace and maximum eigenvalues tests indicate that the spot and futures prices are cointegrated at the 5% significant level. The results support the work of Kaufmann and Ullman (2009), Sivapulle and Moosa (1991) and Bekiros and Diks (2008) in the WTI market, and are consistent with Foster (1996) in the

Brent market. Furthermore, the cointegration test results for cross-contract analysis also support the null hypothesis of one-cointegrating vector between one- and three-month futures prices in each of the oil market, suggesting that a stable linear combination exists between the prices in the long run. This findings support those of Hammaoudeh et al (2003) and Kim (2011) who studies the WTI market. The result of this analysis indicates that there is cointegration relation among the oil prices in each case, with one common stochastic trend that drives them together in the long term[28]. Following this, the chapter proceeds to investigate which market performs the price discovery role.

Table 4.5 Johansen Cointegration Test

Variables	λ trace r=0	λ trace r≤1	λ Max r=0	λ Max r≤1
WTI-S and WTI-C1	101.70* [25.87]	7.375 [12.52]	94.33* [19.39]	7.375 [12.52]
WTI-S and WTI-C3	32.37* [20.26]	2.762 [9.165]	29.61* [15.89]	2.763 [9.165]
WTI-C1 and WTI-C3	56.74* [20.26]	2.759 [9.165]	53.98* [15.89]	2.759 [9.165]
Brent-S and Brent-C1	111.78* [25.87]	6.750 [12.52]	105.03* [19.39]	6.750 [12.52]
Brent-S and Brent-C3	70.85* [25.87]	5.922 [12.52]	64.92* [19.39]	5.922 [12.52]
Brent-C1 and Brent-C3	72.71* [20.26]	2.820 [9.165]	69.98* [15.89]	2.759 [9.165]

Note: * indicates that the null hypothesis is rejected at 5% level of significance. The critical values at 5% level are taken from λ trace and λ max tables, MacKinnon-Haug-Michelis (1999) and are shown in parentheses below the test statistics

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[28] According to the Hasbrouck (1995) information share and Granger –Gonzalo permanent-transitory weight approach this common factor drives the prices in all markets to reach equilibrium position.

4.6.3 Vector Error Correction Approach

Table 4.6 presents the estimated results of the error-correction model for both crude oil markets. In the WTI market, the estimated value for the error correction term coefficients on the spot market is negative and significant, while for the futures market it is positive but insignificant in all markets at different maturities. These results suggest that the futures market responds first to new information on price in all maturities. The Brent market also provides similar results; error correction coefficient for the futures market is insignificant and positive while that of the spot market has the correct sign in all maturities. These results indicate unidirectional causality from futures to spot market in the oil markets at the different maturities. When the absolute value of the error correction terms are compared the results clearly show that the futures market coefficient is lower, implying that the futures prices adjust faster to the long-run equilibrium error. The findings suggest that the futures market impound more information and therefore leads price discovery in both markets at the different maturities.

The results of the cross-contract analysis for both markets are also presented in Table 4.6. The results show that the estimated value of the error correction coefficients on the one-month futures contract are negative and significant, while for the three-month futures contract they are positive but insignificant at the 5% level in each of the crude oil markets. This result indicates unidirectional causality from three-month futures contract to one-month futures and not vice-versa, suggesting that the three-month futures contract leads price discovery by incorporating new pricing information more and that investors should therefore focus on this contract in order to minimize risk. Finally, it is clear that all the crude oil futures markets perform their price discovery function in all maturities but are more efficient at three-month maturity.

Table 4.6 Estimated Results of the VECM Approach

Variables	VECM	Lags
$\begin{pmatrix}\Delta WTI - S \\ \Delta WTI - C1\end{pmatrix}$	-0.0522[-2.695] 0.0133[0.739]	3
$\begin{pmatrix}\Delta WTI - S \\ \Delta WTI - C3\end{pmatrix}$	-0.0397[-2.314] 0.0025[0.164]	8
$\begin{pmatrix}\Delta WTI - C1 \\ \Delta WTI - C3\end{pmatrix}$	-0.0299[-2.513] 0.0049[0.437]	1
$\begin{pmatrix}\Delta Brent - S \\ \Delta Brent - C1\end{pmatrix}$	-0.0661[-4.271] 0.0567[1.990]	2
$\begin{pmatrix}\Delta Brent - S \\ \Delta Brent - C3\end{pmatrix}$	-0.0453[-3.967] 0.0161[1.477]	3
$\begin{pmatrix}\Delta Brent - C1 \\ \Delta Brent - C3\end{pmatrix}$	-0.6413[-3.360] 0.0126[0.707]	4

Note: t- statistics is shown in parenthesis besides the error correction coefficients. The lag lengths are selected by Akaike information criterion (AIC) and Schwartz information criterion (SIC).

4.6.4 Common Factor Weight Approach

The estimated results from the common factor weights are presented in Table 4.7. Following the approach of Baillie et al (2002), these results were obtained from the error correction coefficients as discussed earlier and reported in Table 4.6. In the West Texas Intermediate crude oil market, the results indicate that the spot market contributes 20% to the common factor, while the futures market at one-month maturity contributes 79% to the process of price discovery. The results also indicate that the common factor weight is 5% for the spot and 94% for the futures markets at three-month maturity. In line with the error correction model, the results suggest that the futures market leads the process of price discovery by incorporating more information in all the maturities, and thus support that the futures market performs price discovery function. The finding confirms research by Kim (2010) who, using data for longer period from 1989 to 2010, reports the common factor weight of 82% and 1.1% at one and three-month maturity, respectively.

For the Brent market, the spot market has the common factor weights of 46% and 54% for the futures market at one-month maturity, indicating that the futures market leads price discovery, whereas in the second case, the futures market has even higher common factor weight of 74% at three-month maturity, while for the spot market it is 26%. In common with the WTI market, these results show that new pricing information is incorporated more by the futures market and therefore plays the price discovery role in all the maturities. One important finding is that all the markets show that futures market at longer maturity (three-month) contributes more, suggesting that the longer the futures contract to its maturity, the more the market impounds new pricing information and the less contribution the spot market make in the process of price discovery. Therefore speculative opportunities cannot be exploited in the WTI and Brent market in the long term due to market efficiency.

Table 4.7 Estimated Results of the Common Factor Weights

Variables	Common Factor Weight CFW)
WTI-S	0.2032
WTI-C1	0.7968
WTI-S	0.0590
WTI-C3	0.9407
WTI-C1	0.140
WTI-C3	0.859
Brent-S	0.4617
Brent-C1	0.5382
Brent-S	0.2622
Brent-C3	0.7378
Brent-C1	0.0193
Brent-C3	0.9807

Note: The common factor weight (CFW) for the futures and spot markets are calculated as $CFW_f = \alpha_f \big/ \alpha_f - \alpha_s$ and $CFW_f = -\alpha_s \big/ \alpha_f - \alpha_s$, respectively.

Table 4.7 presents the estimated results obtained from the cross-contract analysis. For the WTI market, the common factor weight for the one-month contract is 14% while for the three-month contract it is 85%, a finding consistent with that of Kim (2010). In the Brent market, the contribution of the three-month contract is much larger at 98%, while the one-month contract contributes only 2%. These results suggest that the three-month futures contract plays the price discovery function in both markets. Another interesting finding is that all the markets provide strong evidence that supports the contribution of three-month futures contract to price discovery, and it can also be seen that the two oil markets have similar characteristics in both the single and cross-market analysis in the long term. In summary, and in line with the majority of previous studies, all the results from the two models support the hypothesis that the leading role is perform by the futures market in price discovery in the two crude oil markets over the study period. Therefore, the crude oil futures markets perform their price discovery function and are efficient in the long term. However, the results also provide strong evidence that three-month contracts leads one-month contracts in all markets and thus investors should focus on the former because the futures markets performance is more efficient at this maturity. The implication of the results is that hedgers would benefit because the markets are able to impound the new pricing information and therefore reduce the unsystematic risk in the different maturities. More so, portfolio diversification would be effective across the oil markets, however, speculative opportunities can be exploited in the two oil markets because the three-month contract leads the one-month contract in the price discovery process.

4.6.6 Garbade-Silber Approach

Table 4.8 reports the results for the Garbade-Silber (GS) short-run dynamic model, estimated using the regression approach. The GS model shows that the value of $\theta = {}^{\beta_s}\!/_{\beta_s} + \beta_f$, will be higher and less than 0.5 when the futures and spot market leads price discovery process, respectively. The Ljung-Box diagnostic Q statistics indicate that the residuals in the regression equations are not autocorrelated up to 36 lags in all the crude oil markets. In panel A, the estimated results show that β_s and β_f are significant and positive in both the WTI and Brent markets at one- and three-month contracts to maturities, implying that the spot and futures prices respond to new pricing information simultaneously. The measure of price discovery is then estimated in order to determine the price leader. The estimated value of θ is 0.68 and 0.73 for WTI at one- and three-month futures contracts, respectively. The results reports that the values are 0.55 and 0.66 in the Brent market at one- and three-month futures contract, which implies that the futures market dominates price discovery process with approximately 55% to 73% between the WTI and Brent markets across the different maturities. It is clear from the results that both futures markets perform their price discovery role in all the maturities. When the results are compared with previous studies the estimates are a little higher than the value obtained by Quan (1992), who reported 0.52 and 0.70 for WTI at one-and three-month futures contracts, respectively. Schwarz and Szakmary (1994) reported the value of 0.55 while Moosa (2002) reported 0.60 at one-month contracts. However, the results contradict those of Kim (2010) who reported 0.17 and 0.87 at one-month and three-month contracts, respectively, yet the difference in the value of θ is not surprising given the differences in the period of study.

The estimates of the coefficient δ show that between the futures and spot prices there is significant mispricing, extending to the next trading day in both markets. The results indicate that the value of δ is 0.91 and 0.93 in the WTI market at one- and three-month contracts respectively. In the Brent, the values of δ are 0.83 and 0.91 at one- and three-month contracts. These results imply that approximately 10 to 17% of the mispricing ranging between the two markets disappears the next trading day. The results also suggest that supply of arbitrage is less at three-month contracts to maturity in both markets, suggesting that price convergence between the prices takes place during small time interval in all markets. The findings are in line with those of Quan (1992) and Schwarz and Szakmary (1994) who studied the WTI market.

Table 4.8 Estimated Results of the Garbade-Silber Approach

Panel: A	β_s	β_f	θ	δ
WTI-S and WTI-C1	0.062** [3.419]	0.029** [1.730]	0.680	0.91
WTI-S and WTI-C3	0.051** [3.470]	0.019* [1.435]	0.733	0.93
Brent-S and Brent-C1	0.095** [7.548]	0.079** [6.305]	0.546	0.83
Brent-S and Brent-C3	0.060** [5.554]	0.030** [3.106]	0.664	0.91

Panel: B	β_1	β_2	θ	δ
WTI-C1 and WTI-C3	0.027** [2.389]	0.003 [0.277]	0.838	0.97
Brent-C1 and Brent-C3	0.088** [5.507]	0.017 [1.183]	0.900	0.91

Note: The coefficients β_s and β_f are error correction terms for spot and futures market, respectively. Also, the coefficients β_1 and β_2 are error correction terms for futures contract at one and three-month, respectively. Garbade and Silber approach assumes the error correction coefficients to be positive. The measure $\theta = {\beta_s}/{\beta_s} + \beta_f$, value greater than 0.5 shows that futures market dominates in price discovery process. The coefficient δ measures the mispricing between the markets. The values in parentheses beside the parameters are the t-statistics and asterisk (*) and (**) indicate significance at the 1% and 5% level.

Table 4.8 also reports the estimates of the cross-contract analysis for both markets in Panel B. The estimated values of β_1 for both markets are positive and significant, suggesting that the one-month contract impounds new pricing information more. However, the estimates of β_2 are positive but insignificant, suggesting that there is little feedback of new pricing information between the one- and three-month contracts in all markets. The value of θ indicates 0.83 and 0.90 for the WTI and Brent markets at one-month contracts, and suggests that the one-month contract leads the three-month contract in the process of price discovery. The results contradict that of the common factor weight analysis in both markets, consistent with Kim (2010) who reported 0.88 in the WTI market.

Furthermore, the estimates of δ in the WTI and Brent markets are 0.97 and 0.91 respectively, indicating that about 9% of the mispricing between two contracts is transferred to the next trading day and thus supply of arbitrage between the two contracts lasts over a short time in all markets. The results show that the futures market leads price discovery in the two crude oil markets and also support that one-month futures contracts leads three-month contracts in the process of price discovery in all the markets in the short term. The implication of the findings is that there is strong evidence that hedging would be effective because the oil markets minimise the high risk associated with oil prices and portfolio diversification across the two markets would be profitable because they are all efficient within the maturity. However, in contrast to the long term analysis the results show that the one-month contract dominates the three-month contract suggesting that both markets are more efficient in the former and thus short term investors should be concerned with this contract.

4.7 Summary and Conclusion

This chapter has investigated the price discovery relationship between the crude oil spot and futures markets. It analyses the contribution to price discovery of the West Texas Intermediate and Brent crude oil markets using daily data from

January 2000 to May 2011, and extends previous studies on price discovery as it examines the process of price discovery across different contracts, with a view to establishing which market (or contract) is more efficient and reducing price risk in international oil markets. The chapter also investigates price discovery using three different measures: the error correction approach, the common factor weight approach and the Garbade and Silber approach. This chapter is significant because the contribution of the futures market to price formation determines whether the market performs its price discovery role or otherwise and the results have important implications for investors, speculators and policy makers.

Empirical results provide strong evidence which show that the futures markets perform the price discovery role in the international oil markets. The results show that the spot and futures prices as well as the futures prices of different maturities are cointegrated, as reported by the Johansen cointegration test in all the oil markets. These results suggest that the prices move together in the long term, implying that they have the ability to predict each other and violating the weak form efficient hypothesis. Using the error correction approach and common factor weight approach, the results indicate that the futures market contributes more to price discovery in both markets at different maturities. These also suggest that the futures price impounds new pricing information more than the spot price in all the oil markets, which shows that market participants prefer to use futures prices to trade crude oil in the international market. Further, the results show that all the oil markets support that the contribution of the futures market to price discovery is greater at three-month contracts to maturity. This is confirmed by the cross-contract analysis which shows that the three-month contract leads the one-month contract in price discovery in both markets. In particular, these findings demonstrate that the crude oil futures market is more efficient at three-month maturity. The results of the Garbade-Silber approach indicate that new pricing information is reflected first in the futures market in both WTI and Brent markets at one and three-month maturities; however, in contrast with the other approaches, the results suggest that the one-month contract leads three-month contracts in the price discovery process in all the crude oil futures markets in the short term. The implication of these findings is that speculative opportunities cannot be exploited in both oil markets, especially at three-month maturity, because arbitrage does not exist. Again, portfolio diversification across the markets would be effective in the long term because they all reduce price risk in all the maturities. However, for cross-contract investment, investors should focus on three-month contracts because both markets are more efficient at this maturity in the long term.

In conclusion, the results from this chapter support the theory that the WTI and Brent crude oil futures markets perform their price discovery function in both the short and long term at different maturities. The cross-contract analysis suggests that the three-month oil futures contract plays the price discovery role in all the crude oil markets in the long term, while the one month futures contract dominates price discovery in the short term. Furthermore, the two crude oil markets have similar patterns because in both markets, the futures prices impound new information faster at the different maturities in the short and long term. Finally, the crude oil futures markets perform their price discovery functions, supporting the market efficiency.

CHAPTER FIVE

Price change and Trading Volume Relationship in the Oil Futures Markets

5.1 Introduction

Price and trading volume are the key factors determining the behaviour of the futures market and are important because they are both influenced by the same fundamental: arrival of new information. Sierimo (2002) pointed out that the changes in price represent how the market values new information while the changes in trading volume represent how investors value the new information. Furthermore, empirical evidence revealed that trading volume reflects the nature of information that flows into the market; low trading volume implies high price volatility and less market liquidity, while high trading volume leads to low price volatility and high liquidity (Floros and Vougas, 2007; Bhar and Malliaris, 1998). The relationship between trading volume and price changes has important implications for market participants and regulators.

Several studies have identified the advantages of research into the price change and trading volume relationship. First, the price-volume relationship can provide information about market structures (Karpoff, 1987). Second, the same relationship suggests whether technical or fundamental analysis should be used in developing trading strategies (Moosa and Silvapulle, 2000), and thirdly, determines the success or otherwise of futures contracts (Bhar and Hamori, 2004). Fourth, it can help understand the informational efficiency of the futures market because the ability of trading volume to forecast futures price changes implies market inefficiency (Lua and Go, 2012; Kocagil and Shachmurove, 1998; Foster, 1995). Finally, the relationship provides hedger, speculators, policy makers and other participants' information on futures market condition (Fujihara and Mougoue, 1997; Bhar and Hamori, 2005).

The research in this area is centred on three important yet conflicting models: the mixture of distribution hypothesis, the sequential arrival of information hypothesis and the noise trader model. The Mixture of Distribution Hypothesis (MDH) postulates that the trading volume and price changes relationship is positive. The model's supporters: Tauchen and Pitts (1983), Harris (1986), Karpoff (1987), Epps and Epps (1976) and Clark (1973) hypothesized that market participants respond to new information simultaneously and therefore neither price change nor trading volume can cause the other in any direction. In contrast, the Sequential Arrival of Information Hypothesis postulates that market participant's responds to new information sequentially and that past values of prices and trading volume can predict each other, or in other words, bi-directional causality exist between them. This model has received support from Copeland (1976) and Jenning et al (1981), among others. Finally, De Long et al (1990) developed the Noise Trader Model which asserts that the price change and trading volume relationship depend on noise trader's action that is not based on any economic fundamentals. The model argues that the noise traders' behaviour of using past information about price changes to make investment decisions explain the positive causal relationship between trading volume and price change in either direction.

The objective of this chapter is to examine the trading volume and price change relationship in the crude oil futures market in order to determine the market efficiency. In doing so, this chapter seeks to addresses two important questions: first, whether there is positive relationship between trading volume and price, and second, whether trading volume contains important information that can predict the crude oil futures price. This chapter contributes to the limited studies on the trading volume and price change relationship in oil futures markets in two ways.

- It extends the work of previous studies which focused on the West Texas Intermediate oil futures market, by exploring the price and trading volume relationship in the Brent crude oil futures market. To my knowledge except Foster (1995) there is no study that investigates the forecast ability of trading volume to price changes in Brent market. This study has important implication because market participants want alternatives for risk diversification and regulators need to know the effectiveness or otherwise of their policies on the international oil market.
- It provides new evidence using updated data that captures the recent period of high volatility in crude oil prices and also employs the impulse response function and variance decomposition analysis.

This chapter is organized as follows. Section 5.2 reviews the literature on the relationship between trading volume and price change in oil futures markets. In this section literature on this relationship in non-oil futures markets are reviewed to have better understanding of the area. Section 5.3 presents theoretical models on the trading volume and price change relationship. Section 5.4 provides brief discussion on the methodology used in the analysis. Section 5.5 describes the data used in the chapter. Section 5.6 presents the empirical results of relationship between price change and trading volume and, Section 5.7 concludes the major findings.

5.2 Literature Review

This section review relevant empirical studies that examine the relationship between price and trading volume in commodity futures markets. Despite the significant of the relationship between trading volume and price changes, research in this area has been abundant in the oil futures markets[29]. This section is divided into two parts. Part one reviews available literature on trading volume and price changes relationship in the oil futures markets. The second part explored the relevant studies that have been conducted in other commodity markets in order to shed more light in the area.

5.3.1 The Oil Futures Market

A limited number of studies have been conducted on the price change and trading volume relationship in the oil futures markets; among the first was that conducted by Foster in 1995 who apply the GARCH and Generalized Method of Moment (GMM) to examine the trading volume and price changes relation in the crude oil futures markets for WTI and Brent. For the analysis, he utilized daily closing futures prices with their corresponding trading volumes during the period from January 1990 to June 1994. A second sample for WTI, covering the period

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[29] There is limited literature on price and trading volume relationship in the oil futures markets may be because of the problem in accessing the trading volume.

January 1984 to June 1988, was also investigated in order to find the maturity effect of trading volume and price relationship. Empirical results from the GARCH model indicate that trading volume cannot serve as an important tool for measuring the new information that enters into both markets and furthermore, the GMM model shows that price variability and trading volume relationship is positive except of the WTI market in the first period supporting the mixture of distribution hypothesis. Foster claims that in the mid-1980s the WTI market may have been affected by factors such as liquidity or a problem of efficiency at its early stage of development. He also found that price variability can be predicted with information on past trading volume in both markets, yet he argued that this finding do not provide support for the sequential arrival hypothesis nor does it contradict the mixture of distribution hypothesis; rather, it results from pricing inefficiency. Finally, he concluded that the inefficiencies result from the traders or market agents' behaviour as they use past information about trading volume to predict market conditions.

Fujihara and Mougoue (1997) employed the Granger causality test to examine the price variability and trading volume relationship in the US petroleum futures market for unleaded gasoline, heating oil, crude oil within the linear and non-linear framework. The analysis was conducted with daily closing futures prices and their corresponding trading volume for each commodity. In the WTI market, the linear causality test shows that lagged trading volume does not cause price changes, while the non-linear causality test indicates bi-directional causality. They observed that this result remains consistent even after accounting for presence of ARCH effect in both the returns and trading volume series; to confirm their results they divide the study into different sub-samples, but the results for both tests are still consistent. The authors confirmed that the WTI futures market is inefficient since past volume can be used to forecast current price movement, and suggest that the inefficiency may be caused by two reasons: first, investors set their prices based on the behaviour of others, and second, investors used past information about trading volume to measure futures market expectations.

Additionally, Kocagil and Shachmurove (1998) analysed the contemporaneous and inter-temporal causality between WTI futures price and trading volume, using both rate of return and absolute return as proxy to price changes. The authors addressed three important issues: whether information flow in the futures market supports the mixture or sequential information hypothesis; whether the price-trading volume relationship is symmetric, and whether lagged trading volume predicts future price changes. Applying the VAR framework, their results provide interesting evidence. First, they show that trading volume is positively correlated with absolute return, but not with rate of return, which supports the mixture of distribution hypothesis. They also found bi-directional causality between absolute return and trading volume, implying that they can both predict each other which support the sequential informational arrival hypothesis. They observed that the inter-temporal causality test indicate that lagged trading volume does not cause return in the crude oil futures market. However, when they re-examined their analysis using the variance decomposition approach the results show that the variance of trading volume is influence by absolute returns, leading them to conclude that the time interval is important in explaining the trading volume and returns relationship and that the crude oil market is inefficient during period of the study. Moosa and Silvapulle (2000) examined the trading volume and price relationship in the WTI market using linear and non-linear causality tests, and daily data for three and six-month futures contracts to maturities. In order to capture the volatile period they carried out their analysis using data over the whole sample and different sub-sample periods, pointing out that the reason for using different futures contracts is to find the maturity effect between price change and trading volume. They also conducted their analysis using absolute and difference price series as a proxy to price changes. In contrast to the results of Fujihara and Mougoue (1997), they found that the linear causality test indicates that trading volume does not cause to price changes, except in the second sample period. However, the non-linear causality confirmed the existence of bi-directional causality running between trading volume and price change. They found that the results remained consistent even after volatility filtering, and suggest that the price and trading volume relationship has a maturity effect which reflects liquidity. They concluded that their findings were inconsistent with market efficiency, but support both the noise trading model and sequential information arrival hypothesis.

Moosa et al (2003), continuing the research in this field, investigated the temporal asymmetry causality between price change and trading volume in the WTI market. They employed the Granger causality test and the data used for their analysis are daily trading volume and futures prices at three and six month contracts. The findings showed that the symmetry model demonstrated that futures price leads trading volume in all the contracts, suggesting that both positive and negative price change leads trading volume while only negative change in trading volume leads price changes. The asymmetric model indicates that both trading volume and price changes leads the other in all the maturities, and specifically, the results support asymmetric relationship because negative changes in price and trading volumes have more powerful impact than positive changes in explaining each other. The authors suggested that their findings specifically provide an important explanation as to why traders' behaviour in relation to price changes and trading volume causes the demand function in the bear market to be steeper than in the bull markets. They argued that their results support the noise trader model but rejects the mixture of distribution hypothesis.

Bhar and Hamori (2005) employed the augmented AR-GARCH model to investigate information dependence and causal relationship between trading volume and price change in the WTI market, using daily data in their analysis. They found that price changes is not caused by trading volume, indicating that past information on volume will not be helpful in forecasting future returns a result that contrast most of the previous studies. However, they also observed that returns leads trading volume with a lag of 15 and 9 days, which according to the authors provides mild evidence in support of noise trading activities. They pointed out that their analysis disagree with the idea of controlling the volatility of price as a way of improving the performance of the oil futures markets because past information about volume cannot assist speculators in forecasting prices and thus, in contrast to Fujihara and Mougoue (1997) and Moosa and Silvapulle (2000) they reports that the WTI crude oil futures market is price efficient. Table 5.1 summarizes the findings obtained from the above review, from which it is clear that conclusions on the relationship between price changes and trading volume are mixed.

Table 5.1 Summary of Previous Results on Price-Volume Relationship in the Oil Futures Market

Author (s) and Years	Data and Market	Methods	Results
Foster (1995)	WTI and Brent daily futures price and trading volume from 1990 to 1994	GARCH and Generalized method of moments	Positive relationship and unidirectional causality between trading volume and price change.
Fujihara and Mougoue (1997)	WTI daily futures price and trading volume from 1984 to 1993	Linear & non-linear causality tests	No linear causality but bi-directional non-linear causality between trading volume and price change.
Kocagil and Shachmurove (1998)	WTI daily futures price and trading volume from 1980 to 1995	Linear causality test and variance decomposition analysis	The contemporaneous test indicates positive correlation and bi-directional causality between oil price and trading volume. The intertemporal causality test also rejects the MDH.
Moosa and Silvapulle (2000)	WTI daily futures price and trading volume from 1985 to 1996	Linear and non-linear causality tests	Linear unidirectional causality and non-linear bi-directional causality from trading volume to price.
Moosa et al (2002)	WTI daily futures price and trading volume from 1985 to 1996	Linear and non-linear causality tests	Bi-directional causality between trading volume and price change.
Bhar and Hamori (2000)	WTI daily futures price and trading volume from 1990 to 2000	AR-GARCH model	Unidirectional causality from price to trading volume and not vice-versa.

From the review it can be seen that the common factor across the research is that it has been devoted to the WTI crude oil futures market, has employed daily data and was undertaken using either the GARCH or Granger causality approach. Moreover, most of the previous studies have shown that the relationship between volume and price changes is positive, which support the mixture of distribution hypothesis; however, there is controversy on the lead-lag relationship between these variables. Not all studies show that both trading volume and price changes can cause each other in support of the sequential information arrival hypotheses and market inefficiency.

5.3.2 The Non-Oil Commodity Futures Markets

In this section, the relevant studies on the price change and volume relationship in non-oil commodity futures markets are reviewed in order to build knowledge of the area. Cornell (1981), using daily data, examined the trading volume and price relationship in eighteen commodities futures markets including four metals, thirteen agriculture and treasury bills. The author used the standard deviation of the log price and daily change in average volume as proxy to price change and trading volume respectively, with two leads and lags for each commodity. He found not only the evidence of positive relationship but also that change in price leads trading volume for fourteen commodities while for the remaining four, the reverse is true. Therefore, it is clear that the analysis supports the mixture of distribution hypothesis by demonstrating that the price change and trading volume relationship is positive. Finally, the lead and lag relationship confirmed the existence of market efficiency in almost all the commodity futures markets because past futures prices cannot be predicted with information on trading volume. Malliaris and Urruitai (1998) further analysed price change and volume relationship for six agricultural commodities futures markets, namely corn, soybean, wheat, oats, soybean meal and soybean oil, using a dynamic model which assumes that trading volume and future price follows a non-stationary process with trend. The model tests three important hypotheses, although only the first two are related to the present work: that both price and volume are non-stationary process and are interrelated, and that cointegration relationship exists between return and trading volume. Data for the analysis is daily and, employing both the Engle-Granger and Johansen cointegration tests, the results indicate that trading volume and price are cointegrated in all commodity markets. When the error correction model test was applied to analyse the short-term and long-term dynamic relationship between trading volume and price changes bi-directional causality was found from trading volume to price changes, supporting the sequential arrival hypothesis in all the markets in the long run. However, they found that price changes cause trading volume in corn, soybeans and soybean meal while the rest of the commodity markets indicate weaker causality in the short run, suggesting that speculative activities will be profitable in the long term.

Wang and Yau (2000) examined the price change and volume relationship in four foreign exchange commodity futures markets, namely S&P 500, Deutschmark, gold and silver using daily data and the Generalized Methods of Moment. They found that trading volume had a positive significant relationship with price change, while price change indicated a negative significant relationship with lagged trading volume in all markets. Their results stand in contrast to the mixture of distribution hypothesis in all markets and neither do they support the market efficient hypothesis because futures price change can be predicted with past information about trading volume. Additionally, using the ordinary least square regression the results were confirmed but shown to underestimate the coefficients in all markets. Building on previous work, Ciner (2002) studied the price change and volume relationship in futures market for three commodities, namely, gold, platinum and rubber traded in the Tokyo Commodity Exchange, using daily data. The study applied the linear and non-linear Granger causality tests, and GMM approach. The GMM results suggest that return and trading volume have positive relationship, consistent with the mixture of distribution hypothesis. Furthermore, the linear causality test indicates that trading volume is caused by returns in all except gold futures, while the non-linear causality test indicates bi-directional causality between them. Ciner observed that when the ARCH effect is accounted for in all the prices, the bi-directional causality disappears but unidirectional causality still exists from return to volume, confirming the mixture of distribution hypothesis which lead the author to argue that trading volume provides market participants with information about the level of price changes but not the direction of the price changes, which in turn supports the market efficient hypothesis.

In a similar vein, Bhar and Hamouri (2004), employing daily data, re-investigate the relationship between change in U.S gold futures price and trading volume using the Granger causality test. They found strong evidence of positive relationship between price and trading volume, consistent with the mixture of distribution hypothesis, as well as mild bidirectional causality from price change to trading volume which shows weaker evidence for the sequential information arrival hypothesis. They noted that the information that flows between price change and trading volume has an impact on price movement in the gold market and concluded that the reason their results contrast with those from the agriculture and crude oil markets is due to the nature of gold, especially the way investments are made when the market underperforms. Gianfreda (2010) also applied the GARCH model to examine the relationship between change in European electricity spot price and trading volume for Germany, France, Spain, Italy and the Netherlands; the empirical results indicate significant but negative relationship between spot price change and volume in all markets except for the Netherlands, where volume and price change show positive relationship. Gianfreda pointed out that price change and trading volume can have positive or negative relationship, depending on the market structure and suggested that in the first case past information on trading volume can help reduce the next day price volatility in the three electricity markets, while in the second case there is optimal production in the market[30].

In the foreign exchange market, McGowan and Muhammad (2004) analysed the dynamics of trading volume and price change relationship for the spot and next month contracts in the Malaysian stock index futures using daily data. They employed the vector error correction model to investigate the relationship over four sub-periods in order to find the variation; a cointegration relationship was shown to exist between both the spot and next month contracts trading volume

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[30] The market is not operating with excess capacity.

and returns. These results show that trading volume cause price change in all the sub-periods for all contracts and suggest that speculators and hedgers can use the information on the price-trading volume relationship to make investment decisions in both markets. Floros and Vougas (2007) then employed the GARCH and Generalized Method of Moments methods to investigate return and volume relationship in Greek stock index futures market for FTSE/ASE Mid-40 index and FTSE/ASE-20 index. Taking their data for the analysis from daily futures price changes and trading volume, the empirical results of the GARCH model indicate that trading volume is positive and significant in explaining price change in the FTSE/ASE-20 index while the GMM estimation shows a significant but negative relationship between lagged trading volume and absolute return. The results for the FTSE/ASE Mid-40 also indicate an insignificant relationship between returns and trading volume in both models. In line with Foster (1995), they conclude that the results of Greek index futures market for FTSE/ASE-20 indicate that both the volume of trade and price changes are not driven by the same fundamentals and that market participant's use trading volume to measure price variability.

Cheng and Ying (2009) investigated the hourly price and trading volume relationship in mini-TAIFEX futures market. They argued that the trading volume and price relationship of financial products cannot be explained by a single model and as a result, they applied the vector error correction model and Granger causality approach. First, the vector error correction model shows the existence of cointegration and significant positive relationship between changes in hourly price and volume of trade. In contrast to Floros and Vougas (2007), their results clearly show that these variables are influenced by information arrival, confirming the MDH. Secondly, the causality test indicate that both price and trading volume lead each other which supports the sequential arrival hypothesis, leading to their suggestion that hedge effectiveness can be increased in the short run by using past information regarding futures prices to forecast trading volume, and vice-versa. Summarizing, they provide strong support for rejecting the efficient market hypothesis in the TAIFEX futures market.

In their study, Mougoue and Aggarwal (2011) using daily data examines the relationship between currency futures price change and trading volume for the US dollar, British pound, Japanese yen and the Canadian dollar. Applying the Generalized Method of Moment, they found a negative but significant relationship between change in price and trading volume in all the currencies, which reject the mixture of distribution hypothesis. They also investigate the linear and non-linear dynamics between trading volume and price changes; both tests provide strong evidence of bi-directional causality from trading volume and returns in all the currency markets, violating market efficiency but supporting the sequential arrival hypothesis. Their results contrast with those of Bhar and Malliaris (1998) who studied the same markets during the period from May 1972 to November 1994. Lau and Go (2012) adopt the AR-GARCH model process to examine the trading volume and returns relationship in Malaysian options and foreign exchange futures. The cross-correlation analysis indicate causality from lag one of trading volume to returns, implying that changes in trading volume for the previous day may induce a positive or negative change in the next day's price. They also found that when the augmented AR-GARCH model is applied the dependence causality from the trading volume to return disappears. They suggest that their findings, which contrast with those of McGowan and Muhammad (2004), support that the Malaysian futures market comprised of investors with noise-trading behaviour. The findings of this study are similar with those of Bhar and Malliaris (1998) although they relate to different foreign exchange markets.

Table 5.2 Summary of Previous Results on Price-Volume Relationship in the Non-Oil Commodity Futures Markets

Author (s) and Years	Data and Market	Methods	Results
Cornell (1981)	US 12 agriculture, 4 metals and 1 financial commodities daily futures prices and trading volume from 1968 to 1974	Ordinary Least Square Regression	Positive relationship but absence of causality between trading volume and returns.
Malliaris and Urruitai (1998)	US 6 agricultural commodities daily futures prices and trading volume from 1980 to 1995	Correlation and Linear causality tests	Positive correlation and bi-directional causality between trading volume and price.
Wang and Yau (2000)	US 2 metals and 2 foreign exchange commodities daily futures prices and trading volume from 1990 to 1994	Generalized Method of Moments	Positive correlation and unidirectional causality from trading volume to price in almost all the markets.
Ciner (2002)	Tokyo daily prices and trading volume for 2 metals and 1 wood in futures markets from 1990 to 1994	GMM, Linear and non-linear causality tests	Positive relationship and unidirectional causality from price to trading volume in all the markets.
Bhar and Hamouri (2004)	US gold daily futures price and trading volume from 1990 to 2000	Linear Granger causality test	Positive relationship and mild bi-directional causality from price change to trading volume.
McGowan and Muhammad	Malaysian stock index daily futures price and trading volume	Vector Error Correction Model	Positive relationship and unidirectional causality from trading volume to

(2004)	from 1997 to 2003		returns.
Floros and Vougas (2007)	Greek FTSE/ASE Mid-20 and FTSE/ASE Mid-40 stock Index daily futures prices and trading volume from 1997 to 2001	GARCH/GMM models	No relationship between returns and trading volume in FTSE/ASE Mid-40 while negative significant relationship exists in FTSE/ASE Mid-20.
Cheng and Ying (2009)	Mini-TAIFEX index daily futures price and trading volume from 2006 to 2007	VECM	Positive relationship and bidirectional causality between price and volume.
Gianfreda (2010)	Daily prices and trading volume for 4 different countries electricity spot markets	GARCH model	Negative relationship between prices and trading volume in three markets while other indicates positive relationship.
Mougoue and Aggarwal (2011)	Six foreign currencies daily futures prices and trading volume from 1977 to 2009	GMM and Linear Granger causality tests	Negative relationship between price and volume, and also bidirectional causality in all markets.
Lau and Gau (2012)	Malaysian options and foreign exchange daily futures price and trading volume from 1995 to 2009	AR-GARCH model	No causality between trading volume and returns.

Table 5.2 summarizes the findings obtained from the review on the price-volume relationship in non-oil commodity futures markets. In general, it can be seen that the studies in both oil and non-oil commodity futures market employed either the GMM or Granger causality approach and that furthermore, they used daily data in their analysis because it has been proven to capture all the available information. They also provide mixed conclusions on the price and volume relationship by supporting or rejecting the market efficient hypothesis.

5.3 Theoretical Framework of Price-Volume Relationship

The price changes and trading volume relationship was originally described in the theory of demand and supply. This theory assumes that a change in price will lead to a change in demand, in turn causing a shift to a new equilibrium position. Accordingly, an increase in price will lead to a decrease in demand, and a simultaneous increase in trading volume and vice-versa no matter the direction of the change (Moosa and Silvapulle 2000). Building on this, a number of different theories have been proposed to offer an explanation on the relationship between price changes and trading volume, the common once are the mixture of distribution hypothesis, the sequential arrival of information hypothesis and the noise trader model. However, conflicting views persist because while some studies provide support for the mixture of distribution hypothesis, pointing out that the trading volume and price changes relationship is positive and they cannot predict each other in line with the efficient market hypothesis; other studies support the sequential arrival hypothesis or the noise trader model, which shows that both trading volume and price changes can cause each other, thus violating market efficiency.

5.2.1 The Mixture of Distribution Hypothesis

Clark (1973) developed the mixture of distribution hypothesis (MDH), built upon the assumption of stochastic dependence between changes in price and volume of trade with the rate of information arrival as the mixing variable. The model postulates that the rate of daily price change and trading volume at any given interval of time is independent and identically distributed, which implies that successive price change and trading volume on individual trades are uncorrelated and follow a random walk process. The model hypothesized that the stock market is always comprised of traders with different expectations regarding prices and that information flows into the market at varying rates; therefore, price change and trading volume depend on the nature and reaction of traders to new information. When all traders receive high quality information at the same time or information is received only by inside traders, an increase in price change will lead to high trading volume and vice-versa. In this framework, trading volume serves as a measure of changes in price. Hence, the total number of increments in daily changes in price and volume of trade that occur in the market each day is equal to the daily change in volume and price that occurs in that particular day: this implies that trading volume and price changes are positively correlated. Epps and Epps (1976) further extend Clark's model by assuming a simultaneous response of both trading volume and price changes to new information. Their model postulates that stochastic dependence exists between change in price and change in trading volume from one transaction to the next and thus with arrival of new information, an increase in excess demand will shift the equilibrium price position in the market. As result, those traders whose null price is above the equilibrium price purchase more from those with a null price below the equilibrium point and accordingly, the rates at which the two traders negotiate on the new price re-establishes another equilibrium price in the market. This process demonstrate that there is positive relationship between trading volume and price changes because the percentage of trading volume in each transaction depends on how traders disagree when they change their null price due to new information.

Tauchen and Pitts (1983) and Harris (1986) also improved on the model of mixture of distribution hypothesis. Both models are based on two important assumptions: first, that trading volume and price change are jointly independent and identically distributed with finite variance. Second, the number of new information flows into the market in each day is not constant. These authors showed that each day market passes through different equilibrium positions as traders try to adjust their null prices in line with the new information they receive, and therefore the proportion of daily changes in price and volume of trade can be determined by the amount of news that enters into the market. The models assume that trading volume and price changes are stochastically independent from each other. In their framework daily trading volume and changes in price reflect the amount or level of news that the market generated from each number of transactions in that day. The implication of these models is that they assume that there is positive relationship between changes in price and trading volume, and also trading volume cannot predict price changes which support the efficient market hypothesis.

5.2.2 The Sequential Information Arrival Hypothesis

Copeland (1976) developed the sequential information hypothesis based on the assumption that trader receive market information individually in sequential and random form. The model postulates that a market passes through different equilibrium positions, but at the initial equilibrium position all traders acquire the same information. However, when new information arrives in the market each individual trader responds and changes his level of demand based on the nature of information flow, behaviour which induces a shift in their respective demand curves up to the point all the traders assimilate that particular information, when a new equilibrium position is re-established. At this point, the traders have the same information and their respective demand curves are identical. Copeland also describes his model by assuming that the traders with new information are either optimists or pessimists: when new information flows each optimist shifts his demand curve upwards, while the pessimist shifts his downwards. The model asserts that price changes that take place from initial equilibrium to successive equilibrium positions are known with certainty and trading volume depends on both the value of new information and the percentage of traders (optimistic or pessimistic) in the market. Thus, both trading volume and price change are considered as random variables because the market passes through successive equilibrium positions in order to adjust, suggesting that the two variables have positive relationship. The model assumes that future price changes can be predicted with lagged trading volume and that future trading volume can be predicted with lagged price change. Most importantly this model shows that trading volume and absolute price changes lead each other and that, furthermore, future price changes can be predicted with information on trading volume, thus providing evidence of market inefficiency.

5.2.3 The Noise Trader Model

De Long et al (1990) developed a model which shows that the noise traders' activities caused the positive relationship between trading volume and price change. The model assumes that since the noise traders' do not based there activities on any economic variables, in the short term they drive the price away from its fundamental value, thereby causing a temporary mispricing. However, in the long term the absences of transitory components drive market prices back to their mean values. The model assumes that for each transaction the market passes through four periods. Again, the market consists of three types of traders: positive feedback traders, informed rational speculators and passive investors. In period 0, there are no activities in the market and the price is set at its initial fundamentals. When rational speculators receive new information, or any signal about the market, they buy more stock today with the expectation of selling tomorrow, while on the other hand, the positive feedback investors respond to this news by buying more tomorrow at the current market price which the rational speculators are selling to make a profit. These activities drive the market price higher in period 1 and 2 up to the point when the market is stabilized, and then the price adjusts back to its fundamental values in the long term or period 3. The model shows that the activities of the positive feedback investors cause the relationship between changes in price and volume of trade to be positive because they use past price changes in order to make a profit tomorrow and therefore price changes are determined by the level at which the noise traders buy or sell stock in the market. The important implication of the noise trader's model is that the positive feedback trading strategies led the price changes and trading volume to have a positive relationship.

5.4 Empirical Methodology

This section briefly discusses the econometric techniques used in the data analysis. Firstly, the generalized method of moment (GMM) applied to estimate the relationship between price changes and trading volume is discussed. Secondly, the vector autoregressive model and its application in testing price and trading volume relationship via the linear Granger causality test are considered, and finally, the use of impulse response function and variance decomposition analysis in investigating the trading volume and price changes relationship are discussed. This chapter chooses these techniques because empirical evidence from previous studies has shown that they are powerful in estimating relationship among macroeconomic variables.

5.4.1 Generalized Method of Moments

The generalized method of moments developed by Hansen (1982) is a simultaneous regression approach used in time series analysis that is robust to heteroskedasticity and autocorrelation in the residuals. According to Hansen, this approach is efficient, consistent and asymptotically normal compared to other standard estimators because it does not account for any information aside those in the moment conditions. It also deals with the problem of simultaneity bias in modelling returns and trading volume relationship (Foster, 1995; Lee and Rui, 2002; Mougoue and Aggarwal, 2011). Following Foster (1995), Ciner (2002) and Floros and Vougas (2007) this chapter used the lagged values of trading volume and price change (returns) as an instrumental variable (IV) estimator[31]. The model can be estimated using the following structural equation:

$$R_t = \alpha_0 + \alpha_1 V_t + \alpha_2 R_{t-1} + \mu_{R,t}$$

$$V_t = b_0 + b_1 R_t + b_2 V_{t-1} + \mu_{V,t} \tag{5.1}$$

where R_t is returns, V_t is trading volume, R_{t-1} is the lagged returns, V_{t-1} is the lagged trading volume and $\mu_{R,t}, \mu_{V,t}$ are error terms. The parameters R_t and V_t are endogenous variables which cannot be estimated using the ordinary least square approach because it will yield inconsistent results since the variables are correlated with their respective error terms (Ciner, 2002). The relationship between trading volume and returns can be determines by significance of the coefficients α_1 and b_1 in equation (5.1). When both α_1 and b_1 are significant it implies that trading volume and returns are related. Hansen (1982) also proposed the used of the J-statistics to find the validity of the model whether it is properly identify or over-identify.

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[31] Ciner (2002) and Floros and Vougas (2007) pointed out that the instrumental variables deal with the simultaneity bias while GMM controls the problem of heteroskedasticity in the system.

5.4.2 Linear Granger Causality Test

Granger (1969) proposed the causality test to determine whether a time series variable can improve the forecast performance of another variable. Granger argued that when two or more variables are cointegrated casualty most exist between them in a least one direction, and it may occur even if the variables are otherwise[32]. The following VAR model can be used to describe the causality relationship between trading volume and returns:

$$R_t = \alpha_1 + \sum_{i=1}^{n} \beta_i V_{t-1} + \sum_{j=1}^{m} \gamma_j R_{t-j} + e_{1t} \qquad (5.2)$$

$$V_t = \alpha_2 + \sum_{i=1}^{n} \theta_i R_{t-1} + \sum_{j=1}^{m} \delta_j V_{t-j} + e_{2t} \qquad (5.3)$$

where, R_{t-1} is lagged returns and V_{t-1} is trading volume, e_{1t} and e_{2t} are assume to be uncorrelated error terms with zero mean and constants variance. The parameters β_i and θ_i are estimated. Granger causality (1969) approach test the hypothesis $H_0 : \beta_i = 0$ that V_t does not linear Granger cause R_t. Likewise, when $H_0 : \theta_i = 0$ then R_t does not linear Granger cause V_t. Granger suggests that when the lagged values of V_t are significant in explaining R_t, V_t Granger-cause

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[32] The Granger causality test determines the ability of the variables in the VAR system to predictive each other in the long term. For example, in a VAR of two variables y_t and x_t, their causal relationship can take three forms: (1) either y_t causes x_t, or x_t causes y_t (unidirectional causality) (2) both y_t and x_t cause each other (bi-directional causality) (3) y_t and x_t do not cause each other (Independent variables). The causal relationship can be linear or non-linear depending on the relationship among the variables in the VAR (For more explanation on the VAR model see Sims, 1980).

R_t and there exists unidirectional causality from trading volume to returns. When lagged values of R_t are significant in explaining V_t, there is unidirectional causality from returns to trading volume. Finally, when lagged return and trading volume are significant in each other's equation, there is bidirectional causality, while the insignificants of the variables in explaining each other implies no causality among them (they are independent). The standard joint F- test is used to examine the Granger causality in a VAR system (see Brooks, 2008; Enders, 1995; Asteriou and Hall, 2007).

5.4.3 Impulse Response Function

Sims (1980) developed the impulse response function to trace responses of all the variables in VAR system to shocks on any of the variables[33]. The impulse response function not only provides understanding of the impact of shocks on variables but show how long the effect persists, its size and direction. The impulse response of price changes (returns) and trading volume can be drive from equation (5.2) and (5.3) as follows:

$$R_t = \sum_{i=0}^{\infty} \varphi_{11i}\varepsilon_{Rt-i} + \sum_{i-0}^{\infty} \varphi_{12i}\varepsilon_{Rt-i} \tag{5.4}$$

$$V_t = \sum_{i=0}^{\infty} \varphi_{21i}\varepsilon_{vt-i} + \sum_{i-0}^{\infty} \varphi_{22i}\varepsilon_{vt-i} \tag{5.5}$$

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[33] Brooks, 2008 pointed out that a VAR system of n variables will produce an impulse response of n^2.

The coefficient ϕ_i can be used to produce the effect of ε_{Rt} and ε_{vt} on the whole time paths of the variables; R_t and V_t. The four elements ϕ_i are impact multiplier and the coefficient $\phi_{12}(0)$ is the effect of a one unit change in ε_{vt} on R_t. The element $\phi_{11}(1)$ and $\phi_{12}(1)$ are the responses of unit changes in ε_{Rt-i} and ε_{vt-i} on R_t over a period. Updating by one period shows that $\phi_{11}(1)$ and $\phi_{12}(1)$ also represents the effect of unit change in ε_{Rt} and ε_{vt} on R_{t+1}. The four coefficients $\phi_{11}(i), \phi_{12}(i), \phi_{21}(i)$ and $\phi_{22}(i)$ are the impulse responses (Enders, 1995).

5.4.4 Variance Decomposition Analysis

The variance decomposition is an extension of the impulse response function which gives the proportion of movement in a variable that is cause from its own shock and shocks on other variables in the VAR system (Sim, 1980). The variance decomposition can be calculated as follows[34]:

$$\begin{aligned}\sigma^2{}_{R,n} &= \sigma_R^2[(\phi_{11}(0)^2 + \phi_{11}(1)^2 + \dots\dots + \phi_{11}(n-1)^2] + \\ &\sigma_v^2[(\phi_{12}(0)^2 + \phi_{12}(1)^2 + \dots\dots + \phi_{12}(n-1)^2]\end{aligned} \qquad (5.6)$$

The variance decomposition can be explained from the impulse response equations. The variable R_t is exogenous in the system when a shocks on ε_{vt} cannot explain its forecast error variance. Likewise, the variable R_t is said to

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[34] The n-step ahead forecast error of p_{t+n} will be:

$$\begin{aligned}R_{t+n} - ER_{t+n} &= (\phi_{11}(0)\varepsilon_{R,t+n} + \phi_{11}(1)\varepsilon_{R,t+n} + \dots\dots + \phi_{11}(n-1)\varepsilon_{R,t+1}) + \\ &(\phi_{12}(0)\varepsilon_{v,t+n} + \phi_{12}(1)\varepsilon_{v,t+n} + \dots\dots + \phi_{12}(n-1)\varepsilon_{v,t+1})\end{aligned}$$

be endogenous in the system when shocks on ε_{vt} explain most of its forecast error variance and the same applied to trading volume (see Enders, 1995; Lutkepohl and Kratzig, 2004).

5.5 Data and its Properties

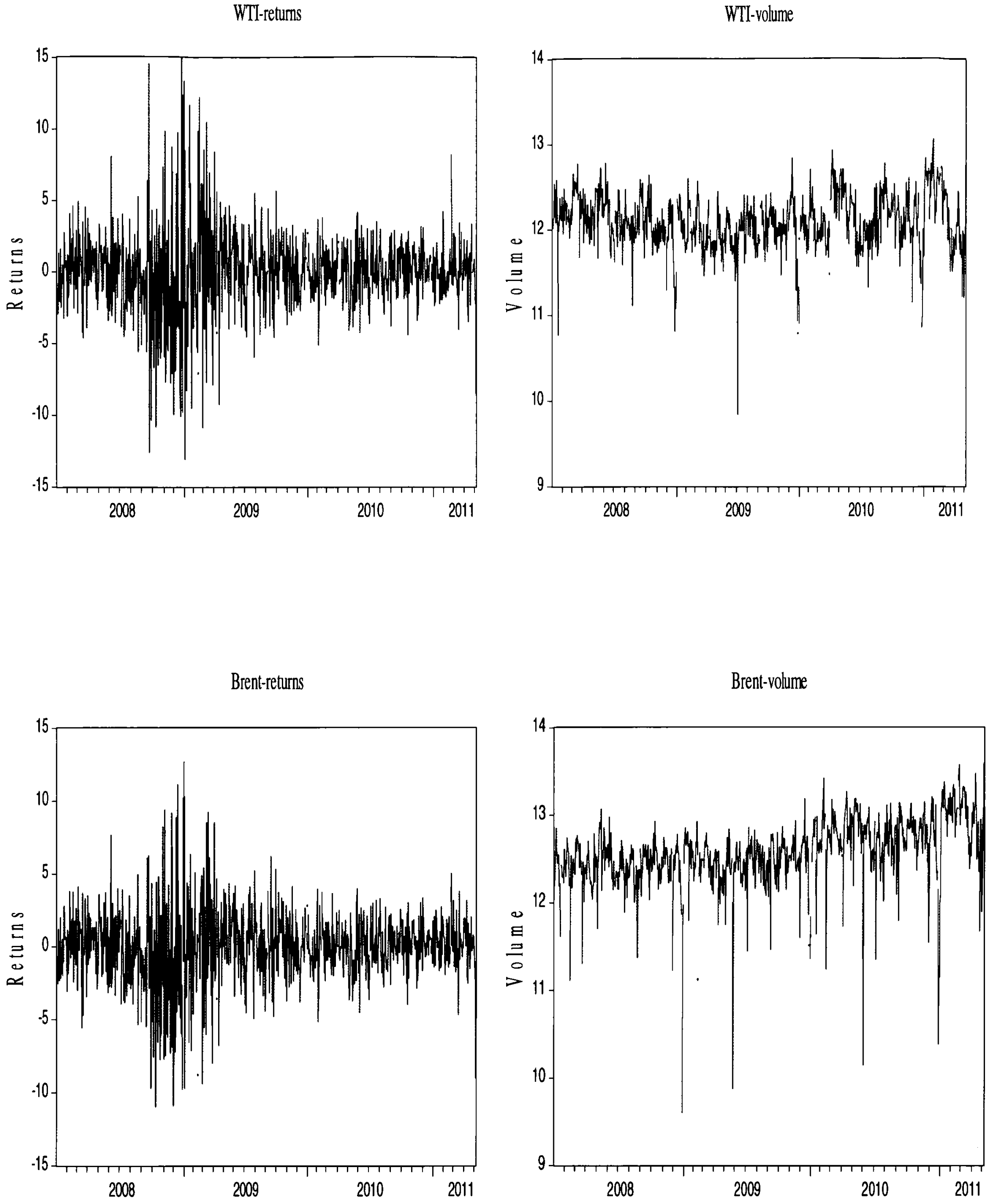
This chapter used data for West Texas Intermediate and Brent crude oil daily closing futures price and their corresponding trading volumes. Data for WTI futures prices was sourced from the Energy Information Administration U.S, while Brent futures prices and all the trading volumes were obtained from the DataStream International. This chapter choose WTI and Brent crude oil markets because in terms of oil commodities, these contracts have the world largest trading volumes and active futures markets. The data for both markets starts from 3 January 2008 and end on 5 May 2011 a total number of 835 observations. The data covers only three years period because of the problem with accessing Brent trading volumes before 2008. All the oil futures price series are converted into log returns series calculated as $r_t = \log(p_t / p_{t-1}) \times 100$, where r_t is the futures return, p_t is the current futures price and p_{t-1} is lagged futures price for one period. The log returns is therefore used as proxy to price change following previous studies. The following notations: WTI-returns, WTI-volume, Brent-returns and Brent-volume are used in this chapter to denote WTI and Brent price changes and trading volumes, respectively. Table 5.3 presents the summary statistics for the daily trading volumes and oil futures returns. This reports the mean, maximum, minimum, standard deviation, skewness; kurtosis and Jarque-Bera probability for each of the oil futures returns and trading volume. The sample mean are higher for the trading volume than for rate of returns in all markets. The standard deviation for the WTI and Brent returns is 3.1123 and 2.7532, respectively, greater than for trading volume in both markets. The results indicate that all the variables are negatively skewed except WTI-return, implying that they are characterised with fatter tail than the normal distribution. The variables also show excess kurtosis, they are all greater than 3 indicating that they are leptokurtic. The Jarque-Bera test indicates that the trading volume and returns series reject the normality hypothesis in all the markets. Figure 5.1 plots the trading volume and futures returns series for WTI and Brent crude oil. It can be seen that the variables returns to their mean values, implying that they are stationary.

Table 5.3 Descriptive Statistics for Crude Oil returns and Trading Volume

Variables	Mean	Median	Max	Min
WTI-returns	0.0009	0.0235	16.410	-13.065
WTI-volume	12.090	12.092	13.061	9.8431
Brent-returns	0.0153	0.0361	12.707	-10.946
Brent-volume	12.568	12.578	13.581	9.6040

Variables	Std.Dev	Skewness	Kurtosis	Jarque-Bera prob
WTI-returns	3.1123	0.2211	6.9558	547.94(0.0)
WTI-volume	0.3319	-0.7678	6.4071	483.01(0.0)
Brent-returns	2.7532	-0.0818	5.9025	292.27(0.0)
Brent-volume	0.3988	-1.6983	11.985	3190.1(0.0)

Figure in brackets are the probabilities for the normality test.



WTI-returns

WTI-volume

Brent-returns

Brent-volume

Figure 5.1: Daily WTI and Brent Returns and Trading Volume, January 2008-May 2011

5.6 Empirical Results

This section provides the empirical evidence obtained by applying the econometric methods discussed to analyse the data. First, unit root tests are used to examine the order of integration in the crude oil price change and trading volume for each market. Second, the Generalized Method of Moments (GMM) approach is employed to estimate the relationship between trading volume and price change. Third, the Granger causality test within the VAR framework is also applied to investigate the relationship. Finally, the impulse response and variance decomposition analysis are used to estimate the response of the trading volume and price change to shock from each other.

5.6.1 Unit Root Test

The unit root test is applied to examine the properties of the oil futures returns and trading volume series. This chapter use three different unit root tests; the Augmented Dickey Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski, and Phillips and Schmidt and Shin (KPSS) unit root tests. The tests are conducted by allowing for deterministic trend and constant, and with constant only in the regression specification. The optimal lag length for the ADF test is selected by the Schwartz information criterion (SIC) while that of the PP and KPSS tests were selected by Bartlett kernel. Table 5.4 reports that the results of the ADF and PP tests indicate that both the oil futures returns and trading volume reject the null hypothesis, implying that the variables are stationary. These results are confirmed by the KPSS test which supports nonstationarity in the levels of all the trading volume and oil futures return series. All the tests results are identical in with constant as well as with constant and trend. It is clear that the returns and trading volume for both the WTI and Brent crude oil futures are stationary I (0).

Table 5.4 Unit Root Test

Variables	**ADF**		**PP**		**KPSS**	
	(i)	(ii)	(i)	(ii)	(i)	(ii)
WTI-returns	-30.588*	-30.510*	-30.734*	-30.809*	0.2281*	0.1005*
WTI-volume	-7.7728*	-7.7790*	-31.089*	-15.758*	0.2778*	0.2484*
Brent-returns	-31.050*	-31.084*	-31.089*	-31.101*	0.2840*	0.1044*
Brent-volume	-8.2167*	-13.515*	-17.539*	-18.162*	2.7090*	0.2476*

Note: * denotes significance at the 5% level. The specification of the unit root test (i) and (ii) represents constant and constant and trend, respectively.

5.6.2 Generalized Method of Moments

Table 5.5 reports the estimated results of the generalized method of moments. For the WTI market, the estimates of the coefficients α_1 and b_1 in equation (1) are (-0.094) and (0.014), respectively; they are all insignificant at the 5% level. Similarly, in the Brent crude oil market, the estimated values are (0.007) and (-0.095), respectively. These results indicate that there is insignificant relationship between trading volume and returns for all crude oil futures markets. The results suggest that changes in trading volume and price change are drive by different information and therefore are not endogenously determined in all markets. It could also be suggested that the variables that influence price changes are different from those of trading volume, implying that they are independent of each other. In particular, the results are inconsistent with the mixture of distribution hypothesis. The J-statistics also cannot reject at the 5% significant level the null hypothesis that the model is valid, suggesting that the data has fit the model in both the WTI and Brent crude oil markets.

Table 5.5 Estimated Results of the Generalized Method of Moments

Coefficients	WTI	BRENT
α_0	1.134(0.133)	-0.065(-0.016)
α_1	-0.094(-0.132)	0.007(0.014)
α_2	-0.066(-1.535)	-0.083(-2.249)*
J-statistics	7.41E-42*	3.68E-42*
b_0	4.702(8.846)*	5.654(7.349)*
b_1	0.014(0.316)	-0.095(-1.040)
b_2	0.611(13.91)*	0.550(8.981)*
J-statistics	0.000*	3.79E-40*

Note: * denotes significance at the 5% level. The t-statistics are shown in parentheses beside the coefficient estimate. The J-statistics test that the null hypothesis that the model is valid and are shown in parentheses below the estimated equations.

The results contradict previous studies by Kocagil and Shachmurove (1998), who concluded that the relationship between WTI oil futures price change and trading volume is positive. On the other hand, the findings are in line with those of Foster (1995), who found an insignificant relationship between these variables in his sub-sample analysis during the period 1984 to 1988 but contrast his results of the whole sample analysis in both markets. The findings can be explains in two ways: First, the difference of this analysis with the previous study may be because the factors that cause the price changes are different over the study periods. Second, the results can also suggest that the policies introduced to regulate daily price changes would have been effective in controlling the trading volume to responding to such movements and thus, the variables are independent of each other. Overall, the results reject the mixture of distribution hypothesis in both markets.

5.6.3 Linear Granger Causality Test

Table 5.6 presents the estimated results obtained from the Granger causality test. Before testing the relationship between price changes and trading volume in the oil futures markets the VAR model specified in equation (5.2) and (5.3) is first estimated. Since the trading volume and returns series for all the markets are stationary I (0), the unrestricted VAR in levels was estimated. The optimal lag lengths in the VAR are selected by Akaike Information Criterion (AIC). The estimated results cannot reject the null hypothesis of trading volume does not cause price change in the WTI market, implying that past values of trading volume cannot assist in predicting oil futures return; likewise, the null hypothesis of trading volume is not cause by return cannot be rejected. Similarly, the results for the Brent market also show that both the null hypothesis of trading volume and returns does not causes the other cannot be rejected at the 1% level of significant. The findings suggest that lagged trading volume does not contain any important information that will be helpful in predicting futures returns, and the analysis supports Clark's (1973) mixture of distribution hypothesis, which put forward that neither trading volume nor return can cause the other in the crude oil futures markets.

Table 5.6 Estimated Results of the Granger Causality Test

Null Hypothesis H_0:	F-statistics	P-values	Lags
WTI-volume does not cause WTI-returns	0.031*	0.861	1
WTI-returns does not cause WTI-volume	0.092**	0.761	1
Brent-volume does not cause Brent-returns	7.325**	0.120	4
Brent-returns does not cause Brent-volume	4.383**	0.357	4

Note: Lag lengths are selected based on Akaike Information Criterion (AIC) and Swartz Information Criterion (SIC). The F-statistics and P-values are shown in parenthesis. * and ** denotes in significance at 1% and 5% levels.

However, it contradicts the sequential arrival hypothesis suggesting bi-directional causality between trading volume and futures return, consistent with Foster (1995) and Bhar and Hamori's (2005) who studied the WTI market. The findings are also in contrasts to those of Fujihara and Mougoue (1997) and Moosa and Silvapulle (2000) whose studies cover the period 1986 to 1996, all of which support either bi-directional or unidirectional causality between trading volume and returns in the oil futures market. Furthermore, the results reject the noise trader model in all the crude oil markets, contradicting Bhar and Hamori's (2005) who found mild evidence of noise trading activity in the WTI market. Therefore, the analysis is in support of the market efficient hypothesis because lagged trading volume does not contain any important information that will be helpful in predicting future returns in all oil futures markets and thus speculators and rational investors cannot use information about trading volume to forecast returns. Finally, the evidence of market efficiency indicates that portfolio diversification and hedging activities will be profitable across these two crude oil futures markets.

5.6.4 Impulse Response Function and Variance Decomposition Analysis

The dynamic relationship between crude oil futures trading volume and returns is further reinvestigated in the crude oil futures markets with the impulse response function and variance decomposition analysis. Figures 5.2 and 5.3 illustrate the impulse response function analyses for the WTI and Brent crude oil futures return and their trading volume, respectively: figure 5.2 for the WTI market indicates the insignificant impact of shock in trading volume on returns and the results show that shock in returns cannot have any significant effect on changing trading volume. In the Brent crude oil market, the results reported in figure 5.3 shows that shock in trading volume is insignificant in changing futures returns; on the other hand, shock to futures returns has insignificant effect on trading volume. These results suggest that past information about trading volume cannot be useful in predicting returns in either the WTI or Brent markets, but that shock on trading volume and returns are important in explaining movement in themselves in all markets. The variance decomposition shows the percentage movement of returns that can be explained by shock on trading volume; Table 5.7 reports the results of the generalised forecast error variance decomposition for the WTI and Brent markets over the period of one, five and ten years. For the WTI market, the results reported in panel A indicate the negligible impact of trading volume on crude oil futures returns from the first to the ten year period, implying that volume does not make a significant contribution to the forecast variance of return. Likewise, the results in panel B for the Brent crude oil market shows that trading volume does not contribute in explaining movement in returns. Yet conversely, the results in panels A and B show that both crude oil futures trading volume and returns are explained by movement in their own shocks. The findings suggest that trading volume has an insignificant contribution in forecasting returns in all the crude oil futures markets and again confirm that there is no causal relationship between them in all markets. In summary, the results support the analysis using the unbiasedness hypothesis and price discovery that the WTI and Brent crude oil futures markets are efficient at one-month maturity in the long term.

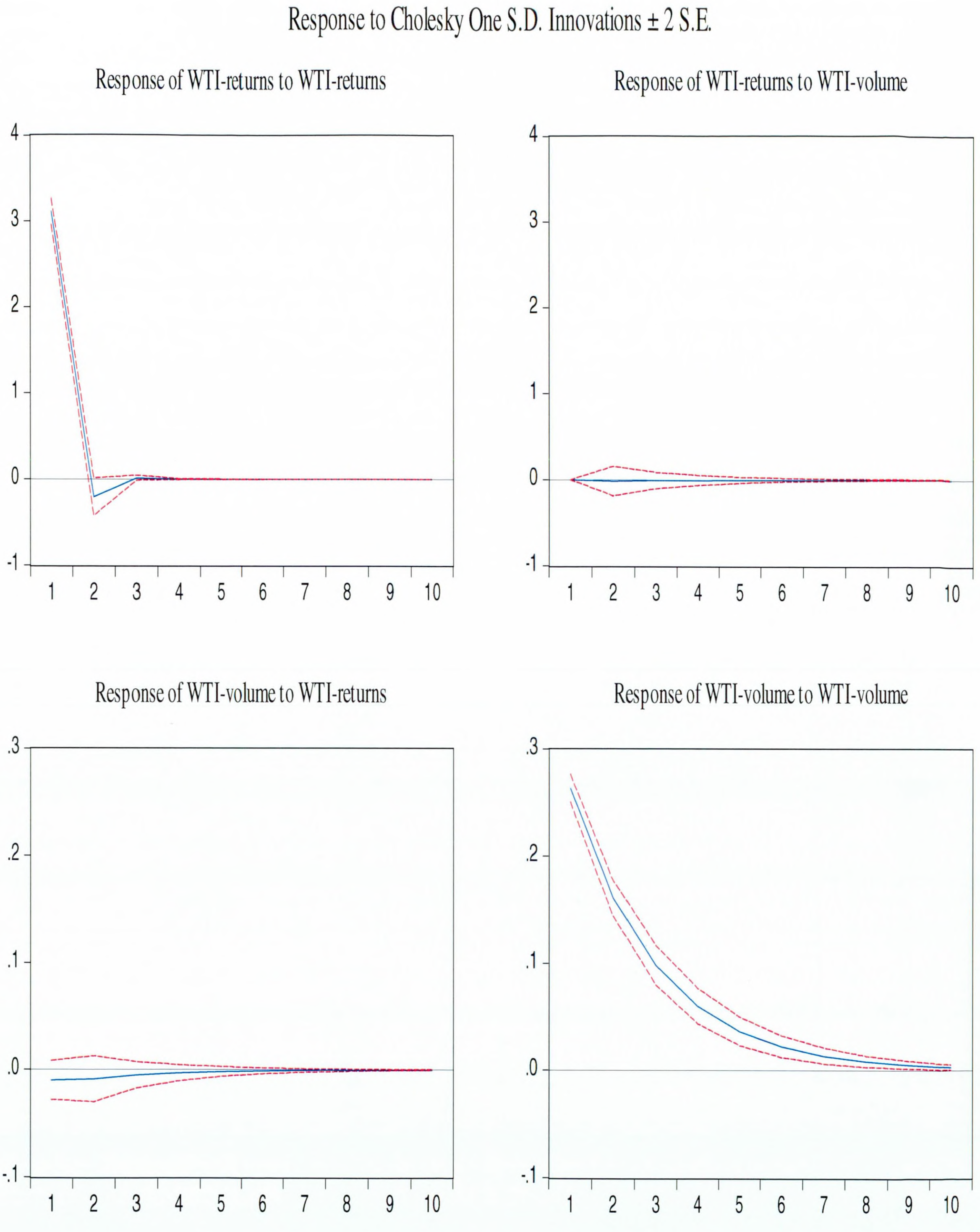
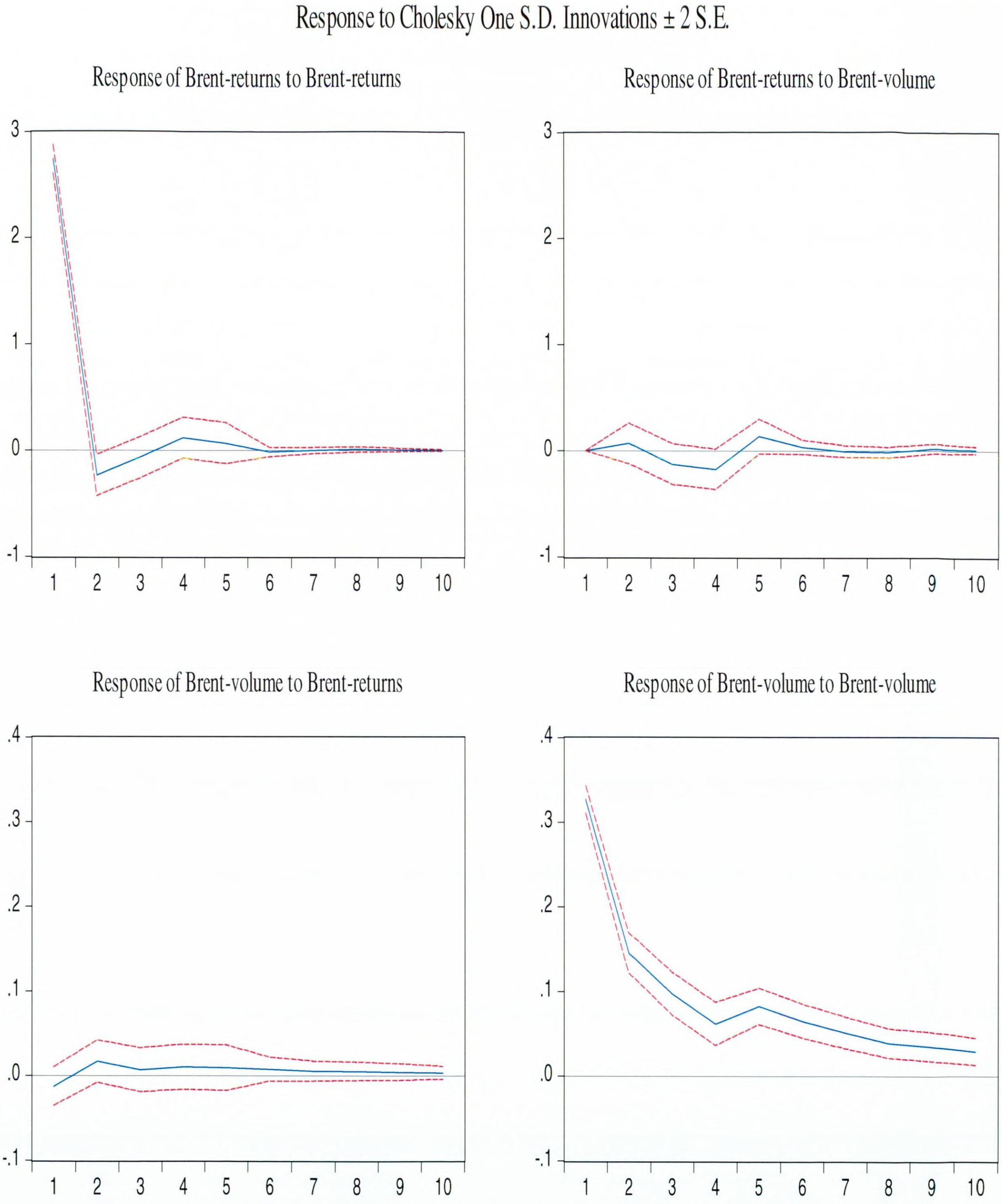


Figure 5.2: Impulse Response Function for the WTI Returns and Trading Volume



Response to Cholesky One S.D. Innovations ± 2 S.E.

Response of Brent-returns to Brent-returns

Response of Brent-returns to Brent-volume

Response of Brent-volume to Brent-returns

Response of Brent-volume to Brent-volume

Figure 5.3: Impulse Response Function for the Brent Returns and Trading Volume

Table 5.7 Estimated Results of the Variance Decomposition Analysis

Panel A:	**Dependent variable WTI-returns**				**Dependent variable WTI-volume**		
Lag	**Standard error**	**Volume**	**Returns**	**Lag**	**Standard error**	**Volume**	**Returns**
1	3.110820	0.000000	100.0000	1	0.263711	99.85819	0.141807
5	3.117684	0.003379	99.99662	5	0.331813	99.80165	0.198355
10	3.117685	0.003437	99.99656	10	0.333003	99.80104	0.198964

Panel B:	**Dependent variable Brent-returns**				**Dependent variable Brent-volume**		
Lag	**Standard error**	**Volume**	**Returns**	**Lag**	**Standard error**	**Volume**	**Returns**
1	2.744223	0.000000	100.0000	1	0.327310	99.85699	0.143014
5	2.770853	0.904728	99.09527	5	0.386201	99.53177	0.468230
10	2.771236	0.927999	99.07200	10	0.399753	99.46731	0.532690

5.7 Summary and Conclusion

This chapter has examined the relationship between trading volume and price change in the West Texas Intermediate and Brent crude oil futures markets from January 2008 to May 2011, one of the most volatile periods in the history of oil prices. It addresses the issue of whether information regarding trading volume contributes to forecasting the magnitude of price change in the markets, an important issue due to the ability of trading volume to predict futures price change, thus implying market inefficiency because futures prices do not corporate all available information. It also examines whether contemporaneous relationship exists between price change and trading volume in the oil futures markets. This chapter contributes to the limited literature by examining the returns and volume relationship in the international oil futures markets, providing findings useful to investors, speculators and policy makers who are all concerned with the predictability of oil futures prices.

The empirical results show that there is no positive relationship between trading volume and price change in all the crude oil markets, suggesting that trading volume and price change are not driven by the same information flow which contradicts the mixture of distribution hypothesis. The results of the Granger causality test between trading volume and price change support the weak form efficiency in all markets. These results indicate that there is no causality from trading volume and price change, implying that trading volume cannot provide information that can be used in predicting futures returns in all the markets, as well as showing that there is no causality from returns to trading volume and therefore contradicting the sequential arrival hypothesis and noise trader model.

The results of the variance decomposition and impulse response analyses also confirms that trading volume does not contribute to explaining movement in prices in both markets. The implication of these results is that the two crude oil futures markets are information efficient because trading volume cannot be utilised in predicting oil price changes in both markets and therefore, hedging activities will be profitable while speculative opportunities cannot be exploited. In particular, the results show that investors would benefit from portfolio diversification across the markets, findings which also support the view of Bhar and Hamori (2005) who argued that the idea of regulating price fluctuation in order to reduce the ability of trading volume to cause changes in return is not of concern in the oil futures market.

This chapter concludes that the results support the efficient market hypothesis in the WTI and Brent crude oil futures markets because trading volume cannot give information that can be used to improve the short term forecast of oil returns in all markets. The results also neither support the mixture of distribution hypothesis because there is no positive relationship between price change and trading volume, nor agree with the sequential arrival of information because no causal relationship exists between the two variables in either direction. The results also reject the noise trader model in all markets because returns cannot predict trading volume. Finally, this chapter suggests that empirical analysis of the relationship between price change and trade volume in international oil markets is significant because information that can be useful in predicting prices may flow within the markets.

CHAPTER SIX

Long Memory in Oil Futures Markets

6.1 Introduction

As among the world's important strategic commodities, and due to the vulnerability of the global economy to its price changes, investigating the dynamic behaviour in oil price returns and volatility is crucial. Long memory is a special form of non-linear dynamics where a time series has non-linear dependence in its first and second moments and between distant observations, and a predictable component that increases its forecast ability (Elder and Serletis, 2008; Thupayagale, 2010)[35]. It also means that a time series displays slow decay in its autocorrelation functions (Mazaheri, 1998; Belkhouja and Boutahary, 2011) and explains the dynamic correlation structure of a time series at long lags (Barkoulas et al, 1997; Floros, 2009). Conversely, short memory explains the low autocorrelation in a time series which is insignificant at long lags (Barkoulas et al, 1997; Jin and Frechette, 2004). Consequently, the existence of long memory in oil futures price is inconsistent with efficient market hypothesis because its autocorrelation dies slowly and therefore past information on prices can be useful in predicting future returns.

Research in this area has utilised several statistical techniques to examine long memory in crude oil prices. These techniques include the detrended fluctuation analysis (DFA); rescale analysis (R/S), wavelets estimator, state space model and

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[35] Elder and Serletis (2008) show that the presences of long memory in a price series explain whether shocks decay slowly or rapidly.

GARCH models. However, there is no clear consensus on which method performs best. Among the most widely used is the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model. A number of studies supports this in modelling and forecasting crude oil price volatility (Mohammadi and Su, 2010; Cheong, 2009; Agnolucci, 2009; Narayan and Narayan, 2007 and Sadorsky, 2006). On the other hand, some studies have argued that the GARCH model captures only short term persistence (or short memory) in volatility (Wei et al, 2010; Kang et al, 2009, Tabak and Cajueiro, 2007). Further extending this work, fractional integrated models such as the fractional integrated GARCH (FIGARCH); fractional integrated EGARCH (FIEGARCH); fractional integrated APARCH (FIAPARCH) and hyperbolic GARCH (HYGARCH) were introduced to deal with long memory properties in time series. Recent empirical evidence has shown that these models can capture well non-linear dependence in crude oil prices (see Cheong, 2009; Mohammadi and Su, 2010; Wang et al, 2010; Belkhouja and Boutahary, 2011; Wei et al, 2010).

The objective of this chapter is to investigate long memory in crude oil futures prices as an alternative to testing market efficiency. It addresses three important questions: Are the oil futures prices characterized by long memory properties, as documented by previous studies such as Tabak and Cajueiro (2007), Wang et al (2010), Cunado (2010) and Arouri et al (2011)? Do the oil futures prices display a similar pattern across contracts? Do oil futures prices display a similar pattern across international oil markets? This chapter contributes to the literature in the following ways:

1. It investigates long memory in the West Texas Intermediate and UK Brent markets to understand whether oil prices exhibit a similar pattern across international oil markets, unlike previous studies which have focused mainly on the WTI. To my knowledge only Tabak and Cajueiro (2007) investigated long memory in the Brent oil futures market.
2. In contrast, this chapter examines long memory in crude oil futures prices across maturities; previous studies have been concerned only with the spot or futures prices for one-month contract. It is clear that futures contracts for different maturities can exhibit dissimilar patterns because they are traded for delivery on different dates.
3. It uses seven different GARCH-type models which include: GARCH, EGARCH, APARCH, FIGARCH, FIAPARCH, FIEGARCH and HYGARCH to test long-term dependence in international crude oil futures prices, in order to arrive at a strong statistical inference.
4. The analysis uses data covering eleven years of high turmoil in crude oil prices from 2000 to 2011.

The chapter is structured as follows: Section 6.2 summarises the relevant empirical literature on the long memory behaviour in the oil futures markets. It also reviewed the literature in non-oil commodities to have insight on the findings of other markets. Section 6.3 discusses the theoretical background of long memory models in time series. Section 6.4 discusses the different methods employed in this chapter. Section 6.5 discusses the sources, type and properties of data used for this chapter. Section 6.6 presents the empirical results that were obtained from the analysis. Section 6.7 summarises and concludes the findings.

6.2 Literature Review

This section will review the relevant empirical literature on long memory in oil and non-oil commodity futures prices, in line with the context of the efficient market hypothesis, and provides insight into the differing methodologies, data frequency and findings of previous studies on the subject. This section first explores the literature on the oil futures markets, followed by the non-oil commodity futures markets.

6.2.1 The Oil Futures Markets

Research on long memory in oil markets has been the subject of much concern in recent years, particularly due to the high volatility of oil prices. Among the studies that have contributed to this area are Alvarez-Ramirez et al (2002), who examined long term dependence in daily crude oil spot prices for WTI, Brent and Dubai markets. The authors divided the data into three sub-periods covering important events that affected world oil prices. Applying the Multifractal Hurst analysis, they found that all markets exhibit persistence, with Hurst value more than 0.5 in each series; they also found that Dubai and Brent crude oil prices have a similar pattern in long memory behaviour. They observed that when the analysis is conducted under a different time scale WTI show less persistence in the short-run comparison to other crudes, but that the three crude oil prices display similar patterns in medium and long-run time scales. They concluded that the crude oil prices have long memory behaviour which contradicts the efficient market hypothesis. Tabak and Cajueiro (2007) investigated long memory in the WTI and Brent crude oil futures prices and volatility, using the rescaled range hurt analysis (R/S), based on shuffling procedure, in order to deal with the problem of short-term autocorrelation. The study focused was to determine whether the deregulation of the crude oil futures markets of the 1990s has improved the efficiency of these markets compared to the 1980s, a more regulated period. By employing daily data, they found that the oil prices followed a long memory process. They also found that in the 1980s the values of the Hurst exponents were higher in both markets, implying that they were more efficient in the deregulated period. In the second case, the results indicate high persistency in price volatility, but WTI prices show more persistence than Brent, leading the authors to conclude that the GARCH and E-GARCH models would be mis-specified in this second case. They believed that the movement of the WTI oil markets towards efficiency was caused by the new policies that were introduced to improve the North American energy industry efficiency during the period.

Alvarez-Ramirez et al (2008) extended previous research by re-examining the presence of long memory and convergence of the WTI, Brent and Dubai crude oil markets towards efficiency using daily spot prices. They carried out their study with their rescaled analysis based on the Detrended fluctuation approach. The empirical results indicate that all the oil prices possess long memory in short horizon less than 1 month because their autocorrelation dissipates at a slow hyperbolic rate, consistent with Alvarez-Ramirez et al (2002). They observed that when the analysis is conducted over 30 days the results show that the autocorrelation is reduced, implying that the oil markets efficiency have increase over time. An interesting finding of this study is that short-term inefficiency appears to prevail in the markets for an approximately 1.85-year cycle before the market converges toward efficiency, allowing the conclusion that the markets are short-term inefficient but move towards efficiency in the long term, and also confirming the results of Tabak and Cajueiro (2007).

Additionally, Elder and Serletis (2008) tested the long term dependence behaviour in the volatility of the energy prices for NYMEX crude oil, gasoline, heating oil, natural gas and propane futures markets by employing the semi-parametric wavelet-based estimator. Their analysis contrasts the previous studies because is based on monthly futures prices. They found that the energy prices display anti-persistence in long memory and predictability in mean, and found that even if the estimation window is increased to 0.5, the energy price series show evidence of anti-persistence with only propane showing infinite persistence. In line with other research, they concluded that all the energy price series show long term dependence, implying market inefficiency. Kang et al (2009), building on the literature, applied the GARCH models to investigate long memory in WTI, Brent and Dubai daily crude oil spot price volatility. First, they used the rescale analysis; their results showed that the level of the spot returns display long memory while volatility reveals high persistent. Second, the results of the GARCH models indicate that the GARCH and IGARCH models were mis-specified, as suggested by Tabak and Cajueiro (2007). However, the CGARCH shows a high degree of persistence in the long-run and in the short-run there is weaker volatility, while the FIGARCH model indicates persistence of long memory in all prices, leading Kang et al to suggest that the GARCH model is less efficient compared to the FIGARCH and CGARCH models when modelling oil prices' volatility. In a similar vein, Cheong (2009) applied the ARCH-type models in examining long memory in time-varying volatility in daily WTI and Brent crude oil spot prices. He also examined various stylized facts, such as asymmetric effect, volatility clustering and heavy tail innovations. The results indicate that the volatility in the oil price exhibits high persistence in long memory in both markets, and also found that WTI oil price show longer persistence than Brent. Again, it was observed that WTI markets show no sign of the leverage effect while the Brent market does, with the conclusion that the slow decay in prices may result from two factors: First, market participants behave differently as a consequence of the way they interpret the same information; and second, the different responses of the market participants to new information results in the market encountering dissimilar volatilities which in turn lead to slow decay in the crude oil market volatility.

Furthermore, Ayadi et al (2009) in his work studied the presence of long term dependence in Nigerian Forcados oil prices using detrended fluctuation analysis and weekly spot prices, they found that the oil price series are characterized by a long lasting autocorrelation structure, implying that the prices follow a non-linear process. In their analysis, these results provide evidence of anti-persistence in long memory of the oil prices. However, the results using the ARMA model show that a low price level can be followed by a high price level and vice-versa, and they suggest both that past price trends may change in the long term and that the impact of shocks on oil prices tends to disappear in the long term, again consistent with Alvarez-Ramirez et al (2008) and Tabak and Cajueiro (2007). Arouri (2010) examine the properties of weekly spot prices of four GCC crude oil markets: Saudi Arabia, Qatar, Kuwait and the UAE using a model that is time-varying with GARCH properties. The empirical results show that all prices exhibit short-term autocorrelation in their returns, becoming more significant by the end of the study period, once more consistent with Elder and Serletis (2008) and Alvarez-Ramirez et al (2008). However, they found that the results do not support the existence of high persistence in oil price returns volatility. They suggest that during the 1990s the markets were weakly efficient and show no sign of becoming efficient in the long run, and concluded that the reasons for efficiency were associated with the cut in oil production quotas by OPEC and the sharp drop in crude oil prices caused by the Asian crisis, while the inefficiency resulted from a boom in the international oil markets.

Gu et al (2010) re-examined the dynamic behaviour of WTI and Brent crude oil daily spot prices over a sample period from 1987 to 2008, in order to find whether the international oil markets operate efficiently during the Gulf War. By employing the multifractal detrended fluctuation analysis, their results indicate that the oil prices are characterised by high persistence in the short-term and weaker anti-persistence in long-term. They also observed that when the data is divided into three subsamples the results show that the Gulf War did not change the time scale of returns in either market; however, the results also indicate that the Brent market shows more persistency, implying that here the impact of the Gulf War was greater. They also pointed out that the pattern of the long memory behaviour in the oil markets can be described as caused by factors such as deregulation rather than only persistency, and concluded that the international oil markets are more efficient in the long term. Mohammadi and Su (2010), further building on the literature, re-investigated the long term dependence in crude oil prices of eleven markets, including oil-producers and oil-consumer countries, by employing four GARCH-class models. They conducted their analysis using weekly spot prices and the empirical results from all models support the existence of time-varying volatility in oil prices, implying that they follow a long memory process. They observed that the FIGARCH model performs weakly in all except one crude oil market, contradicting Kang et al (2009), and therefore they suggest that the autocorrelation in oil price volatility dies quickly as in the GARCH model, and not taking the form of the FIGARCH model. In their study to investigate market efficiency in WTI daily futures prices,

Wang and Liu (2010) applied the multiscale analysis based on detrended fluctuation analysis. They found that the WTI market exhibits long memory persistence in the short term and anti-persistency in the medium term, while inconsistent results were obtained in the long-term. They observed that the oil price moves gradually from short-term inefficiency to long-term efficiency, consistent with the results of Tabak and Cajueiro (2007) and Alvarez-Ramirez et al (2008), but in contrast to Arouri (2010). According to the authors, the WTI market has developed over a long time period under unstable condition, and from this they drew the conclusion that the long-term dynamics are influenced by demand and supply factors, while outside factors are responsible for the short-term behaviour of the market. In the same year Wang et al (2010) re-examined long range dependence in daily spot and futures prices volatility for WTI by employing the detrended fluctuation analysis (DFA), GARCH class models and rescale analysis (R/S). Their work aimed to find whether the GARCH model can well capture the autocorrelation in the oil price volatility, and they found evidence supporting that all the oil prices exhibits long term dependence. They found that the DFA and R/S indicate that a moderate persistence exists in the short-term scale, while in the long term there is a strong degree of long memory. They also pointed out that the difference in the level of long memory between the two time scales results from the diversification of investment across different trading horizons. To examine the performance of the GARCH-class models they divided the data into four non-overlapping subperiods and the results support long memory behaviour in oil prices over a period longer than one year; but, the results also show that the models are mis-specified when the time scale is less than a year. Overall, their analysis supports the findings of Mohammadi and Su (2010) who reports that long memory can be well capture by the GARCH-class models in the long term.

In contrast to other studies, Cunado et al (2010) examined the properties of the energy futures markets returns and volatility, and specifically for NYMEX WTI, heating oil, gasoline and propane, using the nonparametric, semi-parametric and parametric procedures; the data used were daily futures prices at one and four month contracts. They found that all the energy futures prices returns were not long memory process at the different maturities, and also found that when the absolute returns are proxy to volatility the results indicate support of long memory in energy prices, with WTI having higher persistence within the maturities. Power and Turvey (2010) also investigated long-range dependence in four energy (WTI crude oil, heating oil and natural gas) and eleven storable and non-storable agricultural commodities using daily data. By applying the wavelets estimator, it can be shown that the crude oil prices have a constant memory parameter over the sample period. They noted that the major difference between the results of the agricultural and energy commodities is that the former are characterized by seasonal consumption while the latter are characterized by seasonal production. In a similar vein, Fernandez (2010) examined long memory in WTI and nineteen other DJ-AIG commodity futures indices, using daily observations and five different methodologies: namely, the wavelets estimator, the periodogram regression-based method, the Geweke and Porter-Hudak's approach and quasi-maximum likelihood. According to the author, when the properties of an assets returns indicate anti-persistence or persistence, it means that they over- or under-reaction to the new information about market price, which is against the efficient market hypothesis in the weak-form. For the WTI returns, the results indicate that the five methods support either anti-persistence or persistence of long term dependence and the author also observed strong evidence of larger persistence in absolute returns, consistent with previous findings. He concluded that market participants can use non-linear models to improve their short term forecast for WTI because of market inefficiency.

Belkhouja and Boutahary (2011) introduced a GARCH model that allows time-varying in the conditional variance (TV-FIGARCH) to test volatility in crude oil prices, accounting for structural breaks and long term dependence in the conditional variance process. They argued that the long memory component in the FIGARCH model may not necessarily capture the persistence that is caused by structural changes. Using daily data for spot prices of the WTI and S&P 500 index, they found that oil prices in the WTI market were highly volatile in the beginning and second half of the sample period but declined by the intermediate period. They also found that absolute returns in WTI display slow decay, representing long memory, and that it has four structural breaks consistent with the crisis that affected the global oil markets. They noted that the FIGARCH model performs better than the time-varying model in explaining long range dependence, but the out of sample forecast supports the TV-FIGARCH model, suggesting that absolute returns are better examined by models that account for both structural changes and long memory.

Wang et al (2011) examined autocorrelation and cross-correlation in WTI daily spot and futures prices using detrended fluctuation analysis (DFA) and detrended fluctuation cross correlation analysis (DFCC). The results indicate anti-persistence in the returns under a year, while neither autocorrelation nor cross-correlation exist in time scales longer than a year; they also found that the autocorrelation is less than cross-correlation in a short time scale. Summarizing their results, it is clear that the WTI market become more efficient in the long term, supporting previous studies that applied a similar approach. They suggest that traditional hedging strategies will be ineffective because of the strong cross-correlation in the oil price returns. Hou and Suardi (2011) also contribute to the literature by examining long memory in WTI and Brent daily spot prices volatility using the parametric and nonparametric GARCH models. The model measures the unobserved diffusion process in returns using additive functions of lagged innovation and volatilities. The results indicate persistence in oil prices, and that models with long-range dependence are statistically significant in the markets. In contrast to Mohammadi and Su (2010), the results support the hypothesis that the FIGARCH model performs better than others in modelling long memory consistent with Kang et al (2009). They observed that the non-parametric GARCH model fails to capture long memory in the oil returns prices, but in the out of sample analysis, the results indicate its improved forecast ability over the parametric GARCH models. They suggest the use of nonparametric GARCH models as an alternative in studying crude oil price volatility.

Finally, Arouri et al (2012) reinvestigated the significance of structural breaks and long-term dependence in modelling daily energy spot and futures prices volatility for NYMEX WTI crude oil, gasoline and heating oil at one and two-month contracts to maturities, using the GARCH-type models. They found that all the oil prices follow a long memory process, and observed that, after accounting for the possible structural breaks; the degree of persistency in volatility is reduced, implying that the GARCH model does not account for the possible structural changes that occurred in the price series. The results also show that the FIGARCH model performs well in modelling the long memory properties of the oil prices. Next, they conducted the out of sample forecast using other models, such as the Guassian semiparametric, Geweke and Porter-Hudak and Exact maximum likelihood tests. They found that the results of the FIGARCH model with a break explain long memory in oil prices volatility better than the other model in the existence of structural changes.

Table 6.1 Summary of Previous Results on Long Memory in the Oil Futures Market

Author (s) and Years	Data and Market	Methods	Results
Alvarez-Ramirez et al (2002)	WTI, Brent, and Dubai daily spot prices from 1981 to 2002	Multifractal analysis	Long memory exists in all the prices in the long term and less persistence in the short term.
Tabak and Cajueiro (2007)	WTI and Brent daily futures prices from 1983 to 2004	Rescaled Range analysis (R/S)	Long memory exists in all the prices.
Alvarez-Ramirez et al (2008)	WTI, Brent and Dubai daily spot prices from 1987 to 2007	Rescaled Range analysis (R/S)	Long memory exists in the short term horizon less than one month and the markets moves towards efficiency in the long term.
Elders and Serletis (2008)	WTI monthly spot price from 1994 to 2005	Wavelet Estimator	The price show anti-persistence in the long term.
Kang et al (2009)	WTI, Brent and Dubai daily spot prices from 1992 to 2006	GARCH-class models	Long memory exists in all prices.
Cheong (2009)	WTI and Brent daily spot prices from 1993 to 2008	GARCH- class models	Long memory persists in all prices but WTI show high degree of persistence than Brent.
Ayadi et al (2009)	Nigerian Farcados weekly spot price from 1978 to 2007	Detrended fluctuation analysis	Long memory exists in the price but disappears in the long run.
Arouri (2010)	Four GCC daily spot prices	State space model / Kalman filter	Long memory exists with no

	from 1997 to 2010	with GARCH effects	evidence of converging towards efficiency in the long term.
Gui et al (2010)	WTI and Brent daily spot prices from 1987 to 2008	Multifractal Detrended fluctuation analysis	Evidence of high persistence in the short-term and weaker anti-persistence in long-term. The Brent market also shows high persistence than WTI.
Mohammadi and Su (2010)	Weekly data for eleven oil-importing and exporting-countries from 1997 to 2008	GARCH-class models	Long term dependence present in all prices.
Wang et al (2010)	WTI daily spot price from 1990 to 2009	Multiscaled detrended fluctuation analysis (MDFA)	Long memory in WTI price but die in the long run.
Wang et al (2010)	WTI daily spot and futures prices from 1990 to 2009	MDFA, GARCH models and R/S analysis	Long term dependence exists in all the prices.
Cunado et al (2010)	WTI daily futures prices at one and four month contracts from 1983 to 2008	Nonparametric, semi-parametric and parametric procedures	Long memory present in WTI price.
Power and Turvey (2010)	WTI daily spot price from 1990 to 2008	Wavelet estimator	Long memory exists in WTI price.
Fernandez (2010)	WTI daily spot price from 1991 to 2008	Wavelets, periodogram regression, Geweke-Porter-Hudak's and quasi maximum likelihood	Evidence of high degree of persistence in absolute returns.
Belkhouja and Boutahary	WTI daily spot price from	TV- FIGARCH model	Long memory exists in WTI price.

(2011)	1990 to 1999		
Wang et al (2011)	WTI daily spot price from 1990 to 2010	Detrended fluctuation analysis (DFA) and detrended fluctuation cross correlation analysis (DFCC)	Presence of long memory in WTI price in period less than a year and the market move towards efficiency in the long term.
Hou and Suardi (2011)	WTI and Brent daily spot prices from 1992 to 2010	The parametric and nonparametric GARCH models	Long term dependence exists in all the oil prices.
Arouri et al (2012)	WTI daily spot and futures prices at 1 and 2 maturities 1986 to 2007	GARCH-type models	Long memory exists in all prices.

To summarise, the above review shows that long memory in oil prices has been studied extensively. Table 6.1 presents a summary of previous findings in the oil markets. It is clear that crude oil prices are characterised by long-term dependence, violating the argument of the weak form efficient hypothesis because past returns can be used to forecast current future prices. Secondly, the majority of the research show that the long-term dependence in oil prices is driven by factors such as the activities of different groups of agents operating in the oil markets, the way in which these agents perceive new information, and supply and demand factors, among others. Third, most studies are devoted to the oil spot market and NYMEX WTI futures market at one month contracts. Finally, research in this field employs a variety of models, techniques and data for different frequencies to test long-term dependence in oil prices.

6.2.2 The Non-oil Commodity Markets

In this section, the literature on long memory in the non-oil commodity markets is reviewed to enable a better understanding of the area. In their study, Fang et al (1994) examined long-term dependence in five currency (British pound, Japanese yen, German mark and Swiss franc) futures markets using the Geweke-Porter-Hudak (GPH) semi-non parametric procedure and data are daily closing prices. Before conducting their analysis they first applied the autoregressive models and ARCH model to test the price series properties, and found that the futures returns indicate no significant autocorrelation but do reveal the presence of heteroskedasticity in each of the prices. As a result, they suggest that the test for fractional process should account for heteroskedasticity in order to arrive at more reliable estimates. Their analysis with GPH provides support that all the currency futures prices except the British pound show long-range dependence fractional process, and therefore they suggest that currency futures prices exhibit long-term dependence. In a similar vein, Barkoulas et al (1997) investigated long memory in twenty-one commodity markets including agriculture, metals, petroleum and the UNTCAD index by applying the Geweke and Porter-Hudex; the data for their analysis included monthly spot prices. The authors argued for the use of monthly observations because they can provide information about the long memory behaviour of commodity prices in both the short- and long-term. They found that six of the commodities' returns display long memory, while the others displayed different patterns even though the PP and KPSS unit root tests indicate that they are non-stationary process. These results are further confirmed by the ARMA model and consequently the authors suggested the use of different methods in testing long memory in commodity prices in order to arrive at a strong inference. They also suggested that the idea of taking the difference of the data series may not be the best way of modelling the commodity price behaviour, as according to the authors' view, long memory in spot prices implies that the market inefficiency may represent the fundamental factors underlying the prices, which can be attributed by commodity market processes with long-term dependence.

Extending the previous work, Panas (2001) tested long memory in six metals: lead, aluminium, tin, copper, zinc and nickel, traded on the London metals exchange. By applying the rescaled range analysis and daily futures prices, the results support the existence of long-range dependence in all the metals futures returns series. Furthermore, the results obtained using modified R/S analysis also indicates that the commodities, with the exception of aluminium, have a short memory structure. To confirm their results they applied the autoregressive fractionally integrated moving average model (ARFIMA) and found that the returns of lead and nickel provided evidence for short-term memory, aluminium and copper showed long memory while zinc and tin possessed anti-persistent process. They interpret this as strong evidence of long-range dependence in aluminium and copper, consistent with Barkoulas et al (1997) and concluded that the metals futures markets are weak form efficient, although this does not hold for all commodities. In contrast, Jin and Frechette (2004) contributed to the literature by applying the FIGARCH model to investigate short memory and long memory in the agricultural futures markets. They conducted their analysis using daily closing futures prices for 14 commodities including meats, soft commodities and grains, calculating the return series by dividing the settlement prices with their lag values. The log returns were assumed to be zero in order to produce valid results regarding price volatility. They found that all the agricultural commodities display long-term memory, results confirmed by the modified rescale analysis, which shows that the prices disconfirm the weak form efficient hypothesis. They suggested that the FIGARCH model performs better than the GARCH model in explaining long-term memory in all except one commodity futures market.

Elders and Jin (2007) continued research in this area by re-examining long-range dependence in 14 agricultural commodity futures returns volatility, using the wavelet estimator. They modelled volatility using compounded daily returns calculated by taking the difference of the current price and previous period. They found that the predictability of the conditional mean is not consistent with the conditional volatility specification, and thus constructs volatility using absolute returns. The findings showed that some of the commodity futures returns are volatile but all display a high degree of persistence (long memory) in the returns series. Elders and Jin also applied the GARCH, FIGARCH and GPH: the results were consistent with Jin and Frechette (2004) and Barkoulas et al (1997). Additionally, Bailie et al (2007) estimated the long memory in six US commodities: corn, soybeans, cattle, hogs, gasoline and gold futures returns volatility, applying the FIGARCH and semi parametric Local Whittles (LW) estimation to daily and intraday high frequency observations. They argued that the presence of long memory in data for different frequencies implies that the series are self-similar and provide more consistent estimates; in particular, their results support that the commodities display long memory in their returns volatility at both frequencies, however, the estimated value of the intraday returns is little higher than that of daily returns. The semi-parametric Local Whittles (LW) estimation was then applied to absolute returns and the results indicate that both the daily and intraday returns exhibits long memory features, leading to the conclusion that the finding of long memory in different sampling frequencies implies long-term dependence is inherent in the features of the commodity returns and does not arise from shocks or regime shifts.

Floros (2009) using the ARFIMA models investigated long memory in monthly spot prices for fifteen EU milk prices. The empirical results support the existence of long-range dependence in prices for twelve out of fifteen European countries, implying that shock persists over a long time period, making them predictable, results consistent with Bailie et al (2007) and others. Floros also found that the persistence in long memory is larger in the countries with high milk consumption, and he concluded that the market for EU milk is inefficient because past information on prices can be used in making future decisions. Tansuchat et al (2009) also studied long-term dependence in sixteen agricultural commodity futures markets returns using the seven different GARCH models. By employing daily futures prices, they discovered that almost all of these prices are characterised by long term dependence. In line with Jin and Frechette (2004), the results indicate that the FIGARCH and FIEGARCH models out-performed the traditional GARCH and EGARCH models in explaining long memory behaviour in oil price.

Arouri et al (2012), further building on the literature, investigated the long term dependence and structural breaks in the metal markets by employing the parametric and non-parametric models. They conducted their analysis using daily spot and three-month futures prices for four metals including: silver, gold, platinum and palladium. The results show that both the returns and volatility of all the metals display long memory, results confirmed by the ARFIMA-GARCH model, which shows that the prices disconfirm the weak form efficient hypothesis. They also found that even after accounting for the structural changes in the prices, the results still confirm persistence in these markets. They suggest that the conditional returns volatility of these markets can best be described by long term dependence rather than structural breaks.

Table 6.2 Summary of Previous Results on Long memory in the Non-oil Commodity Futures Markets

Author(s) and Years	Data and Market	Methods	Results
Fang et al (1994)	Four currencies: British pound, German mark, Japanese yen and Swiss franc daily futures prices from 1982 to 1991	Geweke-Porter-Hudak semi parametric method	Long memory exists in all the currencies prices.
Barkoulas et al (1997)	21 commodity markets monthly futures prices from 1960 to 1994	Geweke-Porter-Hudak semi parametric method	Long memory exists in all the commodity prices.
Panas (2001)	Six metals: aluminium, copper, lead, tin, nickel and zinc daily futures prices from 1989 to 2000	Rescaled Range analysis	Two of the metals exhibit short-memory, two shows anti-persistence and two indicates long memory.
Jin and Frechette (2004)	Seven US grains daily futures prices from 1994 to 2003	FIGARCH model	All the prices display long term dependence.
Elders and Jin (2007)	US 14 agricultural commodity daily futures prices from 1980 to 1990	Wavelet estimator	All the prices show high degree of persistence.
Bailie et al (2007)	Six commodities daily and intraday futures prices from 1980 to 1990	FIGARCH models and semi-parametric local Whittles estimator	Long memory exists in all the commodities prices.
Floros et al (2009)	Fifteen European countries Milk monthly spot prices from 2001 to	ARFIMA model	Long memory in all the prices but the countries with high consumption

	2008		indicates more persistence.
Arouri et al (2012)	Four metals silver, gold, platinum and palladium daily spot and three-month futures prices from 1999 to 2011	Geweke-Porter-Hudak semi parametric method, Robinson Hendry method, Sowell maximum likelihood test, ARFIMA-FIGARCH model.	All the prices possess long memory process.

Overall, Table 6.2 shows how long memory was investigated in a variety of commodity markets. In general, both the oil and non-oil commodity markets show evidence of long memory in either their absolute returns or volatility, results which oppose the weak form efficient market hypothesis. Moreover, these studies examine long memory using both the same techniques and data for the same frequencies. It is clear that there is no single model that has been agreed to best capture long memory in commodity prices.

6.3 Theoretical Background of Long Memory Models

Most economic and financial theories postulate that the price of an asset is expected to exhibit long-range dependence rather than to follow a random walk process[36]. Long memory in time series was first investigated by Hurst (1951), a hydrologist who analysed 600 years of data on the annual minimum flow of the Nile. In his work Granger (1966) also showed that the majority of economic variables have "typical spectral shape"; because of their low-frequency component the long term fluctuation decreases smoothly over a longer period[37]. Maldelbort and Wallis (1968) named this feature the "Joseph Effect", based on an Old Testament prophet who foretold that Egypt would experience seven years of plenty after seven years of famine. They argued that "a long period of unusual (high or low) participation can be extremely long". Therefore, long memory describes the low power in time series, such that correlation of information disappears over a long-term period. In line with these

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[36] Foo (2009) shows that stock prices follow a Brownian process where prices change randomly and are independent from each other.

[37] "The law of typical spectral shape states that the long-term fluctuations in economic variables, if decomposed into frequency components, are such that the amplitudes of the components decrease smoothly with decreasing periods" (see Granger, 1966).

arguments, many studies have introduced different procedures that can be applied to examine long memory (persistence) in financial time series, among which are the fractional integrated models (see Maldelbort 1971; Granger and Joyeux, 1980; Hosking, 1981). Fractional integration can be defined as a condition where a time series is assumed to be either stationary (integrated of order zero) or non-stationary (integrated of order one) (Elder and Jin, 2007). The presence of fractal structure in an asset price indicates that the series is characterised by irregular cyclical changes and long term dependence (Elder and Jin, 2007). Thupayagale (2010) also argued that a time series with fractional integrated processes display persistent, mean reversion and therefore differs from non-stationary and stationary processes. Hence, a stationary time series r_t display long memory when its autocorrelation functions is non-negative and decay at slow hyperbolic rate, so that

$$p_k \approx ck^{2d-1}$$

where p_k is the autocorrelation function, k is the number of lag which is infinite, c is a constant and d is the parameter that captures the long memory properties in the time series. In contrast, the autocorrelation function of stationary time series takes the form $p_k \approx |\delta|^k$, where $|\delta| < 1$ so that the persistence dissipates at a fast exponential rate (Tansuchat et al, 2009). The more recent fractional integrated models such as the FIGARCH, FIEGARCH, FIAPARCH and HYGARCH developed to capture volatility in conditional variance assumed that r_t is a long memory process when $0 \leq d \leq 1$. Following Thupayagale (2010), Foo (2009) among others this chapter investigates the Efficient Market Hypothesis by testing both the short and long memory behaviour of the crude oil futures returns using fractional integration methods.

6.4 Empirical Methodology

6.4.1 GARCH Model

The generalized autoregressive conditional heteroskedasticity (GARCH) model was introduced by Bollerslev (1986) as an extension of ARCH model where the current conditional variance depend on its own lagged values and the variance includes both autoregressive and moving average elements. Also, the autocorrelation in volatility (long memory) disappear at slow exponential rate. The GARCH (1, 1) model for the oil futures returns can be written as follows:

$$r_t = \mu_t + \varepsilon_t \tag{6.1}$$

where, $\varepsilon_t / \psi_t \sim iid \;\; N(0, \sigma_t)$

$$\sigma^2{}_t = \omega + \beta\sigma^2_{t-1} + \alpha\varepsilon^2_{t-1} \tag{6.2}$$

where r_t represents the dependent variable which is returns, μ_t is the conditional mean, ε_t is the error term which is assume to have zero mean, constant variance and independently distributed, ψ capture all information at time $t-1$, σ_t^2 is the conditional variance, ω is the unconditional mean value which is constant, σ^2_{t-1} is the GARCH term which capture information on the past forecast error variance, ε^2_{t-1} is the ARCH term which capture information on volatility from the past period. Bollerslev (1986) shows that the parameters α and β are expected to be positive with the restrictions $\omega > 0, \alpha > 0, \beta > 0$ to ensure positive conditional variance. The sum of the parameters $\alpha + \beta$ measures the persistence of shock on volatility. If the parameter $\alpha + \beta > 1$, shock to volatility would be unstable while $\alpha + \beta = 1$ imply that volatility is permanent and unconditional variance is infinite representing the Integrated GARCH model (IGARCH) (see Thupayagale, 2010). However, the IGARCH model does not fit in modelling long memory because shock on volatility never dies out (Kang et al, 2009).

6.4.2 EGARCH Model

The exponential GARCH (EGARCH) model was proposed by Nelson (1996) in order to account for the asymmetric response of the conditional variance to both positive and negative shocks. This model also assumes non-negativity in the parameters of the conditional volatility. The conditional variance of the EGARCH (1, 1) model takes the following form:

$$\log \sigma_t^{\ 2} = \omega + \alpha z_{t-1} + \gamma(|z_t| - E|z_{t-1}|) + \beta \log(\sigma_{t-1}^2) \qquad (6.3)$$

where, γ is the parameter that captures the asymmetric effect of shock to conditional variance. The model becomes GARCH (1, 1) when $\gamma = 0$, $\gamma < 0$ implies that positive shock leads to less volatility than negative shock while $\gamma > 0$ is the reverse condition of high volatility than negative shock (Mohammadi and Su, 2011).

6.4.3 APARCH Model

The asymmetric power autoregressive conditional heteroskedasticity (APARCH) model was developed by Ding et al (1993) to capture asymmetric effect of shock to conditional variance and assumes that the effect on residuals follow exponential rate of decay. The APARCH $(1, d, 1)$ model can be written as:

$$\sigma_t^{\ 2} = \omega + \beta\sigma_{t-1}^{\delta} + \alpha\left(\left|\varepsilon_{t-1}\right| - \gamma\varepsilon_{t-1}\right)^{\delta} \qquad (6.4)$$

where γ is the coefficient that captures the asymmetric leverage effect on conditional variance and δ determines the best specification of the model. The restrictions $\delta > 0$ and $-1 < \gamma < 1$ are imposed on the parameters and the model takes the form of GARCH (1,1) when $\delta = 2$ and $\gamma = 0$. The condition $\delta = 1$ means that the conditional standard deviation is the best for modelling shock to volatility while $\delta = 2$ suggest conditional variance.

6.4.4 FIGARCH Model

The fractionally integrated GARCH (FIGARCH) model was proposed by Baillie et al (1996) to capture the long memory in shock to conditional variance and allows the autocorrelation in volatility to die at slow hyperbolic rate. The conditional variance of the FIGARCH $(1, d, 1)$ can be written in the following equation:

$$\sigma_t^{\ 2} = \omega + \left[1 - \beta(L)\right]^{-1} + \left\{1 - \left[1 - \beta(L)^{-1}\right]\phi(L)(1 - L)^{d}\right\}\varepsilon^{2}_{\ t} \qquad (6.5)$$

where d is the fractional integrated parameter that captures long memory in volatility and L is the lag operator. The parameters must take the form $0 \leq d \leq 1$ and $\omega > 0, \phi < 1, \beta < 1$ to ensure positive conditional variance. The superiority of the FIGARCH model over the others is that it permits three different conditions: the intermediate range of persistence (long memory) when $0 < d < 1$, infinite persistence when $d = 1$ and geometric decay when $d > 1$[38]. Ballie et al (1996) suggest that this model is strictly stationary process when $0 \leq d \leq 1$.

6.4.5 FIEGARCH Model

The fractional integrated EGARCH (FIEGARCH) model was introduced by Bollerslev and Mikkelsen (1996) an extension of the EGARCH to capture both asymmetric response of shock and long memory in the conditional variance. In this model the parameters of the conditional variance can be negative not as in the case of FIGARCH model. The conditional variance of the FIEGARCH model can be written as:

$$\ln \sigma_t^2 = \omega + \phi(L)^{-1}(1-L)^{-d}\left[1+\psi(L)\right]g_t(z_{t-1}) \qquad (6.6)$$

where d is the long memory parameter. The model becomes EGARCH when $d = 0$, stationary when $d < 0.5$ and $g_t < \infty$ and $d < 1$ means that shock on conditional volatility decay at slow hyperbolic rate.

6.4.6 FIAPARCH Model

The fractional integrated APARCH (FIAPARCH) model of Tse (1998) was proposed to capture the long memory persistence and asymmetric effect of shock on conditional volatility. The FIAPARCH also permits the effects on the residuals to follow a long memory process. The FIAPARCH $(1,d,1)$ model can be written as:

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[38] Mohammadi and Su (2010) show that the condition when $d = 1$ and $d = 0$ implies existence of short memory and long memory in the conditional volatility, respectively.

$$\sigma_t^2 = \omega + [1-\beta(L)]^{-1} + \{1-[1-\beta(L)^{-1}]\phi(L)(1-L)^d\}(|\varepsilon_t| - \gamma\varepsilon_t)^\delta \qquad (6.7)$$

where $0 \leq d \leq 1, \omega > 0, \delta > 0, \varphi, \beta < 1$ and $-1 < \gamma < 1$. The parameter d captures the long memory properties. The FIAPARCH model becomes APARCH model when $d = 0$ and FIGARCH when $\delta = 2$ and $\gamma = 0$.

6.4.7 HYGARCH Model

Davidson (2004) developed the hyperbolic GARCH (HYGARCH) model as an extension to the FIGARCH is more powerful in investigating long memory in conditional variance. Davidson argued that FIGARCH model is more of a "knife-edge-nonstationary" class because it account for restriction that is applied to models of level. The length of long memory increases here as d approaches zero. The conditional variance of the HYGARCH $(1, d, 1)$ model can be written as:

$$\sigma_t^2 = \omega + [1-\beta(L)]^{-1} + \{1-[1-\beta(L)^{-1}]\phi(L)(1+k)[((1-L)^d - 1)]\}\varepsilon^2{}_t \qquad (6.8)$$

where the parameters restriction $0 \leq d \leq 1, \omega > 0, k \geq 0, \varphi, \beta < 1$ are expected. The HYGARCH model becomes GARCH when $d = 0$, FIGARCH when $k = 1$, IGARCH when $d = 1$ and $k = 1$, nonstationary $k \geq 1$ and stationary $k < 1$ (see Davidson 2004).

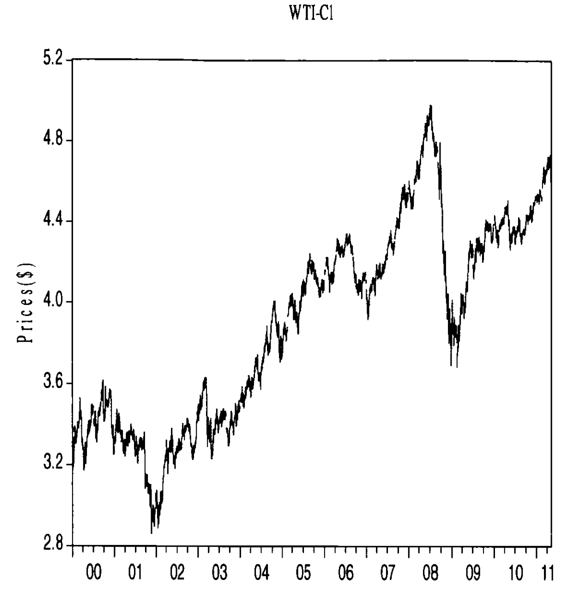
6.5 Data and its Properties

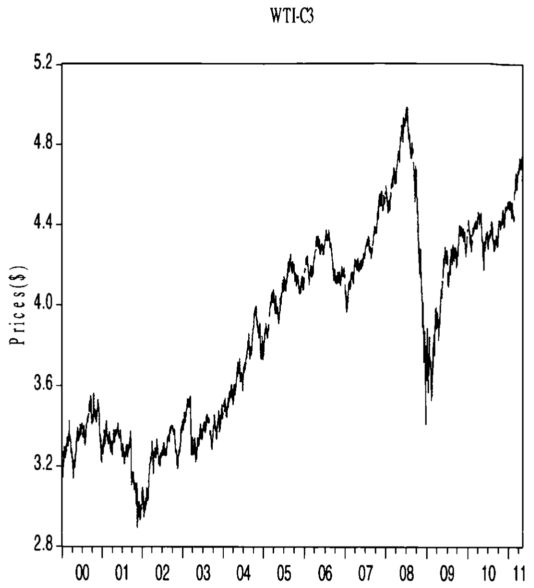
This chapter used daily closing futures prices for West Texas Intermediate and Brent crude oil at one and three-month contracts to maturities. Data for WTI were sourced from the Energy Information Administration U.S, while that of Brent were obtained from the Data Stream and Maslyuk and Smyth (2008). Both WTI and Brent oil futures prices are in US dollars per barrel. The data used starts from 3 January 2000 and ends 5 May 2011, a total number of 2838 observations for the price series in each market. The sample used covers some of the important events that influence recent fluctuation in oil price. First, the period of high volatility that followed the September 11, 2001 events. Second, the period before and after Iraqi war between 2003 and 2005. Third, period during which oil price reached highest level ever $145 per barrel in 2008 and finally, period of political instability and unrest in Arab countries in 2011. All the oil futures price series are converted into log returns series calculated as $r_t = \log(p_t / p_{t-1}) \times 100$, where r_t is the futures return, p_t is the current futures price and p_{t-1} is lagged futures price for one period as in Kang et al (2009) Mohammadi and Su (2010) and Wang et al (2010). Following Ballie et al, 2007, this chapter used absolute returns instead of squared returns to model long memory in oil prices because it can provide strong inference on the autocorrelation structures of returns volatility. This chapter used the following notations: WTI-C1, WTI-C3, Brent-C1 and Brent-C3 to denote WTI and Brent futures prices at one and three-month contract, respectively.

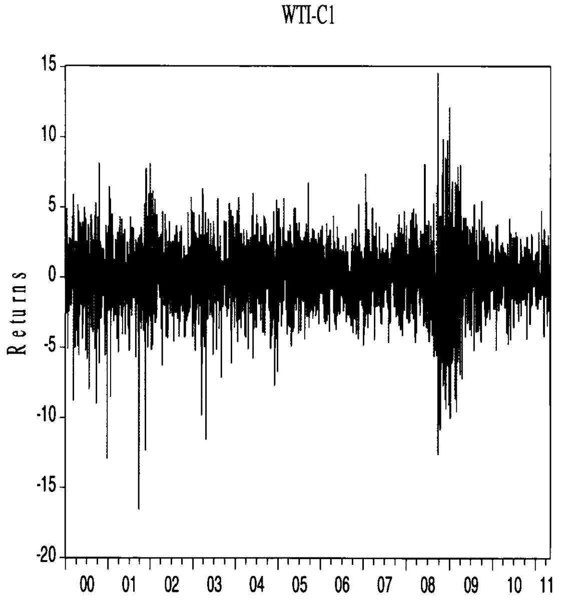
Table 6.3 Descriptive Statistics for Crude Oil futures returns

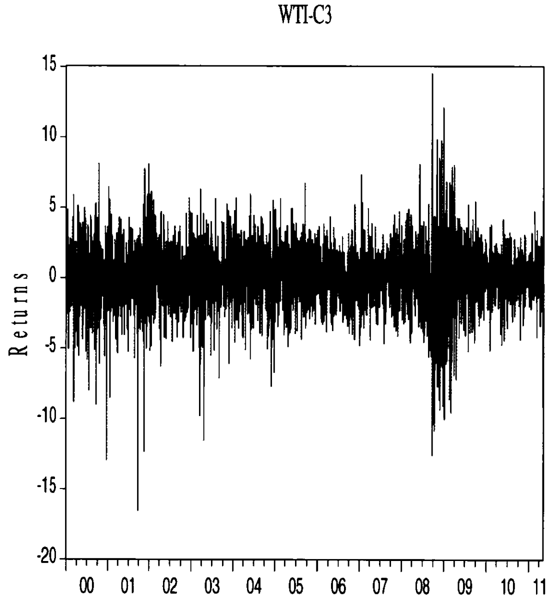
Statistics	WTI-C1	WTI-C3	Brent-C1	Brent-C3
Mean	0.047958	0.050543	0.052725	0.055144
Maximum	14.54637	13.54551	18.12974	12.70660
Minimum	-16.54451	-12.7431	-16.83201	-13.07298
Std. Dev.	2.442167	2.321836	-2.137847	2.164592
Skewness	-0.368575	-0.124603	-0.204659	-0.251373
Kurtosis	6.260568	6.827106	7.064713	6.108438
Jarque-Bera Prob	1320.9(0.0)	1738.7(0.0)	1972.8(0.0)	1172.0(0.0)

Note: Figures in brackets are probability values for the normality test.


WTI-C1
Prices($)
5.2
4.8
4.4
4.0
3.6
3.2
2.8
00
01
02
03
04
05
06
07
08
09
10
11


WTI-C3
Prices($)
5.2
4.8
4.4
4.0
3.6
3.2
2.8
00
01
02
03
04
05
06
07
08
09
10
11


WTI-C1
Returns
15
10
5
0
-5
-10
-15
-20
00
01
02
03
04
05
06
07
08
09
10
11


WTI-C3
Returns
15
10
5
0
-5
-10
-15
-20
00
01
02
03
04
05
06
07
08
09
10
11

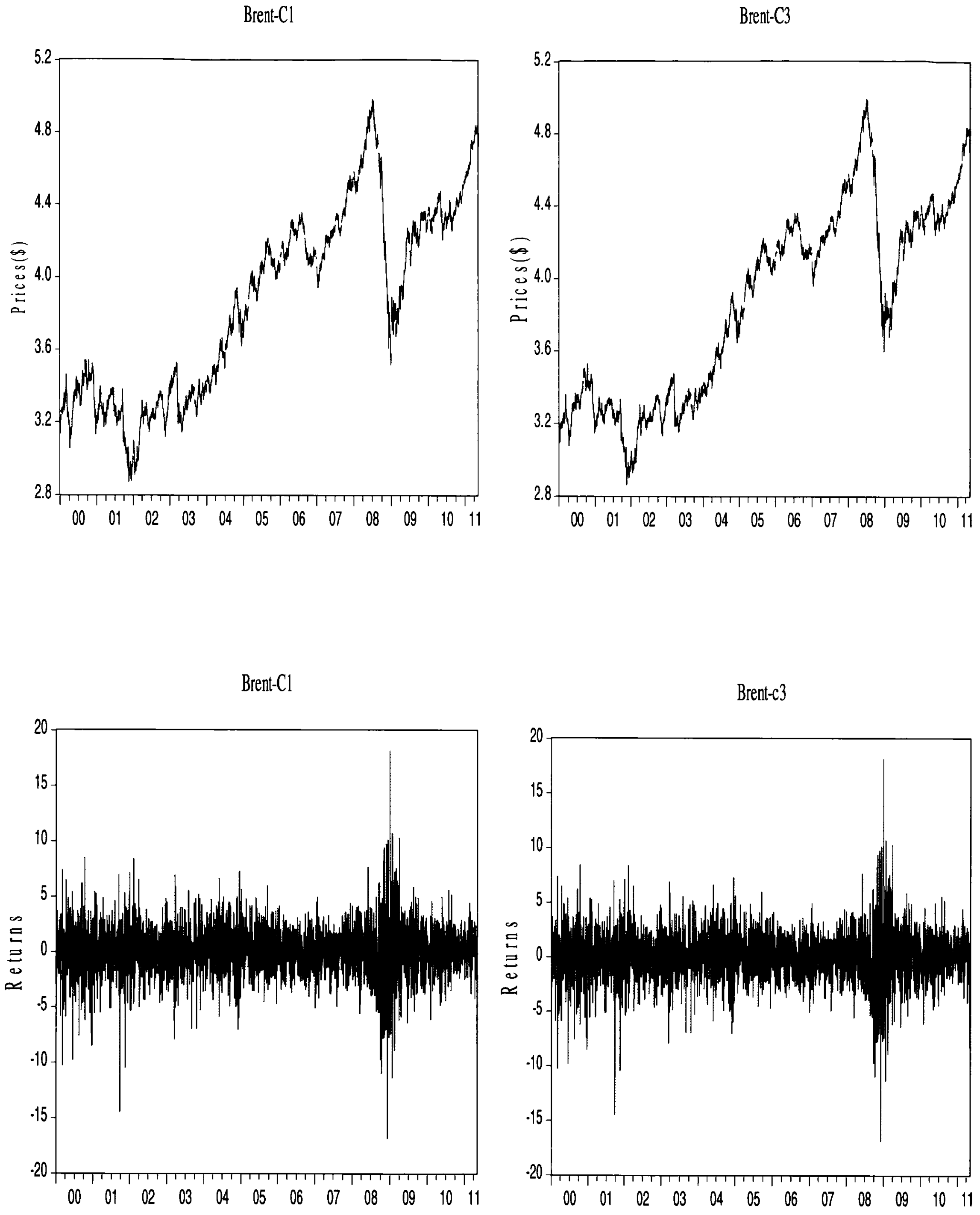


Figure 6.1: Daily WTI and Brent Crude Oil Prices and Returns, January 2000-May 2011

Table 6.3 presents the descriptive statistics for daily oil futures returns. This reports the mean, maximum, minimum, standard deviation, skewness; Kurtosis and Jarque-Bera probability for each of the oil futures returns. The results show that the crude oil markets have mean lower than the standard deviation but that of Brent is higher in all maturities. All the crude oil futures returns series have high kurtosis greater than 3, implying that they are leptokurtic. The returns series show negative skewness, suggesting that the markets are characterised with fatter tail than the normal distribution. Also, the oil prices exhibits longer left tail, indicating that the oil markets experience heavy losses during the study period. For the normality test, the Jarque-Bera probability test indicates that all the oil futures returns are not normally distributed. Figure 6.1 plots the daily crude oil futures prices and returns series. The plot illustrate that the two oil markets experience high fluctuation and jumps particularly in the years 2008 and 2011. Their returns series also appears to revert to their mean, implying that they may possess long memory properties.

6.6 Empirical Results

This section provides analysis of the results obtained using the different techniques discussed in the previous section. First, the stochastic properties of the daily crude oil futures returns are determine using the unit root test (see chapter 3 for explanation of the unit root tests). Secondly, the generalized conditional heteroskedasticity models are used to examine whether the oil futures returns have evidence of long memory properties.

6.6.1 Unit root tests

Two unit root tests are used to examine the order of integration of the oil futures prices series: the Augmented Dickey-Fuller and Kwiatkowski, Phillips, Schmidt and Shin. Table 6.4 reports the results of the unit root tests undertaken using two different specifications: with constant and with constant and trend. The optimal lag length for the ADF and KPSS is selected by the Schwarz Information Criterion (SIC) and Bartlett kernel, respectively. The ADF tests for the two specifications show that all the return series do not contain a unit root, implying that they are stationary. The KPSS test results also show that the oil returns are non-stationary series at the 5% significant level in both specifications. Both unit root tests therefore indicate that all the oil returns series can be used in analysis without any further transformation.

Table 6.4 Unit Root Test

Variables	ADF		KPSS	
	(i)	(ii)	(i)	(ii)
WTI-C1	-54.32*	-54.31*	0.040*	0.041*
WTI-C3	-52.63*	-52.63*	0.042*	0.042*
Brent-C1	-55.41*	-55.40*	0.050*	0.046*
Brent-C3	-56.04*	-56.03*	0.052*	0.052*

Note: * denotes significance at the 5% level. The specification of the unit root test (i) and (ii) represents constant and constant and trend, respectively.

6.6.2 Results of the GARCH Model

Since the descriptive statistics of the crude oil futures returns series indicates evidence of non-normality, this chapter proceed to estimate the seven different GARCH models discussed in section 5.4. The results of the conditional mean and variance equations for the WTI and Brent crude oil markets estimated from these models, along with their diagnostic tests, are reported in Table for each model. Table 6.5 reports that the estimated results obtained from the GARCH (1, 1) model show that the parameters for the conditional variance equation α and β are significant and positive in the two crude oil markets at the different contracts, results which indicate that the model observes positive constraint restrictions. The estimates of the measure of persistence parameter $\alpha + \beta$ are approximately the same and very close to unity in all the markets within the maturities. In the WTI market, the results demonstrate that the values are 0.985 and 0.977 at one and three-month contracts, respectively. Similarly, in the Brent market the results show the value of 0.988 and 0.980 in the maturities respectively. These findings show that the crude oil futures markets exhibit high persistence in their returns which suggest long memory, results consistent with those of Arouri et al (2012) and Wang et al (2010) who studied the WTI futures market. It can be seen that the oil futures returns possess long memory even though the autocorrelation disappears at a slow exponential rate over time. Table 6.5 also reported that the results of the diagnostic tests using the Box-piers test and ARCH test show the absences of serial correlation and heteroskedasticity in the WTI and Brent markets at the different maturities, respectively.

6.6.3 Results of the EGARCH Model

Table 6.6 presents the estimated results of the EGARCH model for the crude oil futures markets. The estimates of the conditional variance equation indicate that α and β are significant at the 5% level and there sum $\alpha + \beta$ is greater than unity in both WTI and Brent markets at the different maturities. The values reported are between 1.128 and 1.493 across the markets and maturities, implying permanent persistence in the returns series and supporting Wang et al (2010), who studied WTI at one-month contract. At the same time, this results means that the EGARCH have taken the form of IGARCH model (Wang, 2003). The results show that the coefficient of asymmetry, γ, are different from zero and significant with values between 0.103 and 0.191 across the markets and maturities, implying that the response of the oil futures price returns to positive shock is followed by high volatility than negative shock of the same amount. The results therefore support the presence of asymmetric leverage effect and long memory in the WTI and Brent markets. The results of the diagnostic tests using the Box-piers test on the standardized residual show no serial correlation and the ARCH test also reject heteroskedasticity in both markets at the different maturities.

6.6.4 Results of the APARCH Model

Table 6.7 reports the results of the APARCH model for the crude oil futures markets. The results indicate that the estimates of the power parameter δ which select the best specification for modelling oil futures returns for the WTI market are 1.249 and 1.283, while in the Brent market the values reported are higher, with δ equalling 1.687 and 1.452 at one and three-month contract, respectively. These results cannot reject the null hypothesis of $\delta = 1$ at the 5% significant level in all the markets, suggesting that their returns are better investigated with conditional standard deviation which supports the presence of long memory. Furthermore, the results indicate that the estimates of the asymmetric parameter γ are between 0.316 and 0.939 across the markets and maturities. These results provide strong evidence of a leverage effect in the WTI and Brent market and thus supporting the EGARCH model. The results of the diagnostic tests using the Box-piers test on the standardized residual reject serial correlation and the ARCH test also reject heteroskedasticity in both WTI and Brent markets at the different maturities.

6.6.5 Results of the FIGARCH Model

Table 6.8 reports the results of the FIGARCH model for the crude oil futures markets. The estimated results show that the values of the parameters for the conditional variance equation are all significant and positive, indicating that the model observes its positive constraint restrictions in all the markets. The estimates of the long memory parameters d show that the fractional integrated coefficient is different from zero and significant in all markets. In the WTI market, the values are 0.408 and 0.406 at one and three-month contract respectively, results consistent with Arouri et al (2012) and Wang et al (2010). In the Brent market, the results reported that the long memory parameter show the values of 0.474 and 0.372 at one and three-month contract respectively. These suggest that the crude oil futures returns for both markets have long memory in their conditional volatility at the different maturities, which is against the efficient market hypothesis in the weak form. The results also fail to support the hypothesis of $d = 0$ and $d = 1$, implying that the FIGARCH model does not reduce to either the IGARCH or GARCH model in both markets. The results support Tabak and Cajueiro (2007) and Cunado et al (2010) that reported long memory in these markets using a different approach and thus show that previous information about oil futures price can help predict future returns in the WTI and Brent markets. The Box-piers diagnostic test on the standardized residual show no serial correlation and the ARCH test also reject heteroskedasticity in all markets within the maturities.

6.6.6 Results of the FIEGARCH Model

Table 6.9 presents the results of the FIEGARCH model estimated for the WTI and Brent crude oil futures markets. The results indicate that the asymmetric parameter γ is significant and non-zero in all the markets supporting the EGARCH and APARCH models. The estimated values are between 0.201 and 0.216 across the markets and maturities, suggesting that the response of the oil futures returns to positive shock is followed by high volatility than negative shock of the same amount. The results also show that the values of the d parameter for long memory vary between 0.576 and 0.728 across the two oil markets and maturities, indicating that the oil futures returns have autocorrelation which disappears at a slow rate. However, the results show that the WTI market has larger persistence than Brent at one-month contract consistent with Tabak and Cajueiro (2007), while the reverse is the case at three-month contract. The results indicate that the returns for both markets can be predictable using their past values which support the FIGARCH model. The diagnostic tests using the Box-piers test on the standardized residual reject serial correlation and the ARCH test reject heteroskedasticity in the WTI and Brent markets at the different maturities.

6.6.7 Results of the FIAPARCH Model

The results of the FIAPARCH model for the crude oil futures markets are reported in Table 6.10. The estimated results show that the value of the power parameter δ which chooses the best specification for modelling oil futures returns are approximately the same with that of the APARCH model in the two oil markets. The results reports that the values are between 1.241 and 1.707 across the markets and maturities which reject the null hypothesis of $\delta = 1$ in the markets, suggesting that returns are better investigated with conditional standard deviation. The findings are consistent with Ding et al (1993) who show that such case provides evidence that the returns possess long memory because the correlation between the squared returns is less than absolute returns. The results also indicate that the long memory parameter *d* has the values between 0.398 and 0.512 across the markets and maturities, implying that the crude oil futures returns are predictable which reject the efficient market hypothesis. These suggest that portfolio diversification across the two markets and within the maturities would not be profitable because they all exhibit similar features. The results of the diagnostic tests using the Box-piers test on the standardized residual reject serial correlation and the ARCH test reject heteroskedasticity in both the WTI and Brent markets at the different maturities.

6.6.8 Results of the HYGARCH Model

The estimated results of the HYGARCH model for the crude oil futures markets are presented in Table 6.11. The results indicate that the coefficient of the long memory parameters *d* is different from zero and significant in all the markets within the maturities. The estimated values reported are 0.569 and 0.955 in the WTI market while for Brent are 0.626 and 0.599 at one-month and three-month contract respectively. These results indicate that the crude oil futures returns have long memory in their autocorrelation which disappear slowing over time in all the markets and maturities. Although to my knowledge there is no study that applied the HYGARCH model to crude oil futures markets, the findings are similar with those of Hou and Saurdi (2011) and Wei et al (2010) in the oil spot market. These results support the FIGARCH, FIAPARCH and FIEGARCH model that the crude oil futures returns possess long memory behaviour in all the markets. These suggest that the markets will have low returns in the long term because their future prices are predictable and as a result, speculators profit more because they can take advantage of market opportunities. Thus, both the WTI and Brent markets have a similar pattern of long-term dependence in their returns, proving weak form inefficiency in the long term. Lastly, the results of the diagnostic test using the Box-piers test and ARCH test for serial correlation conducted confirm the fitness of the model. The Box-piers tests show that the standardised residuals of the crude oil futures prices are not serially correlated in all markets and maturities. The ARCH test also on the standardised residuals for the 10th order serial correlation indicate that the oil prices are homoskedastic in the two markets at the 1% level; results which suggest the absence of serial correlation on the residuals of the two crude oil futures return series.

Table 6.5 Estimated Results of the GARCH Model

	WTI-C1	WTI-C3	Brent-C1	Brent-C3
μ	0.094** (0.041)	0.100* (0.039)	0.108* (0.039)	0.104* (0.036)
ω	0.090** (0.050)	0.110* (0.043)	0.067* (0.029)	0.083* (0.040)
α	0.053* (0.019)	0.059* (0.016)	0.050* (0.012)	0.050* (0.015)
β	0.932* (0.025)	0.918* (0.022)	0.938* (0.015)	0.930* (0.022)
$\alpha+\beta$	0.985	0.977	0.988	0.980
Q(20)	15.64 [0.739]	22.02 [0.339]	25.93 [0.168]	17.28 [0.635]
ARCH(10)	0.650 [0.772]	1.020 [0.423]	1.600 [0.100]	0.999 [0.442]
Log(L)	-6358.7	-6114.3	-6243.9	-5974.7

Note: Figures in bracket are the standard errors in parenthesis below the parameters. Q (20) is the Box-piers test Q-statistics of order 20 for the standardised residuals. ARCH (10) is the t-statistics of the homoscedasticity test with 10 lags. P-values are reported in the square bracket. Significant at 1%, 5% and 10% level are represented by *, **, *** respectively. Log (L) represents the logarithm maximum likelihood function.

Table 6.6 Estimated Results of the EGARCH Model

	WTI-C1	WTI-C3	Brent-C1	Brent-C3
μ	0.068* (0.019)	0.084* (0.036)	0.094* (0.039)	0.095* (0.035)
ω	1.837** (0.147)	1.416** (0.148)	1.802* (0.165)	1.546* (0.134)
α	-0.356** (0.206)	-0.509** (0.120)	0.143** (0.582)	-0.507** (0.120)
β	0.983*** (0.008)	0.989*** (0.004)	0.985*** (0.006)	0.986*** (0.006)
γ	0.191** (0.050)	0.183* (0.036)	0.103** (0.052)	0.187* (0.046)
$\alpha+\beta$	1.339	1.493	1.128	1.493
Q(20)	15.94 [0.720]	22.41 [0.319]	24.94 [0.204]	17.37 [0.629]
ARCH(10)	0.653 [0.769]	0.700 [0.724]	1.631 [0.092]	0.791 [0.637]
Log(L)	-6359	-6082.6	-6254.4	-5974.2

Note: Figures in bracket are the standard errors in parenthesis below the parameters. Q (20) is the Box-piers test Q-statistics of order 20 for the standardised residuals. ARCH (10) is the t-statistics of the homoscedasticity test with 10 lags. P-values are reported in the square bracket. Significant at 1%, 5% and 10% level are represented by *, ** and ***, respectively. Log (L) represents the logarithm maximum likelihood function.

Table 6.7 Estimated Results of the APARCH Model

	WTI-C1	WTI-C3	Brent-C1	Brent-C3
μ	0.066*	0.059*	0.094*	0.085*
	(0.041)	(0.041)	(0.040)	(0.037)
ω	0.052*	0.057**	0.054*	0.054*
	(0.027)	(0.024)	(0.029)	(0.037)
α	0.051**	0.052*	0.050*	0.049*
	(0.209)	(0.015)	(0.014)	(0.016)
β	0.933*	0.934*	0.942*	0.939*
	(0.023)	(0.017)	(0.015)	(0.022)
γ	0.316**	0.501**	0.124**	0.257**
	(0.190)	(0.195)	(0.135)	(0.241)
δ	1.249**	1.283**	1.687**	1.452**
	(0.385)	(0.321)	(0.475)	(0.583)
Q(20)	15.94	21.19	26.06	17.63
	[0.720]	[0.386]	[0.164]	[0.612]
ARCH(10)	0.653	1.418	1.673	1.271
	[0.769]	[0.166]	[0.081]	[0.241]
Log(L)	-6359	-6101.5	-6242.5	-5971.4

Note: Figures in bracket are the standard errors in parenthesis below the parameters. Q (20) is the Box-piers test Q-statistics of order 20 for the standardised residuals. ARCH (10) is the t-statistics of the homoscedasticity test with 10 lags. P-values are reported in the square bracket. Significant at 1%, 5% and 10% level are represented by *, ** and ***, respectively. Log (L) represents the logarithm maximum likelihood function.

Table 6.8 Estimated Results of the FIGARCH Model

	WTI-C1	**WTI-C3**	**Brent-C1**	**Brent-C3**
μ	0.105*	0.110*	0.115*	0.113*
	(0.041)	(0.038)	(0.039)	(0.035)
ω	0.187**	0.142**	0.112**	0.159**
	(0.107)	(0.086)	(0.057)	(0.093)
β	0.649**	0.689**	0.716**	0.660**
	(0.100)	(0.094)	(0.075)	(0.089)
d	0.408**	0.406**	0.474**	0.372**
	(0.091)	(0.108)	(0.104)	(0.091)
φ	0.324**	0.387**	0.311**	0.373**
	(0.083)	(0.065)	(0.068)	(0.070)
Q(20)	15.70	21.82	24.69	17.23
	[0.735]	[0.351]	[0.214]	[0.638]
ARCH(10)	0.340	0.336	1.160	0.630
	[0.970]	[0.972]	[0.312]	[0.789]
Log(L)	-6245.4	-6115.5	-6245.4	-5975.7

Note: Figures in bracket are the standard errors in parenthesis below the parameters. Q (20) is the Box-piers test Q-statistics of order 20 for the standardised residuals. ARCH (10) is the t-statistics of the homoscedasticity test with 10 lags. P-values are reported in the square bracket. Significant at 1%, 5% and 10% level are represented by *, ** and ***, respectively. Log (L) represents the logarithm maximum likelihood function.

Table 6.9 Estimated Results of the FIEGARCH Model

	WTI-C1	WTI-C3	Brent-C1	Brent-C3
μ	0.082** (0.038)	0.075** (0.033)	0.095* (0.0 4)	0.108* (0.030)
ω	2.140* (0.321)	1.796* (0.332)	2.013* (0.336)	1.646* (0.321)
β	-0.617* (0.152)	-0.579** (0.274)	0.783* (0.295)	-0.628* (0.227)
γ	0.216* (0.041)	0.206* (0.036)	0.108** (0.053)	0.201* (0.036)
d	0.728* (0.053)	0.704* (0.054)	0.576* (0.183)	0.710* (0.062)
φ	0.380** (0.190)	0.410* (0.229)	0.303 (0.784)	0.380 (0.274)
Q(20)	14.97 [0.778]	21.35 [0.377]	26.06 [0.164]	18.64 [0.545]
ARCH(10)	0.516 [0.880]	0.590 [0.823]	1.405 [0.171]	0.768 [0.660]
Log(L)	-6353.3	-6106.4	-6252.5	-5974.1

Note: Figures in bracket are the standard errors in parenthesis below the parameters. Q (20) is the Box-piers test Q-statistics of order 20 for the standardised residuals. ARCH (10) is the t-statistics of the homoscedasticity test with 10 lags. P-values are reported in the square bracket. Significant at 1%, 5% and 10% level are represented by *, ** and ***, respectively. Log (L) represents the logarithm maximum likelihood function.

Table 6.10 Estimated Results of the FIAPARCH Model

	WTI-C1	WTI-C3	Brent-C1	Brent-C3
μ	0.074**	0.067**	0.107*	0.093*
	(0.053)	(0.038)	(0.031)	(0.037)
ω	0.181**	0.161**	0.151**	0.182**
	(0.067)	(0.051)	(0.064)	(0.080)
β	0.706**	0.721**	0.734**	0.693**
	(0.086)	(0.063)	(0.082)	(0.092)
γ	0.312**	0.509**	0.072**	0.279**
	(0.199)	(0.223)	(0.095)	(0.223)
δ	1.252**	1.241**	1.707**	1.444**
	(0.361)	(0.264)	(0.244)	(0.387)
d	0.487**	0.415**	0.512**	0.398**
	(0.101)	(0.094)	(0.124)	(0.107)
φ	0.318**	0.417**	0.293**	0.398**
	(0.075)	(0.065)	(0.079)	(0.107)
Q(20)	15.30	21.34	24.96	17.86
	[0.759]	[0.377]	[0.203]	[0.597]
ARCH(10)	0.506	0.453	1.140	0.566
	[0.887]	[0.920]	[0.327]	[0.843]
Log(L)	-6350.6	-6099.3	-6243.9	-5970.4

Note: Figures in bracket are the standard errors in parenthesis below the parameters. Q (20) is the Box-piers test Q-statistics of order 20 for the standardised residuals. ARCH (10) is the t-statistics of the homoscedasticity test with 10 lags. P-values are reported in the square bracket. Significant at 1%, 5% and 10% level are represented by *, ** and ***, respectively. Log (L) represents the logarithm maximum likelihood function.

Table 6.11 Estimated Results of the HYGARCH Model

	WTI-C1	**WTI-C3**	**Brent-C1**	**Brent-C3**
μ	0.105** (0.041)	0.106* (0.038)	0.116* (0.030)	0.114* (0.035)
ω	0.310** (0.147)	0.099 (0.080)	0.202** (0.098)	0.276** (0.122)
β	0.712* (0.114)	0.921* (0.060)	0.769* (0.111)	0.735* (0.097)
d	0.569* (0.144)	0.955* (0.136)	0.626* (0.196)	0.599** (0.149)
φ	0.261* (0.068)	0.092 (0.100)	0.238* (0.095)	0.271* (0.080)
Q(20)	16.15 [0.707]	22.16 [0.332]	26.06 [0.164]	16.91 [0.659]
ARCH(10)	0.349 [0.967]	0.342 [0.970]	1.141 [0.327]	0.534 [0.867]
Log(L)	-6357.6	-6110.5	-6244.1	-5972.9

Note: Figures in bracket are the standard errors in parenthesis below the parameters. Q (20) is the Box-piers test Q-statistics of order 20 for the standardised residuals. ARCH (10) is the t-statistics of the homoscedasticity test with 10 lags. P-values are reported in the square bracket. Significant at 1%, 5% and 10% level are represented by *, ** and ***, respectively. Log (L) represents the logarithm maximum likelihood function.

6.7 Summary and Conclusion

This chapter has examined long-term dependence in the West Texas Intermediate and Brent crude oil futures markets, using daily data from January 2000 to May 2011. It contributes to the existing literature by investigating long memory in different crude oil futures markets within maturities and also addresses the asymmetric leverage effect in their oil futures returns volatility. Theoretically, it is argued that evidence of long memory in asset prices means that past information can be used to forecast returns, an indication of market inefficiency in the weak form. GARCH class-models that account for short- and long-term persistence in prices were applied to model the behaviour of the crude oil futures returns. The results of this chapter have several implications because policy makers want better knowledge on the informational efficiency of oil futures prices and furthermore, investors want to know whether portfolio diversification across different crude oil markets or maturities reduces investment risk and uncertainty.

Empirical results show that the fractional integrated GARCH models - the FIGARCH, FIEGARCH, FIAPARCH and HYGARCH model which captures long memory in conditional volatility - indicates high persistence, with the parameter *d* being significant in both the WTI and Brent crude oil markets at different maturities. The results suggest that returns volatility in the two crude oil markets have long memory behaviour, contrary to the weak form efficient hypothesis. The results are consistent with Tabak and Cajueiro (2007), Cunado et al (2010), Wang et al (2010) and Arouri (2012) (see Table 6.1). They further indicate that the short memory models, GARCH, EGARCH and APARCH, also confirm the presence of a high degree of persistence in all the crude oil futures returns, which dies at an exponential rate at the different maturities. The results, consistent with that of Wang et al (2010) and Arouri (2012), support the hypothesis that returns can be predicted using past information, which implies that the oil prices do not incorporate all the necessary information in both markets at different maturities. Lastly, the results also show that the results of the asymmetric models (the EGARCH, APARCH, FIEGARCH and FIAPARCH models) provide evidence of a leverage effect in the WTI and Brent market at different maturities. These findings suggest that the response to good news (positive shock) of oil futures prices in both markets is followed by higher volatility than bad news (negative shock) of the same degree, results consistent with those of Cheong (2009), Wei et al (2010) and Hou and Suardi (2011) in the oil spot markets. The major implication of the results is that investors would not profit more from portfolio diversification across the two oil markets and within the maturities because, even though WTI shows larger persistence than Brent, they all exhibit similar features. Furthermore, speculative activities will be profitable because past information can be used to help exploit arbitrage opportunities in both the short and long term. It can be suggest, based on the results that the long-term dependence in the crude oil prices may be caused by a number of reasons: first, there may be an increase in investment, based on past information about prices that is attributed to high expectations of future returns. Second, it may be that the investors respond sequentially to the arrival of new information, causing time-varying dependence in oil prices because each takes decisions based entirely on his own perception. Thirdly, the high fluctuation in oil prices may have increased uncertainty in the mind of the market participants, leading them to shift their investment to the spot market; as a result the oil futures prices are determined from spot prices.

The results from this chapter lead us to conclude that the WTI and Brent crude oil futures prices show higher persistence and exhibit long memory properties in all maturities, which reveal that although WTI shows larger persistence than Brent in all the maturities, the international oil futures markets have a similar pattern. Additionally, the results indicate that the WTI and Brent oil spot and futures prices exhibit similar pattern in term of long term dependence. The findings show that the markets violate the weak form efficient hypothesis within the maturities in the long term.

CHAPTER SEVEN

Summary and Conclusion

7.1 Summary of Results

Oil prices have been highly volatile since the price shock of the 1970s and the oil futures market was established during the 1980s as a mechanism for price discovery and risk management as a consequence of the high risk and uncertainty which continues to surround them. However, the price of oil has continued to increase and during the last decade it became even more volatile, which may result in market inefficiency. Evidence of inefficiency in the futures market implies that hedging and portfolio diversification would be ineffective, while speculative and arbitrage opportunities can be exploited. The broad objective of this thesis is to examine the performance of the WTI and Brent crude oil futures markets by addressing four important issues: firstly, the unbiasedness of the oil futures markets; the price discovery of the oil futures markets; the price change and trading volume relationship in the oil futures markets, and finally the long memory properties of the oil futures markets. The thesis applies different methodological approaches and data of different frequencies in the analysis covering the period 2000 to 2011 (with the exception of the third case, which begins from 2008). Its findings have significant implications for hedgers, speculators, regulators, financial analysts and policymakers.

The empirical results show that the oil futures markets are unbiased in the long term, the markets perform their price discovery and risk management functions and their trading volume cannot help to improve the short term forecast of future returns supporting market efficiency. However, the result also indicates strong evidence of short term inefficiency and the multi-market and multi-contract efficiency are not supported in the markets at all maturities. Moreover, the findings show evidence of long memory in the oil futures prices returns. Overall, the results support the efficiency of the oil futures markets; however, it cannot be generalized because the markets also show sign of inefficiencies in the short term. The thesis therefore concludes that the efficiency of the oil futures markets varies across maturities, framework and models.

7.2 Reconsideration of the Research Objectives

This thesis adds to the understanding of the performance of the crude oil futures markets by examining four important objectives as specified in chapter one. The results obtained provide strong evidence which proofs that these objectives have been met. Firstly, the short- and long-term efficiency of the crude oil futures markets is examined by testing the unbiasedness hypothesis; that is, whether the price of crude oil futures has the ability to predict the expected spot price. It also investigates the multi-market and multi-contract efficiency as evidence for the semi-strong form efficient hypothesis. The findings suggest that the crude oil futures price is unbiased in predicting the expected spot price in both the WTI and Brent markets in all and one-month maturity, respectively, indicating that they are weak form efficient in the long term. The results are not surprising because the WTI market has more liquidity and a larger trading volume, attracting more investors and thus increasing its efficiency. Additionally, the results support the theory that the existence of co-integration between the spot and futures prices does not imply market efficiency as seen in the case of the Brent market at three-month contracts. The results also indicate that the oil markets reject the unbiasedness hypothesis in the short term within the maturities. In particular, it is found that the presence or absence of a time-varying risk premium does not contribute to the short term inefficiencies because it is insignificant in explaining the predictive power of the futures price regarding the expected spot price. Finally, in the multi-contract analysis, the results indicate that the crude oil markets support the efficient market hypothesis at one-month maturity, while that of the multi- market analysis shows only three-month contract in the WTI market. The results obtained indicate that objective one was met.

Secondly, the thesis examines the price discovery relationship between the crude oil spot and futures markets and across contracts, with a view to establishing which market or contract is more efficient and reducing price risk in the international oil markets. The main finding is that the empirical results indicate that the futures markets react first to new pricing information in all the maturities in both the short and long term. The results also suggest that the contribution to price discovery is greater at three-month contracts to maturity in all the markets. Furthermore, the results of the cross-contract analysis show that new pricing information is reflected first in the three-month contract in the long term while the one-month contract dominates price discovery process in the short term and in all the markets. These results also confirm that the three-month contract impounds more information than the one-month contract in price discovery in the long term. The results indicate that objective two was achieved.

Thirdly, the thesis examines the dynamic relationship between price changes and trading volume in the crude oil futures markets. The result indicates that both the oil futures markets reject positive relationship between price change and trading volume over the sample period. These results suggest that trading volume and returns are not driven by an exogenous variable, information flow, contradicting the mixture of distribution hypothesis. The results regarding the ability of the trading volume to forecast returns indicate that the two variables cannot provide useful information that can assist in one predicting the other. This suggests that there is no causality from returns to trading volume, therefore contradicting the noise trader model and the sequential arrival hypothesis which argues bi-directional causality between the variables. The findings provide strong evidence which shows that neither the positive nor causal relationship exists between price changes and trading volume in the oil futures markets. The results show that objective three was met.

Lastly, the thesis investigates the long memory properties of the crude oil futures markets. The results presented shows that the fractional integrated GARCH models indicate that the crude oil futures markets returns are characterised by long memory properties, with the parameter d being significant in both the crude oil markets at different maturities. The results suggest that the oil futures returns have predictability components because their autocorrelation dissipates at a slow hyperbolic rate. The results of the short memory models also confirm the presence of a high degree of persistence in oil returns, rejecting the weak form efficient hypothesis. More so, the results indicate the presence of an asymmetric leverage effect in the crude oil futures markets returns at different maturities, suggesting that the response of oil futures prices to positive shock in both markets is followed by higher volatility than its response to negative shock of the same degree. The findings indicate that the international crude oil futures markets exhibit long range dependence in their returns volatility at different maturities. The results show that objective four was achieved.

7.3 Contributions and Policy Implications

This thesis contributes to knowledge on the efficiency of the oil futures markets in the following ways: First, the thesis provide evidence on the short term efficiency of the oil futures markets allowing for a constant and a time varying risk premium, and also investigates the multi-market and multi-contract efficient hypothesis which to the best of my knowledge no previous study has done. The results suggest that both the long-term and short-term efficiency of the oil markets should be considered when developing strategies and policies because this will provide insight into their overall efficiency. Focusing on long-term efficiency alone may result in the introduction of ineffective measures as evidence has shown that the oil markets are inefficient in the short-term. Again, the interest in controlling the existence of risk premium between spot and futures prices will have an insignificant impact on the reduction of market inefficiencies, and therefore factors like high speculation, investor's behaviour and other market fundamentals, among others, should be taken into account in policymaking. It is also suggested that policymaking and research conducted in this area should not be restricted to the weak-form efficiency of the markets, because the results from the multi-market and multi-contract analyses clearly indicate that rational investors can use other information to exploit arbitrage opportunities across contracts and markets. As a result, measures that would reduce the forecast ability of futures prices using any outside information are needed to improve the performance of these markets. Moreover, the interaction of the international oil markets (or contracts) should be taken into account in decision-making for sound policies and portfolio management strategies, and in line with this there is a need to increase the collective efficiency of both the crude oil futures markets and contracts.

Furthermore, the thesis extends the previous studies that focus on price discovery between the spot and futures markets as it provides new insight on price discovery in the international oil markets across maturities. The result suggests that market participants prefer to use futures prices to trade crude oil in the international market, which results in them impounding more information than spot prices. The results also indicate that the futures contracts for different maturities do not respond to new information instantaneously because the three-month contract dominates price discovery in the long term and the relationship changes in the short term with one month dominating the process. This suggests that investors should focus on three-month contracts because the markets are more efficient at this maturity in the long term. The thesis suggest the need for strategies and policies that would ensure instantaneous response of crude oil futures contracts to new information flow in order to control the dominant role of different contracts in the process of price formation and increase market efficiency. Regulators concerned with market integration should also understand that policies designed to reduce the high price risk in the futures market will be inappropriate in the spot markets because they do not impound new information at the same time.

Another contribution of this thesis is that it increase understanding of the price change and trading volume relationship in the oil futures markets, an important area previously ignored in the literature. Despite the fact that oil futures contract is the world's largest traded commodities and oil prices have been highly volatile, there is little evidence on this relationship which focus mainly on the WTI market. The results provide evidence that daily price movement and trading volume do not respond to the same information flow and therefore the measures that control price volatility may not have impact on volume of trade as shown in chapter five. Thus, the strategies that focus on regulating trading volume should be introduced in order to have fruitful outcomes. Moreover, traders and investors who participate in oil futures should not base their decisions on past trading volume because it will lead to profit loss; the results also have implications for market efficiency as past information cannot assist speculators in forecasting futures returns in all the markets.

Finally, the thesis provide new evidence on long memory in the international oil futures markets across maturities using the GARCH models which to the best of my knowledge there is no study of this kind, with implications for portfolio diversification and policymaking. The results suggest that the international oil markets are characterized with high persistence in long memory at different maturities a feature similar to that of the spot prices. Specifically, the thesis recommends the need for effective strategies that would prevent sequential arrival of news across the oil markets and maturities, in order to avoid long term dependence of information. More importantly, there is also a need to control the correlation of information regarding oil prices over different time periods. Finally, policy makers and regulators should investigate different issues when considering policy analysis in order to understand the behaviour of these markets and help develop sound measures and strategies for the oil markets and the global economy.

7.4 Limitations of the thesis and Recommendations for Future Research

There are some limitations and recommendations of this thesis which needs to be acknowledged. First, the short term and long term efficiency in the oil markets is tested using the sample data for ten year period and the existence of time-varying risk premium is considered only in the short term which limits the generalization of the findings. Future studies could therefore investigate the short- and long-term efficiency using data for longer period, and could also account for the existence of time-varying risk premium in the long term. Future research might investigate the multi-market and multi-contract efficient hypotheses in these markets in the short term; the results may be different from those of the long-term analysis because efficiency may vary across the markets and maturities. The semi-strong form efficiency test can also be conducted using macroeconomic variables such as GDP, foreign exchange, interest rates and stock indexes among others, because they have a significant impact on oil prices.

Another weakness is that the thesis analysed price discovery in the oil markets using models that account for transitory shock while results may be different with those that consider permanent shock. Future studies should investigate price discovery using structural measures such as the Price Discovery Efficiency Loss (PDEL) and the Adjustment Share Approach recently developed by Yan and Zivot (2010) and Kim (2011), respectively. These measures model how fast the market adjusts to permanent shock in the long run. Research could also be conducted on price discovery in the oil markets around transitory factors such as macroeconomic announcements, volatility, liquidity, and so on, because they can drive price dominance between the spot and futures markets.

Additionally, the thesis investigates price-volume relationship in oil markets only at one-month futures contract to maturity using data for two years. It is suggested that the future study should investigate this relationship across maturities and markets to help understand whether the relationship between the variables is still the same in different contracts. Another proposal is that price change and trading volume relationship be examine using alternative, more advanced models such as the dynamic correlation analysis (DCC) or smooth transition regression which may provide new evidence.

Lastly, the long memory in the oil returns is modelled in this thesis using the GARCH models without accounting for structural breaks as some researchers, such as Thupayagale (2010), have argued that it may lead to spurious results. A significant recommendation for future study is to examine long memory in oil futures markets across maturities by accounting for the existence of structural breaks. It would also be interesting to investigate long memory in the crude oil futures markets across maturities with other approaches such as the Multifractal detrended fluctuation analysis and rescaled analysis and so on, because they consider time-scaling in order to confirm the findings.

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