UNIVERSITY OF MINES AND TECHNOLOGY (UMaT),

TARKWA

FACULTY OF ENGINEERING

DEPARTMENT OF MATHEMATICAL SCIENCES

A THESIS REPORT ENTITLED

COINTEGRATION ANALYSIS OF THE RELATIONSHIP BETWEEN THE PRICES OF CRUDE OIL AND PETROLEUM PRODUCTS IN GHANA

BY

BELINDA KOASIBA ETTIH

SUBMITTED IN FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF PHILOSOPHY IN FINANCIAL ENGINEERING

THESIS SUPERVISORS

DR LEWIS BREW

&

DR ERIC NEEBO WIAH

TARKWA, GHANA

MARCH, 2020

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DECLARATION

I declare that this thesis is my own work. It is being submitted for Masters of Philosophy in Mathematics (Financial Engineering) in the University of Mines and Technology, Tarkwa. It has not been submitted for any master's degree or examination in any other university.

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(Signature of Candidate)

……. Day of …………. 2020.

ABSTRACT

This research work sought to investigate the relationship between crude oil prices, dollar-cedi exchange rate and the prices of petroleum products in Ghana. The nation depends heavily on crude oil and its refined products for almost all productive economic activities. The research is based on a monthly data of Brent crude oil, gasoline, gas oil, residual fuel oil and premix fuel for the period from January 2009 to June 2019. The Autoregressive Distributed Lag (ARDL) Bounds cointegration test was employed to show the existence of a long run relationship between crude oil prices and the prices of gasoline, gas oil and residual fuel oil. Results from the cointegration test revealed the inexistence of a long run relationship between the prices of crude oil and premix fuel prices. An ARDL based error correction model (ECM) was used to estimate the short and long run effect of between the variables. It was established that crude oil prices have a significant positive effect on the prices of gasoline, gas oil and residual fuel oil in both the short and the long run. Exchange rate had a significant negative effect on the prices of Gasoline, Gasoil and Residual fuel oil in both the short and long run. Inflation on the other had had a significant positive effect on only the prices of Residual fuel oil in both the short and the long run. Results from the Wald's Granger Causality test indicated a uni-causal relationship running from Crude oil to Gasoline, Gas oil and RFO. There is a bi-causal relationship between Exchange rate and Gasoline, Gas oil and RFO. There is a uni-causal relationship running from Inflation rate to RFO. There is no causal relationship between Inflation rate and Gasoline, Gas oil.

DEDICATION

This thesis work is dedicated to my parents, Benneth Kaku Ettih and Grace Ettih, who always believed in me and motivated me to go higher in life.

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Crude oil is presently one of the most important sources of energy and commodity in the global economy (De Salles and Almeida, 2017). The energy, industrial, domestic, transportation and economic sectors heavily depend on crude oil. According to Clews (2016) Crude oil is a mixture of hydrocarbons (compounds composed mainly of hydrogen and carbon), though it also contains some nitrogen, sulfur, and oxygen. These hydrocarbons were formed from plants and animals that lived millions of years ago. These elements form a large variety of complex molecular structures, some of which cannot be readily identified. Regardless of variations, almost all crude oil ranges from 82 to 87 percent carbon by weight and 12 to 15 percent hydrogen by weight. It is found in vast underground reservoirs where ancient seas were located.

Crude oil according to Eneh (2011) has two main uses: as a fuel and also as a synthesis of organic compounds. Crude oil has been a source of energy for heating, lighting and locomotion and particularly the most convenient fuel for the internal combustion engine. This has increased rapidly in importance with the coming of the motor car and a wide range of other applications of internal combustion engine (Eneh, 2011). By 1965, about 80% of the world organic chemicals were synthesized from petroleum. This figure rose to 98% in 1980 and 99% in the year 2000. Thus, commercially important ones include gasoline and kerosene (Arene and Kitwood, 1979).

Crude oil is usually black or dark brown, but can also be yellowish, reddish, tan, or even greenish extracted with giant drilling machines. Variations in color indicate the distinct chemical compositions of different supplies of the crude oil. After crude oil is removed from the ground, it is sent by pipeline, ship or barge to a refinery, where different parts of the crude oil are separated into useable petroleum products (Eneh, 2011).

Filtration separates sand and other solid matters from the crude oil which can stand in reservoir for the denser water to form a lower layer from the oil layer above (Shama, 2002). The latter is pumped through pipelines to the refinery, where continuous distillation or fractionation separates the crude oil into a number of 'cuts' or fractions of different boiling ranges (Shama, 2002). Crude oil when refined produces gasoline which is an important product in our everyday lives and other useful petroleum products.

Petroleum products are usually grouped into four categories: light distillates (Liquified Petroleum Gas (LPG), gasoline, naphtha), middle distillates (kerosene, jet fuel, diesel), heavy distillates and residuum (heavy fuel oil, lubricating oils, wax, asphalt) (Speight, 2015).

Crude oil is measured in Barrels (bbl). A 42-U.S. bbl. of crude oil provides slightly more than 44 gallons of petroleum products. One barrel of crude oil, when refined, produces about 19.6 gallons of gasoline, 10 gallons of diesel, 4 gallons of jet fuel, 1.7 gallons of heavy fuel oil, 1.7 gallons of liquefied petroleum gas as well as 7.6 gallons of other petroleum products (Eneh, 2011).

1.2 Statement of the Problem

Crude oil prices continue to be the main driver of petroleum products prices (Mandal *et al.,* 2012). The movement of crude oil price can affect not only the consumption and production expenditures, but also future investment decisions. Since 1989, economists have conducted several researches on how crude oil and products prices more especially gasoline prices adjust over time. One observation is that changes in crude oil prices are not instantly reflected in changes in spot or wholesale gasoline prices, and changes in those prices are not instantly reflected in retail prices.

Owing to the importance of gasoline and other petroleum refinery products in consumers' budgets and the economy as a whole, the price of these products is of acute interest to the public and to policy-makers. There is a remarkable interest in the relationship between the prices of crude oil and other commodities due to the need to understand the key characteristics and determinants of long-term and short-term price movements in petroleum products (Bakhat and Würzburg, 2013).

Crude oil prices are determined by the world oil market and therefore, both consuming and producing countries suffer the shocks of the market (Bjørnland, 2009). Hence, the two most important determinants of petroleum product prices in the local markets are crude oil prices (denominated in US dollars (USD)) and local currency-USD exchange rate (Berument *et al.*, 2014).

Because fuels are an important factor of production in transport and industry, etc., they determine the rate of overall price growth (Peltzman, 2000). As a result, they have a significant effect on the course of economic growth. The fuel industry is important because crude oil-based products actually do not have substitutes. This means that economies are heavily dependent on crude oil and its products. The Ghanaian economy most especially, is heavily dependent on crude oil and related products for almost all productive economic activities ranging from electricity generation, transportation and manufacturing industries which makes it crucial to know the factors affecting the prices of refinery of the products (Marbuah, 2017).

Among the numerous researches into the price relationships between crude oil and its products are that of Elgowainy *et al.* (2014) who researched into the relationship between crude oil prices and diesel prices in China. In the United States of America, Weinhagen (2018); Bachmeier and Griffin (2003) studied the relationship between the prices of crude oil and gasoline whereas Kaufmann and Laskowski (2005) researched into the relationship between the prices of crude oil and home heating oil.

Pokrivčák and Rajčaniová (2011) investigated the relationship between prices of crude oil and gasoline prices in Germany. Aduda *et al.* (2018) also looked at the cointegration relationship between the prices of crude oil and distillate fuels from the world market perspective.

Most of these existing works payed attention to the relationship between the prices of crude oil and gasoline whiles few focused on the middle distillates. That notwithstanding, as far as Ghana is concerned, there are few studies that explored the price relationship between crude oil and petroleum products.

Hence the main aim of this study is to examine the relationship between the prices of crude oil and its product prices taking into consideration a product in each category (Gasoline, Gas oil, Residual fuel oil and Premix) of its refined products in Ghana.

1.3 Research Objectives

The objectives of the research are to:

i. establish the cointegration relationship between prices of crude oil and petroleum products
ii. determine the short term and long-term effects of the prices of crude oil on its products
iii. examine the causal relationship between prices of crude oil and petroleum products

1.4 Methods Used

The methods and procedures to be used include:

i. reviewing of relevant literature
ii. data collection
iii. testing for unit root of the data by using the ADF, PP and the KPSS tests
iv. applying the Johansen test to determine whether cointegration exist between the independent variables
v. formulation of the cointegration model and estimation of the Long-run relationship between the prices of Crude oil and Petroleum products
vi. employing the Granger causality test to examine the direction of the causal relationship between the dependent and independent variables.

1.5 Organisation of the Thesis

This thesis is structured into five chapters. Chapter 1 is the introductory chapter that accounts for the background of crude oil and its refined products, the statement of the problem, the objectives of the research and finally the methods employed to achieve the stated objectives. Chapter 2 entails the review of literature relevant to the study. Chapter 3 explains the methods employed to achieve the objectives of the research. Chapter 4 presents the analyses of the data and discussions of the results. Conclusions and recommendations are finally captured in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter is divided into five subsections. The first section describes the variables employed in the research. The second subsection highlights on petroleum refining and market institutions. The third part is on the prices of crude oil and petroleum products. The fifth part presents the theoretical review of the research whereas the final subsection focuses on the empirical review of related works.

2.2 Brief Description of Variables

The dependent variables used in this research includes the prices of Gasoline, Gas oil, Residual Fuel oil and the Premix fuel. Crude oil (Brent crude oil) prices, exchange rate and inflation rate were captured as the independent variables.

2.2.1 Brent Crude Oil

The price of crude oil in international markets is considered the most important factor in the gasoline and diesel prices because it represents the largest component of the producing and marketing cost. World crude oil prices are established in relation to three market traded benchmarks (Aduda *et al.,* 2018): West Texas Intermediate, Brent Blend and Dubai/Oman. The Brent crude oil is extracted from the North Sea and is the most imported by the European countries. The type of benchmark crude oil used in the research is the Brent crude oil. A benchmark crude oil is a crude oil that serves as a reference price for buyers and sellers of crude oil. There are three primary benchmarks, West Texas Intermediate (WTI), Brent Blend, and Dubai Crude. Other well-known blends include the OPEC Reference Basket used by OPEC, Tapis Crude which is traded in Singapore, Bonny Light used in Nigeria, Urals oil used in Russia and Mexico's Isthmus. Benchmarks are used because there are many different varieties and grades of crude oil and thus using benchmarks makes referencing types of oil easier for sellers and buyers.

The Brent was used as the benchmark for the prices of crude oil since petroleum production from Africa tends to be priced relative to this oil type.

2.2.2 Gasoline

Gasoline also known as Petrol is a colorless petroleum-derived flammable liquid that is used primarily as a fuel in most spark-ignited internal combustion engines (Mehlman, 1990). It consists mostly of organic compounds obtained by the fractional distillation of petroleum, enhanced with a variety of additives. Gasoline is the most important refinery product. It is a blend of relatively low-boiling hydrocarbon fractions, including reformate, alkylate, aliphatic naphtha (light straight-run naphtha), aromatic naphtha (thermal and catalytic cracked naphtha) and additives. Gasoline blending stocks have boiling points which range from ambient temperatures to about 204 °C, and a flashpoint below 40 °C (Baumbach *et al.*, 2003). The critical qualities for gasoline are octane number (anti-knock), volatility (starting and vapour lock) and vapour pressure (environmental control). Additives are used to enhance gasoline performance and provide protection against oxidation and rust formation. On average, a 42-U.S.-gallon (160-liter) barrel of crude oil yields about 19 U.S. gallons (72 liters) of gasoline (among other refined products) after processing in an oil refinery, though this varies based on the crude oil assay (Mehlman, 1990).

2.2.3 Gas Oil

The Gas oil which is also known as the diesel fuel in general is any liquid fuel used in diesel engines, whose fuel ignition takes place, without any spark, as a result of compression of the inlet air mixture and then injection of fuel (Knothe *et al.,* 2006). Diesel fuels are light-coloured mixtures of paraffins, naphthenes and aromatics, and may contain moderate quantities of olefins. Distillate fuels have flashpoints above 60 °C and boiling ranges of about 163 °C to 371 °C, and are often hydrodesulphurised for improved stability (Knothe *et al.,* 2006). Distillate fuels are combustible and when heated may emit vapours which can form ignitable mixtures with air. The desirable qualities required for distillate fuels include controlled flash- and pourpoints, clean burning, no deposit formation in storage tanks, and a proper diesel fuel cetane rating for good starting and combustion (Knothe *et al.,* 2006). One of the main users of gas oil is the construction sector, with excavators, generators, cranes, dumper trucks and lots of other machines and vehicles.

2.2.4 Residual Fuel Oil

Residual fuel oil is a general classification for the heavier oils, known as No. 5 and No. 6 fuel oils, that remain after the distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations (Anon., 2005). Residual fuel oils contain traces of metals and may have entrained hydrogen sulphide, which is extremely toxic. Residual fuels which have high cracked stocks boiling above 370 °C contain carcinogenic PAHs. Repeated exposure to residual fuels without appropriate personal protection, should be avoided, especially when opening tanks and vessels, as hydrogen sulphide gas may be emitted. The primary end use for residual fuel oil is as a fuel in simple furnaces such as power plants and industrial boilers. It is also the primary fuel used on ocean-going ships, where it is called bunker fuel (Anon., 2005).

2.2.5 Premix Fuel

According to the National Petroleum Authority, the refinery of crude oil produces a purposely made fuel known as premix for fisher folks who use outboard motors. It is a blend of marine mix lubricants and gasoline in the ratio 1: 29. Premix is suitable for two stroke engines (Anon., 2019).

2.2.6 Exchange Rate

In finance, an exchange rate between two currencies is the rate at which one currency will be exchanged for another (Saeed, 2012). It is also regarded as the value of one country's currency in terms of another currency. Exchange rates are determined in the foreign exchange market, which is open to a wide range of different types of buyers and sellers, and where currency trading is continuous (Kirui *et al.*, 2014). The spot exchange rate refers to the current exchange rate. The forward exchange rate refers to an exchange rate that is quoted and traded today but for delivery and payment on a specific future date. In the retail currency exchange market, different buying and selling rates will be quoted by money dealers. Most trades are to or from the local currency.

The buying rate is the rate at which money dealers will buy foreign currency, and the selling rate is the rate at which they will sell that currency. The quoted rates will incorporate an allowance for a dealer's margin (or profit) in trading, or else the margin may be recovered in the form of a commission or in some other way. Different rates may also be quoted for cash usually notes only (Saeed, 2012), a documentary form such as traveler's cheques or electronically (such as a credit card purchase). The higher rate on documentary transactions has been justified as compensating for the additional time and cost of clearing the document. On the other hand, cash is available for resale immediately, but brings security, storage, and transportation costs, and the cost of tying up capital in a stock of banknotes.

The US dollar is the currency of international crude oil trading. Exchange rate variations in the U.S. dollar can affect the world price of oil because oil is priced in US dollars and generally paid for in US dollars. The idea that there is a relationship between oil prices and exchange rates has been around for some time (Golub, 1983). Bloomberg and Harris and Zabka (1995) provide a good description, based on the law of one price, of how exchange rate movements can affect oil prices. Commodities like oil are fairly homogeneous and internationally traded. The law of one price asserts that as the US dollar weakens relative to other currencies, ceteris paribus, international buyers of oil are willing to pay more US dollars for oil.

2.2.7 Inflation Rate

Inflation is the percentage change in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as monthly, quarterly or yearly (Kuwornu and Owusu-Nantwi, 2011). It also refers to the general increase in the prices of goods and services in the economy. Price increase reduces the purchasing power of money that in turn has an adverse impact on consumers' welfare. The common measures of inflation include: Consumer Price Indexes (CPIs), Producer Price Indexes (PPIs) or Wholesale Price Indexes (WPIs), commodity Price Indexes, Core Price Indexes, GDP deflator, Asset Price Inflation and Employment Cost Index (ECI). Inflation is usually estimated by calculating the inflation rate of a price index.

The inflation rate reflects the annualised percentage change in the consumer price index, which tracks the rate of change in the prices of goods (such as petrol) and services purchased by consumers (Kuwornu and Owusu-Nantwi, 2011). The impact of petrol price changes on inflation and the vice versa occurs directly by virtue of petrol being part of the CPI basket and indirectly through its impact on the prices of other non-petrol products that use energy products in the CPI.

2.3 Petroleum refining and market institutions

According to Gary *et al.* (2007), Crude oil in its natural state has no value to consumers and must be transformed into products that can be used in the marketplace such as gasoline and diesel. Thus, crude oil producers must sell and transport their products to refineries. The market for crude oil involves many players, including refiners, speculators, commodities exchanges, shipping companies, integrated oil companies, international oil companies, national oil companies, independents, and OPEC. Various physical and chemical methods are used in refining processes. Heat, pressure, catalysts, and chemicals are applied under widely varying process designs, operating conditions, and chemical reactions to convert crude oil and other hydrocarbons into petroleum products. The first refineries to process crude oil used existing coal oil refineries or were built where oil was found. Early refineries were simple devices that used large horizontal tanks to heat oil to separate the volatile components. The world's first oil refinery opened at Ploiesti, Romania, in 1856. In the United States, the first refinery opened in 1861. Over subsequent decades, the development of electricity and the advent of the internal combustion engine significantly impacted the demand for refined products, with ever-increasing amounts of gasoline and diesel fuels required in place of kerosene.

Petroleum refining has evolved continuously in response to changing consumer demand for better and different products. The original requirement for the refining process was to manufacture kerosene as a cheaper and better source of lighting fuel than the whale oil. Internal combustion engine invention has contributed to the production of benzene, gasoline, and diesel fuels (Shama, 2002). The evolution of the airplane created a need for high-octane aviation gasoline and jet fuel, which is a sophisticated form of the original refinery product, kerosene. Present-day refineries produce a variety of products, including many which are used as feedstocks for cracking processes and lubricant manufacturing, and for the petrochemical industry. These products can be broadly classified as fuels, petrochemical feedstocks, solvents, process oils, lubricants and special products such as wax, asphalt and coke (Shama, 2002).

Refining begins with distillation by boiling crude into separate fractions or cuts. All crude oils undergo separation processes through distillation, and so it is common to express the capacity of a refinery in terms of its distillation capacity (Young, 2006). The resultant products are directly related to the characteristics of the crude oil being processed. Most of these products of distillation are further converted into more useable products by changing their physical and molecular structures through cracking, reforming and other conversion processes. These products are subsequently subjected to various treatment and separation processes, such as extraction, hydro treating and sweetening, in order to produce finished products. Whereas the simplest refineries are usually limited to atmospheric and vacuum distillation, integrated refineries incorporate fractionation, conversion, treatment and blending with lubricant, heavy fuels and asphalt manufacturing; they may also include petrochemical processing.

Two measures are commonly used: Barrels per Stream Day (BPSD) and Barrels per Calendar Day (BPCD). A barrel per stream day is the maximum number of barrels of input that a distillation facility can process when running at full capacity under optimal crude and product slate conditions with no allowance for downtime. A barrel per calendar day is the amount of input that a distillation facility can process under usual operating conditions, making allowances for the types and grades of products to be manufactured, environmental constraints, and unscheduled and scheduled downtime due to maintenance, repairs, and shutdown (Gary *et al.*, 2007).

The petroleum industry consists of three distinct sectors: exploration and production (upstream); refining and marketing (downstream); and the transportation infrastructure used in shipping crude oil and refined petroleum products (midstream) (Gary *et al.*, 2007). Refining is the process of transforming crude oil into petroleum products ranging from gasoline, kerosene and distillate fuel oil to heavier products such as asphalt; some refineries, especially those with small distillation capacity, may not produce gasoline at all but instead may produce only asphalt. Some petroleum companies are fully vertically integrated across industry sectors, while others may operate within a subset of the distinct industry sectors (Zavaleta *et al.*, 2015).

Petroleum refining processes and operations are classified into five basic types (Shama 2002):

- Distillation which is the separation of crude oil in atmospheric and vacuum distillation columns into groups of hydrocarbon compounds based on molecular size and boiling-point ranges.
- Conversion processes change the size or structure of hydrocarbon molecules by Decomposition: Breaking down large molecules into smaller molecules with lower boiling points through cracking and related processes. Unification: Building small molecules into larger molecules through alkylation, polymerization, and related processes. Reforming: Rearranging molecules into different geometric structures in isomerization, catalytic reforming, and related processes (Shama, 2002).
- Treatment processes prepare hydrocarbon streams for additional processing and to prepare finished products using chemical or physical separation. Processes include desalting, hydrodesulfurization, solvent refining, sweetening, solvent extraction, and dewaxing.

- Blending is the process of mixing and combining hydrocarbon fractions, additives, and other components to produce finished products with specific performance properties.

A graphical representation of the refining process of crude oil is shown in Figure 2.1

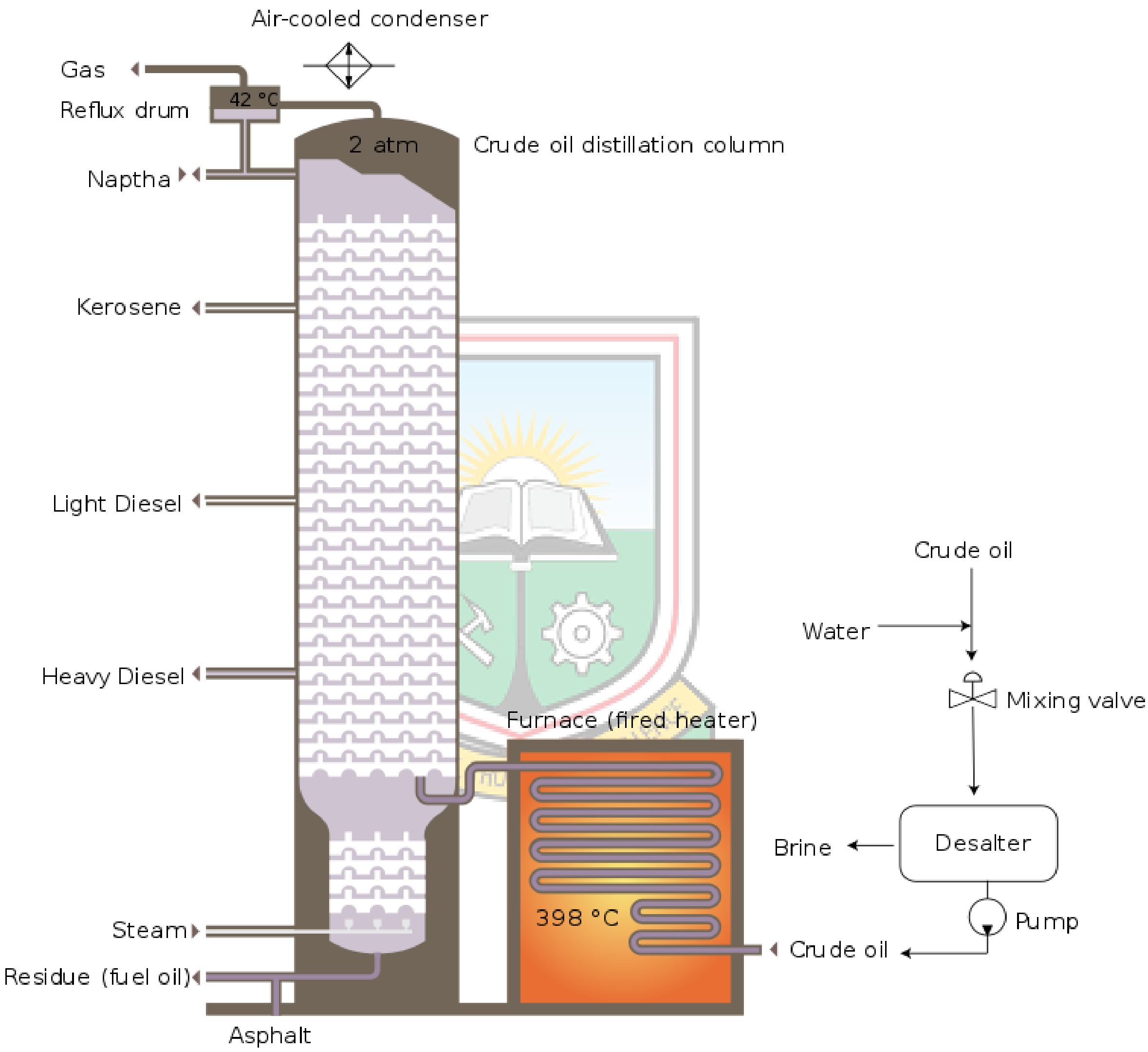

Figure 2. 1 Crude Oil Refining Processes (Shama, 2002)

2.4 Crude Oil Prices and Product Prices

Prices of petroleum products are closely linked by the technology and economics of re fining to the price of crude oil. The price of oil is determined on a world market, and its availability can change dramatically within a very short period of time (Bharati *et al.*, 2012). The price of oil also strongly influences the prices of refined products and primary fuels depending on market conditions. Crude oil prices are a fundamental determinant of gasoline prices. Crude oil and refinery petroleum products, especially gasoline and the middle distillates, have generally followed a similar path over the past 2 decades. Refined product prices have historically reacted to changes in the acquisition cost of crude oil in both directions, with falling crude prices leading to declines in refined product prices, and vice versa (Lichtblau *et al.*, 2004).

The U.S. Energy Information Administration (EIA) estimates that, in 2017, the cost of crude oil contributed 50% to the retail cost of a gallon of gasoline in the United States, down from 57% in December 2014. The remaining cost includes 19% taxes, 17% distribution and marketing costs, and 14% refining costs. The corresponding figures for diesel are 45% crude oil, 20% taxes, 17% distribution and marketing costs, and 18% refining costs (Ederington *et al.*, 2018).

2.5 Petroleum Market in Ghana

According to the Oxford Institute for Energy Studies, the history of Ghanaian petroleum activity can be traced back to the turn of the 20th century. The Tano and Keta Basins had small-scale production in the early 1900s, and the Saltpond field has been operating since the 1970s. However, it was the discovery of the offshore Jubilee field in 2007, with an estimated 700 million barrels of oil (MMbo) and 800 billion cubic feet (Bcf) of gas that put Ghana on the map as a commercial oil and gas producer (Skaten 2018). Since the Jubilee field reached first oil in 2010, two new projects have been developed in Ghana's offshore waters. The Twenneboa, Enyenra, and Ntomme (TEN) fields (with an estimated 240 MMbo and 396 Bcf of gas) started production in August 2016, and the Sankofa, Gye, and Nyame fields (hereafter Sankofa field) (with an estimated 500 MMbo and 1.45 trillion cubic feet of gas) started production in May 2017. Despite the low price of crude oil since 2014/2015 and a maritime border dispute affecting the Tano blocks, Ghana's petroleum industry has developed at a steady pace. A development plan for the Greater Jubilee field received government approval in October 2017 to start drilling the Mahogany and Teak fields. The Greater Jubilee field is estimated to add 60 MMbo and 100 Bcf of gas to Ghana's production levels. Ghana has experienced external and domestic macroeconomic shocks since 2012, which led to a decline in economic growth from an average of 10–15 per cent in 2011–2012 to below 5 per cent in 2014 and 2015 (Owusu, 2018). The unreliable and low volume of gas imported through the West African Gas Pipeline has forced the country to import oil to generate electricity. The dramatically increased fuel bill and electricity shortages have had a substantial negative impact on the economy. The development of the petroleum industry has been key to reviving growth in Ghana's economy, with the trading of crude oil to gain much-needed foreign exchange and development of the domestic gas industry to help resolve Ghana's electricity shortage (Skaten, 2018).

2.6 Theoretical Review

A wide variety of studies in the economic literature accounts for several techniques that have been employed to research on the relationship between crude oil price and its product prices so far. In the vast majority of cases, these researches were based on the use of techniques of cointegration. Two principal approaches have been adopted: the two-step residual-based procedure for testing the null of no-cointegration (Engle and Granger, 1987; Phillips and Ouliaris, 1990) and the system-based reduced rank regression approach by Johansen (1995). In addition, other procedures such as the variable addition approach of Park (1992), the residual-based procedure for testing the null of cointegration by Shin (1994), and the stochastic common trends (system) approach of Stock and Watson (1988) have also been considered. All of these methods concentrate on cases in which the underlying variables are all integrated of order one.

The reparameterised result gives the short-run dynamics and long run relationship of the underlying variables. However, given the flexibility of cointegration technique in estimating the relationship between non-stationary variables and establishing short-term characteristics with long-term equilibrium, most researchers are still using the traditional estimation method such as simple linear regression, ARMA models and other time series models thereby presenting misleading inferences.

More specifically, Reilly and Witt (1998) used Wolfram's segmentation in first differences of explanatory variables and employed Engel-Granger specification for his crude oil gasoline prices analysis. Liu (1991) employed the Box-Jenkins ARIMA and transfer function models to study the relationship between the prices of crude oil and the UK gasoline price. Bacon (1991) employed a quadratic quantity adjustment function to also test for price asymmetry. Kirchgässner and Kübler (1992), used an error correction model to investigate possible price asymmetries in the wholesale and retail gasoline and heating oil markets in Germany. Ripple and Wilamoski (1995) for instance applied a correlation analysis with a structural shift to study the long run effect of crude oil prices to retail fuel prices. Bachmeier and Griffin (2003) employed the standard Engel-Granger procedure on the US gasoline market. Frey and Manera (2007) studied price asymmetries for five European countries, using three different methods, namely asymmetric error-correction models (ECM), and autoregressive threshold ECM. Using a joint vector autoregression (VAR), Kilian (2010) estimates varying magnitudes, trends, and durability in response to demand and supply shocks in the global market for crude oil and the U.S. market for gasoline.

In order to obtain robust results, some researchers utilize the Autoregressive Distributed Lag (ARDL) cointegration technique or bound test of cointegration (Pesaran and Shin, 1999 ; Pesaran *et al*., 2001) approach to establish the existence of long-run and short-run relationship between the prices of crude oil and its products as well as reparameterising them to the Error Correction Model (ECM). ARDL is extremely useful because it allows us to describe the existence of an equilibrium relationship in terms of long-run and short-run dynamics without losing long-run information. The main assumption of ARDL is that the variables in the model are cointegrated to the order of I(0) or I(1) or both. For instance, Shin *et al.* (2014) proposed an asymmetric cointegrating ARDL model using partial decompositions of positive and negative sums to establish the long and short run relationship between global crude oil price and the prices of gasoline.

2.7 Relationship between Crude Oil Price and Product Prices

Within the last years there is a substantial body of literature investigating the existence of price asymmetry in the gasoline market. Most of these studies examine the relationship between prices of crude oil and products' prices based on linear causality relationship and Vector Error Correction Model (VECM) modeling that show there is unidirectional causality from the price of crude oil to that of gasoline. Crude oil being the principal input in the production of gasoline, one would expect crude-oil prices to be a primary determinant of gasoline prices.

In these body of literature, there is a wide diversification concerning one or more of the following aspects: the country under examination, the time frequency of the period of the data used, the stage of the transmission mechanism (retail or wholesale) and the econometric model employed in the empirical investigation. The analytical literature on the general relationship between oil prices and the price of oil products indicates that petroleum products prices and global oil price move together over the long term Grasso and Manera (2007)

Reilly and Witt (1998) fitted an error correction model to monthly data on net retail prices for the UK for the period spanning from January 1982 to June 1995 in order to examine the short term response of retail petrol prices to changes in input costs and the exchange rate. The hypothesis of a symmetric response by petrol retailers to crude price fluctuations was rejected by the data over the period examined. A similar hypothesis in regard to the exchange rate was also rejected by the data.

Liu (1991) studied the dynamic relationships between crude oil prices and US gasoline prices. Using monthly data between January 1973 and December 1987, he came to a concession that the US gasoline price is mainly influenced by the price of crude oil. The author also suggested that, the dynamic relationship between the prices of gasoline and crude oil changes over time, shifting from a longer lag response to a shorter lag response.

In a study of the gasoline market in the UK, Manning (1991) used monthly data on crude oil prices and retail prices from the period 1973 to 1988 to conclude the existence of price asymmetry in the UK gasoline market. While the researcher's results indicated a cumulative adjustment period of two years, any asymmetry after four months was totally absent.

Bacon (1991) also analysed semi-monthly data from 1982 to 1989 and reported evidence of a faster and more concentrated response of the retail price to spot price increases. His analysis was also done for the UK gasoline market. He showed that an extra week is necessary for the adjustment of a crude oil prices reduction while increases are full transmitted within two months. Bacon (1991) described this asymmetric effect as "Rockets and Feathers" resembling the price of oil derivatives accelerates like rockets as it increases at a faster and larger magnitude as the price of crude oil rises, but falls as a feather, as price reduction takes place at a much lower rate and lesser magnitude in response to decrease in the price of crude oil. He also considered fluctuations of exchange rate as a source of disturbance in the transmission.

Kirchgässner and Kübler (1992), investigated possible price asymmetries in the wholesale and retail gasoline and heating oil markets in Germany for the period 1972 to 1989. In contrast to other studies, their results indicated that during the seventies the short run response of the wholesale price to a decrease of the spot price was greater than to an increase. They attributed their conflicting result to the fact that fuel distributors may hesitate to raise prices quickly to avoid allegations of abusing their price setting power.

Borenstein *et al.* (1992) studied the price relationship between crude oil and gasoline and claimed that gasoline prices showed asymmetry. The analysis was made for the United States using weekly data that spans from the year 1986-1990 weekly at various points of production and distributional chain. Their research empirically verified the belief that retail gasoline prices respond faster to crude oil price increases than decreases thereby confirming Bacon (1991)'s rockets and feathers movements in retail fuel prices. They further probed into the price transmission at different points of the distribution chain using bivariate error-correction models. It was revealed that the most considerable asymmetry appears in the reaction of retail prices to wholesale price changes.

Borenstein *et al.* (1997) estimated a Vector Autoregression (VAR) model for the American gasoline market using semi-monthly data over the period 1986 to 1990. Their results also indicated that retail prices adjust more quickly to crude oil price increases than to decreases. The researchers argued that price asymmetries might have different sources at different stages in the distribution chain. They also concluded that adjustment of the spot price to changes in the crude oil price is responsible for some of the asymmetry, which may reflect inventory adjustment effects. Finally, retail prices showed asymmetry in responding to wholesale price changes, possibly indicating short run market power among retailers.

Akarca and Andrianacos (1998) explored the dynamic relationship between crude oil and retail gasoline prices during 1976 to 1996 and concluded that gasoline prices including higher profit margins, respond substantially less to changes in crude oil prices (but within one month), and are more volatile.

With regards to the U.K. gasoline market, Reilly and Witt (1998) also conducted a research into the relationship between crude oil price and gasoline price. The dollar-pound exchange rate was used for their estimation for the period spanning from January 1982 to June 1995. An error correction model was fitted to monthly data on net retail prices for the UK gasoline market to examine the short-run reaction of retail gasoline prices to changes in input costs and exchange rate. The authors failed to achieve asymmetric relationship between crude oil prices and gasoline for the period. Their estimates only provided evidence of an asymmetric response among retailers to changes in both crude oil prices and the exchange rate. They deduced that, 10% fall in the crude oil price leads on impact to an estimated 1.9% fall in the retail price, while a corresponding rise in the crude oil price leads to a 4.1% rise in the retail price.

Gjolberg and Johnsen (1999) analysed the relationship between monthly prices of crude oil and six oil products (gasoline, naphtha, jet fuel, gas oil, light fuel oil 1%, and heavy fuel oil 3.5%) for the period 1992-1998. Brent crude oil that is oil observed on the Northwestern European market was used as the benchmark price for crude oil. They estimated a single-equation models treating crude oil as exogenous and conclude that the price of crude oil determines its product prices.

Girma and Paulson (1999) investigated the long-run relationship among crude oil and gasoline, and found that the prices are cointegrated. They also found a stationary relation between crude oil and its end products.

Godby *et al.* (2000) examined whether an asymmetric response to unanticipated positive and negative crude cost shocks could be identified in Canadian retail gasoline price using weekly data for thirteen cities from 1990 to 1996. Using the Threshold Autoregressive model, they failed to find asymmetric response of gasoline prices to changes in crude oil prices and further suggested that the reason for the different result was related to differences in market structure, in dataset, and in the methodology.

Asplund *et al.* (2000) used daily data to examine price responses to changes in the spot price, exchange rates and taxes for the period January 1980 to December 1996 on the Swedish gasoline market. They found support for the hypothesis that the retail price responds quicker in increment in crude oil price than decrement. The authors further examined the separate effect of the US dollar and Swedish crown/dollar exchange-rate changes in the spot price. The retail price responded faster to changes in the exchange rate than to spot price movements. They attributed the different price response to exchange rates and spot prices to means of the volatility of both series.

Indejehagopian and Simon (2000) focused on the German and French heating oil market and attempted to link them via cointegration techniques to Brent prices and the respective currency to USD exchange rates. The research was conducted for the period January 1987 to December 1997. The results obtained confirmed the existence of a long-run relationship between the price series. They also indicated that the observed asymmetry was caused by the exchange rates but not by the upstream (crude oil) prices.

Wlazlowski *et al.* (2009) conducted a research on the relationship between crude oil prices, the dollar-pound exchange rate and petrol prices in the European petroleum market over the period 1982 to 2001. The researcher applied asymmetric ECM, threshold autoregressive model (TAR) and momentum TAR, all of which gave the evidence of asymmetry for European petroleum petrol market. Both sort-run and long-run responses exhibited asymmetry with larger effect of oil prices increment than decrement.

Adrangi *et al.* (2001) considered daily prices of diesel fuel in Los Angeles and crude oil of Alaskan North Slope. They employed VAR methodology and bivariate GARCH model to investigate the causal relationship between crude oil prices and diesel prices. Results from their analysis showed that there is a strong evidence of a uni-directional causal relationship between the two prices. The L.A. diesel market was found to bear the majority of the burden of convergence when there is a price spread. Evidence from the research suggested that the derived demand theory of input pricing may not hold in their case. They also reported that the Alaska North Slope crude oil price is the driving force in changes of L. A. diesel price.

Salas (2002) used an ordered probit, a partial adjustment, and a vector ECM to characterize price adjustments in the Philippine retail gasoline market since its deregulation. He finds that pricing decisions of oil firms depend significantly on eight weeks of previous changes in crude cost. Moreover, the speed of adjustment of retail prices to their long-run equilibrium relation with crude cost has been following an accelerating trend but is vulnerable to intervening factors. Lastly, the empirical evidence suggests that pump prices respond more quickly and fully to increases in crude cost rather than to decreases.

Borenstein and Shepard (2002) estimated an asymmetric partial adjustment model and a VAR model on weekly observations at 188 terminals for the period 1986 to 1992.

They found that the terminal price responds asymmetrically to changes in the crude oil price.

Eckert (2002) showed that retail prices display a cyclical pattern inconsistent with the asymmetric explanation. The author's results support the theory of asymmetry and the assumption that prices rise faster when costs increase than when they decrease.

Hammoudeh *et al.* (2003) examined daily spot and futures prices for crude oil, heating oil and gasoline for the period 1986 to 2001. The authors performed their research in five commodity trading centers within and outside the United States of America. They found evidence of bidirectional causality between daily crude and gasoline prices, and a unidirectional causal relationship between crude oil and heating oil prices running from the former to the latter.

Bachmeier and Griffin (2003) have also analysed the relationship between crude oil prices and gasoline prices. Their analysis was done using daily US data over the period 1985 to 1998. Their findings conformed to that of Reilly and Witt (1998) and Godby *et al.* (2000). They also found no evidence for asymmetry in the price of crude oil and gasoline prices.

Asche *et al.* (2003) performed a research on the price relationships between crude oil and refined product prices. Their analysis was based on the relationship between monthly prices of Brent Crude oil and four oil products (Gas oil, Heavy fuel oil, Naphtha and Kerosene) traded on the Rotterdam market in a period spanning from 1992 to 2000. Their model employed the Johansen framework to assess the long run relationship and to check whether their spreads were constant. They employed a multivariate Vector Error Correction Model. Their results indicated that heavy fuel oil had no long run relationship with the price of crude oil, suggesting that heavy fuel oil price is independent of crude oil price, whereas all other prices appeared to be cointegrated with crude oil price. Inference from their analysis suggested that the price of crude oil is what determines petroleum product prices and that petroleum product prices do not influence the price of crude oil. They also found out that crude oil price is weakly exogenous for fuel products implying that relationships can be tested by single equation model.

Galeotti *et al.* (2003) focused on the issue of presumed asymmetries in the transmission of shocks to crude oil prices onto retail prices of gasoline in selected European countries from 1985 to 2000 by using monthly data. Their results strongly confirmed the findings of previous researches that the prices of gasoline respond faster to increasing crude oil price than decreasing crude oil price.

Bettendorf *et al.* (2003) accessed whether an asymmetric pricing could be identified in the Dutch gasoline market by estimating an asymmetric error correction model on weekly price changes for the years 1996 to 2001. Five datasets, one for each working day were constructed. In the datasets, retail and Rotterdam spot prices that were observed on the same day were grouped. The estimation results showed that crude oil price change fully affects Dutch retail gasoline price in the long run.

Radchenko (2005a) researched into the relationship between the price of crude oil and gasoline prices in the Ukrainian gasoline market. The research examined the evidence on the role of gasoline margins and volatility in the asymmetric response of gasoline prices to oil price changes at different distribution stages. It was evident from their research that asymmetry between wholesale gasoline prices and retail gasoline prices is as a result of volatility. It was also established that wholesale gasoline prices play an important role in the asymmetric response of retail gasoline prices. Also, oil prices were found important in explaining asymmetry in ECM spot gasoline prices.

Lanza *et al.* (2005) investigated the relationship between the prices of crude oil and product price dynamics using weekly and monthly data for the period running from 1994 to 2002 using cointegration and ECM. The authors presented a comparison among ten price series of crude oils and fourteen price series of petroleum products, taking into account four distinct market areas (Mediterranean, Northwestern Europe, Latin America, and North America). The petroleum products considered belong to three different quality categories: unleaded Gasoline, Gasoil and Fuel oil. They were however, interested in models that explain regional oil prices, as they used models that link these prices to benchmark oil prices such as WTI or Brent, as well as two product prices, low sulfur oil, and gasoline. Crude oil and product prices dynamics was modelled with an Autoregressive Distributed Lag (ADL) specification. They concluded that there is a different relation between a given crude oil price, its area-specific market and the related petroleum products. Empirical evidence showed that product prices are statistically relevant in explaining short- and long-run adjustment in petroleum markets. They also found that long-run adjustment coefficients are sensitive to the gravity of the specific crude.

The asymmetry between the price of crude oil and motor gasoline prices based on monthly data on the American petroleum market for the period January 1986 to December 2002 was examined by Kaufmann and Laskowski (2005) using the asymmetric ECM. Their results indicated that retail price adjustments in the home heating oil market are asymmetric while there was a little evidence for asymmetry in the retail motor gasoline market.

Radchenko (2005b) used a Markov-switching model and found significant different responses of retail prices to long-term variations in crude oil prices from short-term variations. The study also further considered the link between oil price volatility and asymmetry. Results from the research showed a negative relationship between the two variables for the U.S.

Chen *et al.* (2005) examined the asymmetry in the response of retail prices to changes in both the spot price of crude oil and wholesale gasoline. The research provided new supporting proof for asymmetric adjustment in U.S. retail gasoline prices. The asymmetric transmission was found to arise not just through the spot markets of crude oil and refinery gasoline but also over their future markets. Further evidence also indicated that the observed asymmetry in price transmission primarily arises downstream other than upstream in the transmission process.

Denni and Frewer (2006) applied alternative GARCH models to analyse the relationship between crude oil and petroleum product prices. They found that these two variables are cointegrated when studying the effects of Brent crude oil in European markets. They used a weekly time series that includes observations from January 1990 to September 2005.

Abosedra and Radchenko (2006) used monthly data for the period February 1983 to November 2003 to examine the role of margins and volatility in asymmetry of US gasoline prices. In their analysis, they compared the results from models with margins and volatility with results from reference models to determine which of the two variables is more dominant in explaining the observed asymmetry between oil prices and gasoline prices. The obtained evidence supported the search theory explanation of asymmetry more than the oligopolistic coordination theory. However, they found that both theories seem to be consistent with empirical evidence on wholesale gasoline price-retail gasoline price without tax relation.

Chouinard and Perloff (2007) estimated for all contiguous 48 states and the District of Columbia reduced form models for retail and wholesale gasoline prices using monthly observations for the period from March 1989 to July 1997. The authors analyzed both factors which can push gasoline prices over time and across geographic areas as well as factors such as taxes, refinery outages, various regulatory effects, environment, station ownership controls and vertical relationships, refinery mergers, and crude oil prices. They concluded that the total variation in national prices was due to changes in the price of crude oil and cyclical fluctuations and not to changes in taxation, requirements for quality and other factors. They also identified that taxation, population density, and age distribution of the population of a state are the primary determinants of price differentials across States.

Frey and Manera (2007) reviewed the price adjustments in the Netherlands gasoline market by estimating an asymmetric error correction model by employing daily data for the period January 1996 to December 2001. The results of the estimation showed that a spot price shift is transferred entirely to the results of the estimation indicating that the day for which prices are measured matters for the results, as the findings on price asymmetry were not consistent across the five datasets.

Using threshold and momentum models of cointegration and daily data at different stages in the distribution chain, Al-Gudhea *et al.* (2007) found that transmission between upstream and downstream prices is mostly asymmetric in the momentum model. They found that an increase in upstream prices are passed on to downstream prices more quickly than decreases.

Blair and Rezek (2008) estimated an asymmetric error-correction model and found an evidence of market imperfections in the price pass-through from crude oil to spot gasoline markets in the Gulf Coast region from 2000 until Hurricane Katrina.

Meyler (2009) tested the symmetry hypothesis for the twelve initial Euro member countries from 1994 to 2008, by using weekly data and finds weak evidence of statistically significant asymmetries across the countries examined.

Shin *et al.* (2014) examined the asymmetries that characterise Korea's retail gasoline market response to spot price fluctuations in crude oil and the Korean Won / US Dollar exchange rate over the 1991-2007 era. Based on findings from the research, it is suggested that the long-run relationship is linear with respect to both variables, indicating that Korean energy retailers pass cost changes through to consumers fully in the long-run. Nonetheless, their findings support Asplund *et al.* (2000)'s findings that the short-term reaction of gasoline prices to the exchange rate is more pronounced than that associated with fluctuations in crude oil prices.

O'Brien and Woolverton (2010) also found a strong positive correlation of 93% between the gasoline prices and oil prices in the 2007 to 2009 period. A 10% increase in U.S. domestic oil prices led to about a 6.14% increase in the U.S. Midwest gasoline prices.

Honarvar (2009) tested for asymmetry between components of retail gasoline prices and crude oil prices in the U.S. by using a Crouching Error Correction Model through the application of hidden cointegration approach. Monthly data from the U.S. Department of Energy (EIA) was used for the analysis. Honarvar (2009) established that the behavior of gasoline prices (premium unleaded and all types) depends on whether crude oil price increases or decreases. He also suggested that the shocks that originate in gasoline markets are distinguished from the shocks that originate in crude oil markets.

The long-run and short-run determinants of unleaded petrol prices in Australia's capital cities was accessed by Valadkhani (2009) using a monthly data set to test whether prices respond asymmetrically to external shocks. The research examined whether the long-run petrol prices are mainly determined by the Tapis crude oil and Singapore petrol prices. It was established that in the long-run, petrol prices are mainly determined by the Tapis crude oil. There was some evidence of asymmetric price adjustments in the short-run since petrol price increases was felt faster than price decreases in four capital cities with respect to changes in crude oil prices.

Wlazlowski *et al.* (2009) analysed the horizontal and vertical price dynamics in the EU petroleum markets. The results indicated that the cross-country price differentials have significant impact on the local price adjustments. They also found empirical evidence, although indirect, for the politically charged concept of "fuel tourism", using a pan-European cross-product time series dataset.

Leszkiewicz-Kędzior, and Welfe (2014) examined the relationship between the prices of crude oil and three petroleum products (gasoline, diesel and heating oil) with an ECM methodology for two Euro area members (France and Germany). Asymmetry was clearly present for the diesel in both countries. It was established that the appreciation of exchange rate smoothes the impact of crude oil price on retail prices while its depreciation had no effect in the transmission.

Kendix and Walls (2010) quantified the impact of petroleum industry consolidation on refined product prices. An econometric model for refined-product prices that accounted for industry consolidation as well as many other structural factors associated with the market for refined petroleum products was constructed. The model was estimated using data from 78 to 82 US wholesale gasoline prices. The results of the empirical analysis showed that some petroleum industry mergers resulted in statistically significant increases in refined product prices while others resulted in statistically significant declines. Many mergers had no impact at all.

Clerides (2010) tested the response of retail gasoline prices (with and without taxes) to changes on the world oil price by using weekly data for all EU 27 countries and finds significant variation in the adjustment mechanism across countries while evidence of asymmetric adjustment was fairly weak.

Polemis and Fotis (2013) investigated the issue of asymmetries in the transmission of shocks to input prices and exchange rate onto the wholesale and retail price of gasoline respectively. For this main, an error-correction methodology was utilised in the Greek gasoline market using a monthly data covering the period of January 1988 to June 2006. The results favoured the common perception that retail gasoline prices respond asymmetrically to cost increases and decreases both in the long and the short-run. There was also an evident of a symmetric response of the spot prices of gasoline towards the adjustment to the short-run responses of the exchange rate.

Bermingham and O'Brien (2011) in a study of the Irish and the UK liquid fuels market, used threshold autoregressive models characterised by asymmetric pricing behaviour. The econometric assessment used threshold autoregressive models and a dataset of monthly refined oil and retail prices covering the period 1994 to 2009. In particular, the possibility of conflicting price pressures arising from short-run dynamics in retail prices and responses to disequilibrium errors was explicitly modelled. In terms of the asymmetric behaviour of these markets, the paper finds no evidence to support the "rockets and feathers" hypothesis that prices rise faster than they fall in response to changes in the value of international oil prices.

Pokrivčák and Rajčaniová (2011) researched into crude oil price variability and its impact on gasoline prices. The methods used in conducting the research involved the Vector Autoregression (VaR) and the Impulse Response Function (IRF). Their findings indicated that crude oil price shock has a larger effect on gasoline prices than gasoline prices have on the prices of crude oil.

Leszkiewicz-Kędzior (2011) analysed fuel pricing in Poland in the period January 2000 to March 2011. Two levels of prices were considered; that is wholesale prices set by Polish refineries and retail prices paid at petrol stations. Because refinery product prices are strongly dependent on the zloty exchange rate, a large part of the article deals with the modelling of the PLN/EUR exchange rate. The multivariate cointegration analysis employed showed that the wholesale and retail prices of fuels and the exchange rate are linked through long-run relationships. The author found that the wholesale price of fuel depends on the crude oil price and the PLN/EUR exchange rate. Another finding was that changes in the wholesale price are fully transmitted to retail prices.

Radchenko and Shapiro (2011) estimated empirical responses to the anticipated and unanticipated changes in oil prices and gasoline prices. The results of their estimations showed that gasoline price adjustments are faster and stronger for anticipated changes in oil prices than for unanticipated changes. They also found that positive and negative changes in oil prices have asymmetric effect on gasoline prices.

Remer (2015) investigated the cause of asymmetric pricing: retail prices responding faster to cost increases than decreases. Using daily price data for over 11,000 retail gasoline stations, from the study it was found that prices fall more slowly than they rise as a consequence of firms extracting informational rents from consumers with positive search costs. The researcher found a strong evidence in support of asymmetric pricing.

Gholampour *et al.* (2012) used a nonlinear threshold model to examine the asymmetric relation between Iran's crude oil and imported gasoline prices for the period 1987 to 2008 based on linear causality relationship and Vector Error Correction Model (VECM) modeling. Based on the results of the Error Correction Model – Threshold Autoregressive ECM-TAR models estimate there was a unidirectional short-term causality from the price of crude oil to the price of imported gasoline, whereas in the long run there is bidirectional causality between them.

Venditti (2013) employed the impulse-response test to examine the question of whether fuel prices respond asymmetrically to oil price changes. The author analyzed weekly gas oil and gasoline prices and oil prices for the United States, the euro area and the four major euro-area countries (Germany, France, Italy, and Spain) for January 1999 to September 2009, as well as US WTI and Brent prices for Europe. The author points out that "the gap between crude oil spot prices and retail prices accounts for production and shipping costs, distribution costs and margins, while the disparity between wholesale and retail prices only includes distribution costs and margins. He also tests for asymmetry in response using the ECM framework as described above. Based on the traditional asymmetric ECM approach, the author finds evidence that U.S. retail prices adjust asymmetrically to changes in both spot oil prices as well as wholesale fuel prices, but only weak evidence for the European countries.

Nguyen (2013) investigated the stability relationship between crude oil price and petrol price as well as their behaviour using daily U.S. price series in the period from January 11th 1988 to May 20th 2011. Van 2013 suggested that univariate GARCH (1, 1) is likely the most suitable model to measure the volatility of relative changes in the crude oil price and the petrol price.

Asare-Otoo and Schneider (2015) also investigated the international crude oil prices to pump price transmission at national level. They found a positive asymmetric relationship for both gasoline and diesel for the period spanning from 2003 to 2007. They indicated that pump prices react faster to increases, while for the period 2009 to 2013 they detect negative asymmetry for retail prices.

Berument *et al.* (2014) employed weekly data from January 03, 2005 to October 22, 2012 for France, Greece, Italy and Spain and from January 01, 2005 to December 25, 2011 for Turkey to estimate the relative effects of crude oil price and exchange rate on petroleum product prices. The authors concluded that one percent increase in exchange rate (depreciation) increases petroleum product prices more than a percent increase in exchange rate increases petroleum product prices less than one percent increases in crude oil prices does.

Atil *et al.* (2014) developed a nonlinear autoregressive distributed lags (NARDL) model to examine the pass-through of crude oil prices into gasoline prices. They tested for both the short- and long-run nonlinearities through positive and negative partial sum decompositions of their explanatory variables. The obtained results indicate that oil prices affect gasoline prices in an asymmetric and nonlinear manner.

Zlatcu *et al.* (2015) studied the price volatility and the response of retail fuel prices to changes in international crude oil prices on the Romanian fuel market and on four other markets, namely Germany, France, Poland and Czech Republic, during the period between 2008 and 2014. They estimated a univariate and multivariate GARCH models, as well as an MTAR threshold cointegration approach. The study found similar patterns across the markets under which the research was performed. Their results showed the presence of cointegration among the variables and detected some signs of asymmetric adjustments, supporting the hypothesis of a faster adjustment above the threshold in most cases.

Kristoufek and Lunackova (2015) reinvestigated the "rockets and feathers" effect between retail gasoline and crude oil prices in a new framework of fractional integration, long-term memory and borderline non-stationarity. Error-correction model was employed to examine in detail the price relationship between crude oil prices and gasoline prices. It was realised that the prices returned to their equilibrium value much more slowly than would be typical for the error-correction model.

In the United States of America, Pal and Mitra (2015) also studied the influence of changes in the prices of crude oil on that of petroleum products. An evidence of long run relationship between the prices of crude oil and its refined products was established. They also found that prices of petroleum product respond faster and in larger magnitude to the increase of crude oil price, while the price of the former drops at a comparatively slower rate and in smaller magnitude in response to fall in crude oil price.

Zavaleta *et al.* (2015) analysed the relationships between the American and European markets for crude oil and major refined petroleum products. This result showed that the international crude oil market constitutes a single market. Second, and more importantly, the econometric results indicate that cointegration relationships exist between the American and European prices for conventional gasoline, kerosene-type jet fuel and residual fuel oil.

Bagnai and Ospina (2015) using monthly data from 1994 to 2013, analysed the long-term relationship between the pre-tax retail prices of gasoline and crude oil, and the nominal exchange rate. A strong long-run relationship was established. The authors then used a nonlinear ARDL (NARDL) model to evaluate both the short- and long-run elasticity asymmetries and the role of hysteresis in the pricing actions. The results of the estimation led to the discovery of asymmetry in long-term elasticity, with significant differences between the price of crude oil and the exchange rate, as well as the presence of hysteresis in the relation between the retail price of petrol and crude oil prices.

Karagiannis *et al.* (2015) examined the nature of price adjustments in the gasoline markets of Germany, France, Italy and Spain. They examined whether crude oil prices are transmitted to the retail gasoline prices in the short and long run and also tested the symmetry of price adjustments hypothesis. An Error Correction Model, which accounts for possible asymmetric adjustment behaviour was applied for the estimation of the international crude oil price pass-through and testing of the symmetric/asymmetric nature of the retail fuel price adjustments in these economies. Findings from the research did not provide strong evidence to support the "rockets and feathers" hypothesis that crude oil price increases are passed along to the retail customer more fully than the crude oil price decreases.

Rahman (2016) examined whether the relationship between the prices of crude oil and gasoline is symmetric using tests of the null hypothesis of symmetric impulse responses.

Based on monthly U.S. data over the period from January 1978 to November 2014, the results of this research work showed that gasoline prices respond asymmetrically to positive and negative oil price shocks. It was also established that oil price volatility has a positive effect on the price of gasoline and contributes to the asymmetries in the transmission of oil price shocks.

Gurgur and Kilinc (2016) also investigated the relationship between the cost of crude oil and retail price of gasoline in Turkey. A long run relationship existed between the cost of crude oil and gasoline prices. The authors also found a strong effect of exchange rate on the prices of gasoline.

Han *et al.* (2017) also researched on the relationship between international crude oil prices and China's refined oil prices based on a structural VAR model. The Granger causality test, Vector Autoregression model, Impulse response function and variance decomposition methods were used in investigating the relationship between the prices of international crude oil and the prices of China's refined oil. They used monthly data of the prices of Brent Crude oil and China's refined oil was represented by average China national monthly retail prices of diesel. Their study revealed that crude oil prices has a significant positive impact on domestic diesel prices.

Ederington *et al.* (2018) extended the analysis to a study of the relations between Brent oil futures prices and gasoline and heating oil futures prices for contracts traded on the NYMEX. Their results showed consistent evidence that causality runs from oil futures prices to product futures prices. Nevertheless, the authors also found evidence in an examination of the daily data during the post-2005 period that product prices triggered oil prices, indicating causality ran in both directions during that time when tested at the daily level.

Aduda *et al.* (2018) researched on Cointegration Relationships between Crude Oil and Distillate Fuel Prices. The study used cointegration to analyse the long-term equilibrium relationship between the prices of crude oil and distillate fuels. Monthly data for Cushing Oklahoma West Texas Intermediate (OK WTI), Reformulated Blend stock for

Oxygenate Blending (RBOB), and the number 1 heating oil futures contracts were considered for the period running from 2nd January 2006 to 22nd May 2015. Cointegration was tested using the trace test. In their study, both the E-G test and the Johansen's test were used to explore the presence of co-integrating relations between the daily prices of crude oil and distillate fuels. The researchers fitted VECM and tested for Granger Causality. The Durbin-Watson (D-W) test was used to check for spurious regression. Their results indicated a long run relationship between the prices of crude oil and distillate fuels. They also found from the results of the Granger causality test that there was a bidirectional causality between almost all the series.

Weinhagen (2018) examined Crude Petroleum prices and retail fuel margins. The study used error-correction model to analyze the response of retail fuel margins to changes in crude petroleum prices. The analysis was done using a monthly data from April 2009 through September 2016. The Author's results showed a negative simultaneous response of retail automotive fuel margins to rising and falling changes in crude petroleum prices.

Chen *et al.* (2005) built a pooled panel GMM threshold model within an error correction framework. The sample employed for the study included weekly observations for the 27 EU countries over the period 1994 to 2015. All variables were converted to their natural logarithms expressed in real terms. Brent crude oil price were taken from the USA Department of Energy while the exchange rate effect is quantified by two indicators: The Dollar trade-weighted exchange rate index drawn directly from the Federal Reserve Bank of St. Louis and nominal effective Euro trade-weighted exchange rate index obtained from the European Central Bank. Findings revealed that asymmetric gasoline price adjustment fluctuations can be attributed to exchange rate swings.

Yaya and Ogboma (2018) modelled the relationship between the prices of Crude oil and petroleum products. Their model used the dynamic conditional correlation GARCH models to model the price nexus between the Cushing West Texas Intermediate (WTI) Crude oil and gasoline, heating oil, kerosene, propane and diesel. According to the study, with the exception of propane own market spillover, the persistence of overall volatility of spillovers from the own market and other markets for crude oil nexuses and the other four petroleum products (gasoline, heating oil, diesel and petroleum) were a major reversal.

Apergis and Vouzavalis (2018) also investigated the asymmetric pass-through of oil prices to gasoline prices under the non-linear autoregressive distributed lags (NARDL) model. The analysis added to the unsettled discussion of whether retail gasoline prices respond asymmetrically to oil prices and it was carried out for the US, the UK, Spain, Italy and Greece, spanning the period January 2009 to July 2016. The analysis considered markets that differ in terms of their structure. Both short- and long-run non-linearity were tested by deriving both the positive and negative partial sum decompositions of the dependent variable. The findings indicated that oil and gasoline prices provide mixed evidence of an asymmetric behavior. Short-run asymmetry was found in the Italian market, while in the Spanish market there was an evidence of both short- and long-run asymmetry. Greece, the United Kingdom, the United States demonstrated a symmetrical oil pass-through system for retail prices of gasoline.

In conclusion, most of the above studies carried on individual markets considered only the response of gasoline prices to changes in crude oil prices. In this research work, the relationship between crude oil prices and retail fuel prices (Gasoline, Gas oil, Residual fuel oil and Premix fuel) is studied. This is done to assess whether a change in crude oil will be transmitted to the pump fuel prices on the Ghanaian fuel market.

CHAPTER 3

METHODS USED

3.1 Overview

This chapter presents the methods used for the study. The chapter is divided into 5 sections. The first part talks about the data source and type. The second section accounts for stationarity and unit root testing. Cointegration test is described in the third section. The fourth sub division presents the error correction model whiles the final subdivision highlights on the granger causality.

3.2 Data Source and Type

The analysis is based on monthly series of exchange rate, inflation rate, the price of crude oil, and four major Crude oil products in the period of January, 2009 to March, 2019. The crude oil data used in this research is Brent, i.e. crude oil originating from the UK continental shelf. Crude oil product prices employed in the research are that of Gasoline, Gas oil, Residual Fuel Oil (RFO), and Premix traded on Ghanaian refueling stations and reported by the Ghana National Petroleum Authority. The exchange rate data was also obtained from the National Petroleum Authority whiles that of the inflation rate was obtained from the World Bank. Crude oil price is in US$ per barrel whiles all products prices are in US$ per liters.

3.3 Stationarity and Unit Root Testing

The long run relationship between the prices of Crude oil and its products can be analysed, by first confirming that the data consist of unit root processes. This was done by allowing the data to undergo a unit root processes test to identify the order of integration of all the processes involved in the analysis. The Unit-root tests are used to determine whether the time series is stationary or non-stationary (Shrestha and Bhatta, 2018). A time series data is called stationary if its value tends to revert to its long-run average value and properties of data series are not affected by the change in time only

(Shrestha and Bhatta, 2018). If the mean and autocovariances of the series do not depend on time, the series is said to be weakly stationary (Nason, 2006).

The need to test for the presence of unit root is to avoid the problem of spurious regression. If a variable contains a unit-root it is non-stationary since its current value is equal to the last value plus a white noise term. However, if it combines with other non-stationary series to form a stationary cointegration relationship, then regression involving the series can falsely imply the existence of a meaningful economic relationship (Niyimbanira, 2013). Literature accounts for several ways of testing for the presence of a unit root. The emphasis here will be on using the Augmented Dickey Fuller approach (ADF), the Phillips Perron (PP) test, and the Kwiatkowski Phillips-Schmidt-Shin test (KPSS).

3.3.1 Augmented Dickey Fuller (ADF) Test

The Dickey-Fuller test was the first statistical test developed to test the null hypothesis that a unit root is present in an autoregressive model of order one of a time series, and that the process is thus not stationary. The original test treats the case of a simple lag-1 AR model. The ADF test expands the Dickey-Fuller test equation to include high order regressive process in the model. The more differencing terms added to the ADF test adds more thoroughness to the test.

$$y_t = c + \beta_t + \alpha y_{t-1} + \phi_1 \Delta Y_{t-1} + \phi_2 \Delta Y_{t-2} + \ldots + \phi_p \Delta Y_{t-p} + \varepsilon_t \tag{3.1}$$

where

$y(t-1)$ = lag 1 of the time series

ΔY_{t-p} = first difference of the series at time $t-p$

Depending on constant or trend component in the model, the ADF test consider these three different regression models

$$\Delta y_t = \theta y_{t-1} + \sum_{j=1}^{p} \gamma_j \Delta y_{t-j} \in_t \tag{3.2}$$

$$\Delta y_t = \beta_1 + \theta y_{t-1} + \sum_{j=1}^{p} \gamma_j \Delta y_{t-j} \in_t \tag{3.3}$$

$$\Delta y_t = \beta_1 + \beta_2 t + \theta y_{t-1} + \sum_{j=1}^{p} \gamma_j \Delta y_{t-j} \in_t \tag{3.4}$$

The test statistic for the ADF test is given by $t_{\theta=0} = \frac{\hat{\theta}}{\sigma(\hat{\theta})}$ where $\hat{\theta}$ is the OLS estimate of θ and $\sigma\hat{\theta}$ is the standard error of the estimate. We note that $\theta = 0$ (stationary process) indicate existence of a unit root in equation (3.2). The t- statistic for θ is performed on the null hypothesis $H_0 : \theta = 0$ of unit root against the alternative hypothesis ($H_1 \neq 0$) of stationarity.

3.3.2 Kwiatkowski Phillips-Schmidt-Shin test (KPSS)

The KPSS test was proposed by Kwiatkowski *et al.* (1992). Contrary to the Dickey-Fuller family of tests, the null hypothesis for the KPSS test assumes stationarity around a mean or a linear trend, while the alternative is the presence of a unit root. It is often used to complement the Dickey-Fuller type tests. The test is based on linear regression, breaking up the series into three parts: a deterministic trend (β_t), a random walk (r_t), and a stationary error (ε_t), with the regression equation: $X_t = r_t + \beta_t + \varepsilon_t$ where $r_t = r_{t-1} + \mu_t$ and $\mu \sim (0, \sigma^2)$ is an independent and identically distributed (*iid)* process. The null hypothesis is thus stated to be $H_0 : \sigma^2 = 0$ (H_0 : Unit root is stationary) while the alternative hypothesis is $H_1 : \sigma^2 > 0$. The test statistics for the KPSS is stated in equation 3.5.

$$\eta = \frac{\sum_{i=1}^{T} s_t^2}{T^2 \sigma^2} \tag{3.5}$$

where $S_t = \sum_{s=1}^{t} e_s$ is an estimate of the long run variance of $e_t = (Z_t - \bar{Z})$. Consequently, it is possible to construct a one-sided test based on η, where H_0 is rejected if η is bigger than the appropriate critical value.

3.3.3 Phillips Perron (PP)

Phillips and Perron's test statistics can be viewed as Dickey–Fuller statistics that have been made robust to serial correlation by using the Newey and West (1987) heteroskedasticity and autocorrelation-consistent covariance matrix estimator. Under the null hypothesis that $\rho = 0$, the PP Z_t and Z_π statistics have the same asymptotic distributions as the ADF t-statistic and normalized bias statistics.

However, some advantages of the PP tests over the ADF tests are that the PP tests are robust to general forms of heteroskedasticity in the error term u_t and the user does not have to specify a lag length for the test regression. The normalised bias $mT\ (\pi - 1)$ has a definite limiting distribution that does not depend on nuisance parameters and can also be used as a test statistic for the null hypothesis $H_0 : \pi = 1$.

3.4 Cointegration Test

Cointegration analysis can be used to evaluate the co-movement of a long-term asset price within an equilibrium model. It establishes a long-term relationship by calculating long-run equilibrium asset prices. Two (or more) time series are considered to be cointegrated when they each possess a unit root and a linear combination of the variables is a stationary process (Chang *et al.*, 2008) Assume two time series Y_t and X_t, are integrated of order $d(Y_t, X_t \sim I(d))$. If there exists β such that $Y_t - \beta * X_t = \mu_t$, where is integrated of order less than $d(d-b)$, we say that $Y_t$and X_t are cointegrated of order $d-b$, $Y_t, X_t \sim CI(d,b)$. In words, the nonstationary time series in Y_t are cointegrated if there is a linear combination of them that is stationary). If some elements of β are equal to zero then only the subset of the time series in Y_t with non-zero coefficients is cointegrated. The linear combination βY_t is often motivated by economic theory and referred to as a long-run equilibrium relationship. The intuition is that $I(1)$ time series with a long-run equilibrium relationship cannot drift too far apart from the equilibrium because economic forces will act to restore the equilibrium relationship.

The presence of cointegration was tested using the Johansen cointegration test and confirmed by the ARDL Bounds cointegration test. The two tests were employed because each of the test has an advantage(s) over the other in one way or the other.

3.4.1 Johansen Cointegration Test

The Johansen process is a maximum likelihood method that determines the number of cointegrating vectors in a non-stationary time series. According to Johansen (1995), for n number of variables, where n is more than two variables, there can only be up to n-1 cointegration vectors. The Johansen and Juselius (1990) methodology takes its starting point in the Vector Autoregression (VAR) of order p given by equation (3.6)

$$y_t = \mu + A_1 y_{t-1} + \ldots + A_p y_{t-p} + \varepsilon_t \tag{3.6}$$

where y_t is an $n \times 1$ vector of variables that are integrated of order one which is commonly denoted as $I(1)$ and ε_t is an $n \times 1$ vector of innovations. This VAR can be re-written as:

$$\Delta y_t = \mu + \prod_1 y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-1} + \varepsilon_t \tag{3.7}$$

where $\Pi = \sum_{i=1}^{p-1} A_{i-1}$ and $\Gamma_i = -\sum_{j=i+1}^{p} A_j$

If the coefficient matrix Π has a reduced rank, $r < n$ then there exist $n \times 1$ matrices α and each with a rank r such that $\Pi = \alpha\beta I$ and $\beta I y_t$ is stationary. r is the number of cointegrating relationships, the elements of α are known as the adjustment parameters in the Vector Error Correction model and each column of β is a cointegrating vector. It can be shown that for a given r, the maximum likelihood estimator of β defines the combination of y_{t-1} that yields the r largest canonical correlations of Δy_t with y_{t-1} after correcting for lagged differences and deterministic variables when present.

The Johansen cointegration procedure uses two tests to determine the number of cointegration vectors namely, the Maximum Eigenvalue test and the Trace test (Asari *et al.*, 2011). The Maximum Eigenvalue statistic tests the null hypothesis of r cointegrating relations against the alternative of $r+1$ cointegrating relations for $r = 0, 1, 2, ..., n-1$. The test statistic is computed as:

$$LR_{\max}(r/n+1) = -T * \log(1-\hat{\lambda}) \tag{3.8}$$

where λ represents the Maximum Eigenvalue and T is the sample size. The Trace statistics investigates the null hypothesis of r cointegration relations against the alternative of n cointegrating relations. The trace statistics is computed as:

$$LR_{tr}(r/n) = -T * \sum_{i=r+1}^{n} \log(1-\hat{\lambda}_i) \tag{3.9}$$

where n represents the number of variables in the system, $\hat{\lambda}_i$ is the i^{th} largest canonical correlation and $r = 0, 1, 2, ..., n-1$. In a case where the Trace statistics yield different result from the Maximum Eigenvalue Statistics test, the Trace test is preferred to the Maximum Eigenvalue Statistic test since it appears to be more robust to skewness, excess kurtosis and can be adjusted for degrees of freedom, which can be of importance in small samples (Asari *et al.*, 2011).

Neither of these test statistics follows a chi square distribution in general; asymptotic critical values can be found in Johansen and Juselius (1990) and are also given by most econometric software packages. Since the critical values used for the maximum eigenvalue and trace test statistics are based on a pure unit-root assumption, they will no longer be correct when the variables in the system are near-unit-root processes.

The tests for determining the number of co-integrating vectors are nested. The test should therefore be performed by starting from the hypothesis of zero cointegrating vectors. Thus $H_{0,1}$: 0 cointegrating vectors is tested against the alternative $H_{1,1}$: at least one cointegrating vector. If $H_{0,1}$ is accepted, then it means there is no cointegration among the variables. However, if $H_{0,1}$ rejected, the next test is $H_{0,2}$; 1 cointegrating vector against $H_{1,2}$; at least two cointegrating vectors. This goes on until the null hypothesis is accepted. The level of acceptance shows the number of cointegrating vectors in the model.

Although Johansen's methodology is typically used in a setting where all variables in the system are $I(1)$, having stationary variables in the system is theoretically not an issue and Johansen (1995) states that there is little need to pre-test the variables in the system to establish their order of integration. If a single variable is $I(0)$ instead of $I(1)$ this will reveal itself through a cointegrating vector whose space is spanned by the only stationary variable in the model. The lack of need to *a priori* distinguish between $I(1)$ and $I(0)$ variables is based on the assumption that any variable that is not $I(1)$, or a pure unit-root process, is a stationary $I(0)$ process.

It is commonly acknowledged that the statistical properties of the Johansen procedure are generally better and the cointegration test is of higher power compared to the one proposed by Engle and Granger (1987).

3.4.2 ARDL Bounds Cointegration Test

The ARDL bounds test was performed by estimating Equations 3.10 - 3.12 using Ordinary Least Squares (OLS). Then, to test for existence of a long-run relationship among the variables, we conduct an F-test for the joint significance of the coefficients of the lagged level variables. The ARDL models are characterised by having lags of the dependent variable, as well as lags of the independent variables.
Autoregressive distributed-lag models (ARDL model, *hereon*) are widely employed in the analysis of long-run relations when the data generating process underlying the time

series is integrated of order one (i.e. I(1)). Recently, the application of ARDL model procedure to difference- stationary series has been evolving.

We implement the ARDL approach in two main steps. First, we test for cointegration to ascertain whether there is any long-run equilibrium relationship among the variables in the model to be estimated. If cointegration is established, we then estimate the long-run coefficients and the associated short-run parameters.

The bounds test is a cointegration test based on the assumption that the variables under consideration are either stationary at level or are difference stationary. In other to apply the bounds test, the order of integration of all the variables must be known by testing for the unit root. The reason is to ensure that the variables are not integrated of order two which may result in spurious regression.
The null hypothesis of no cointegration or no long-run relationship among the variables is:

$$H_O : \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4$$

And the alternative hypothesis of cointegration among the variables is:

$$H_1 : \lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4$$

Pesaran *et al.* (2001) provides two sets of critical values in testing for cointegration when the underlying variables are I(1) or I(0). If the calculated F-statistic exceeds the upper critical bound at conventional significance levels, then we can reject the null hypothesis of no cointegration. Conversely, if the calculated F-statistic falls below the lower critical bound, the null of no cointegration is not rejected. If it however falls within the band, then the test is inconclusive.

The advantage of the ARDL approach is that while other cointegration techniques require all of the regressors to be integrated of the same order; the ARDL approach can be applied whether the repressors are $I(1)$ or $I(0)$. This means that the ARDL approach avoids the pre-testing problems associated with standard cointegration, which requires that the variables be already classified into $I(1)$ or $I(0)$ (Pesaran *et al.*, 2001). Also, the ARDL model is the more statistically significant approach to determine the cointegration relation in small samples (Ellahi and Mahmood, 2012). With the ARDL approach it is possible that different variables have different optimal numbers of lags (Nkoro and Uko 2016).

As the long run relationship between the prices of crude oil and petroleum products in Ghana is studied, the following unrestricted error correction model (UECM) is selected for the ARDL bounds testing (Equations 10 to 13):

$$\begin{aligned}\Delta \ln GS_t = \beta_o + \sum_{i=1}^{q} \alpha_1 \Delta \ln GS_{t-i} + \sum_{i=1}^{p_1} \beta_1 \Delta \ln CRD_{t-i} + \sum_{i=1}^{p_2} \chi_1 \Delta \ln EXR_{t-i} \\ + \sum_{i=1}^{p_3} \gamma_1 \Delta \ln INF_{t-i} + \lambda_1 \ln GS_{t-1} + \lambda_2 \ln CRD_{t-1} + \lambda_3 \ln EXR_{t-1} \\ + \lambda_4 \ln INF_{t-1} + \mu_t\end{aligned} \tag{3.10}$$

$$\begin{aligned}\Delta \ln GO_t = \beta_o + \sum_{i=1}^{q} \alpha_2 \Delta \ln GO_{t-i} + \sum_{i=1}^{p_1} \beta_2 \Delta \ln CRD_{t-i} + \sum_{i=1}^{p_2} \chi_2 \Delta \ln EXR_{t-i} \\ + \sum_{i=1}^{p_3} \gamma_2 \Delta \ln INF_{t-i} + \lambda_1 \ln GO_{t-1} + \lambda_2 \ln CRD_{t-1} + \lambda_3 \ln EXR_{t-1} \\ + \lambda_4 \ln INF_{t-1} + \mu_t\end{aligned} \tag{3.11}$$

$$\begin{aligned}\Delta \ln RFO_t = \beta_o + \sum_{i=1}^{q} \alpha_3 \Delta \ln RFO_{t-i} + \sum_{i=1}^{p_1} \beta_3 \Delta \ln CRD_{t-i} + \sum_{i=1}^{p_2} \chi_3 \Delta \ln EXR_{t-i} \\ + \sum_{i=1}^{p_3} \gamma_1 \Delta \ln INF_{t-i} + \lambda_1 \ln RFO_{t-1} + \lambda_2 \ln CRD_{t-1} + \lambda_3 \ln EXR_{t-1} \\ + \lambda_4 \ln INF_{t-1} + \mu_t\end{aligned} \tag{3.12}$$

$$\begin{aligned}\Delta \ln PR_t = \beta_o + \sum_{i=1}^{q} \alpha_4 \Delta \ln PR_{t-i} + \sum_{i=1}^{p_1} \beta_4 \Delta \ln CRD_{t-i} + \sum_{i=1}^{p_2} \chi_4 \Delta \ln EXR_{t-i} \\ + \sum_{i=1}^{p_3} \gamma_4 \Delta \ln INF_{t-i} + \lambda_1 \ln PR_{t-1} + \lambda_2 \ln CRD_{t-1} + \lambda_3 \ln EXR_{t-1} \\ + \lambda_4 \ln INF_{t-1} + \mu_t\end{aligned} \tag{3.13}$$

where Δ is the first difference operator, μ represents the white noise error term, GS represents Gasoline, GO represents Gas oil, RFO represents Residual Fuel oil, PR represents Premix, CRD represents Crude oil, EXR represents Exchange rate and INF represents Inflation rate. All variables are in their natural logarithmic form.

3.5 Error Correction Model (ECM)

Evidence of a long run relationship among the variables from the Bounds test pave way for the second step to the cointegration analysis. The second step is to estimate the long-run and short-run elasticity by the ARDL and ECM model. For the long-run coefficients, models $ARDL(p, q_1, q_2, q_3)$ as listed in Equations 3.14 to 3.16 are employed:

$$LNGS_t = c_1 + \sum_{i=1}^{p} \alpha_1 LNGS_{t-i} + \sum_{i=0}^{q_1} \beta_1 LNCRD_{t-i} + \sum_{i=0}^{q_2} \lambda_1 LNEXR_{t-i} + \sum_{i=0}^{q_3} \gamma_1 LNINF_{t-i} \quad (3.14)$$

$$LNGO_t = c_2 + \sum_{i=1}^{p} \alpha_2 LNGO_{t-i} + \sum_{i=0}^{q_1} \beta_2 LNCRD_{t-i} + \sum_{i=0}^{q_2} \lambda_2 LNEXR_{t-i} + \sum_{i=0}^{q_3} \gamma_2 LNINF_{t-i} \quad (3.15)$$

$$LNRFO_t = c_3 + \sum_{i=1}^{p} \alpha_3 LNRFO_{t-i} + \sum_{i=0}^{q_1} \beta_3 LNCRD_{t-i} + \sum_{i=0}^{q_2} \lambda_3 LNEXR_{t-i} + \sum_{i=0}^{q_3} \gamma_3 LNINF_{t-i} \quad (3.16)$$

where $\alpha, \beta, \lambda, \gamma$ are the long-run multipliers. The lag orders (p, q_1, q_2, q_3) are selected by Bayesian Information Criteria (BIC). The short-run dynamic coefficients are obtained by the corresponding ECM model as Equations 3.17 - 3.19:

$$\begin{aligned}\Delta LNGS_t = c_1 &+ \sum_{i=1}^{p} \alpha_1 \Delta LNGS_{t-i} + \sum_{i=0}^{q_1} \beta_1 \Delta LNCRD_{t-i} + \sum_{i=0}^{q_2} \lambda_1 \Delta LNEXR_{t-i} \\ &+ \sum_{i=0}^{q_3} \gamma_1 \Delta LNINF_{t-i} + \varepsilon_1 ECM_{t-1} + \mu_{1t}\end{aligned} \quad (3.17)$$

$$\begin{aligned}\Delta LNGO_t = c_2 &+ \sum_{i=1}^{p} \alpha_2 \Delta LNGO_{t-i} + \sum_{i=0}^{q_1} \beta_2 \Delta LNCRD_{t-i} + \sum_{i=0}^{q_2} \lambda_2 \Delta LNEXR_{t-i} \\ &+ \sum_{i=0}^{q_3} \gamma_2 \Delta LNINF_{t-i} + \varepsilon_2 ECM_{t-1} + \mu_{2t}\end{aligned} \quad (3.18)$$

$$\begin{aligned}\Delta LNRFO_t = c_3 &+ \sum_{i=1}^{p} \alpha_3 \Delta LNRFO_{t-i} + \sum_{i=0}^{q_1} \beta_3 \Delta LNCRD_{t-i} + \sum_{i=0}^{q_2} \lambda_3 \Delta LNEXR_{t-i} \\ &+ \sum_{i=0}^{q_3} \gamma_3 \Delta LNINF_{t-i} + \varepsilon_3 ECM_{t-1} + \mu_{3t}\end{aligned} \quad (3.19)$$

where $\alpha, \beta, \lambda, \gamma$ are the short-run coefficients, ε is the error correction term which is the speed of adjustment from which the prices of the petroleum products returns to equilibrium after an adjustment in crude oil prices, exchange rate and inflation rate.

3.6 Granger Causality

We needed to run a causality test in order to explore if there is a "Granger causality" among the analyzed variables. A Wald test is commonly used to test for the Granger causality. Each row of the table reports a Wald test that the variable in the "excluded" column does not Granger cause the variable in the "equation" column. Causality tests answer the question which of the observed commodities is a price leader and which are the price followers, or that none of the commodities is more important than the other (Ciaian, 2011). The fundamental Granger causality method is based on the hypothesis that the compared series are stationary or I(0). Hassapis *et al.* (1999) show that in the absence of cointegration, the direction of causality can be decided upon via the standard F-tests in the first differenced VAR. X Granger causes Y, if the past values of X can help to explain Y.

To analyse the causal relationship between the prices of crude oil and the prices of petroleum products in Ghana, the study made use of Wald's Granger Causality test developed by Granger (1969). The test is one of the most interesting and widely used VAR applications.

The intuition behind it is that if previous values of variable X significantly influence current values of variable Y, then it suffices to say that X granger causes Y. This statement implies that the variable X is very useful in predicting Y. Since this technique is used in several economic studies, only a brief explanation of this method is provided below. A general specification of the Granger causality test in a bivariate (X, Y) context can be expressed as Equation (3.20):

$$
\begin{cases}
y_t = \alpha_o + \sum_{i=1}^{n} \alpha_i y_{t-i} + \sum_{j=1}^{n} \beta_i x_{t-i} + \varepsilon_t \\
x_t = \alpha_o + \sum_{i=1}^{n} \alpha_i x_{t-i} + \sum_{j=1}^{n} \beta_i y_{t-i} + \varepsilon_t
\end{cases}
\tag{3.20}
$$

Since the independent variables are identical for each equation, this specification assures us that the error term is not correlated between the two equations and allows us to use Ordinary Least Squares. In the model, the subscripts denote time periods and is ε_t the error term or white noise. The constant parameter represents the constant growth rate of X and Y in equation 3.20, and thus the trend in these variables can be interpreted as general movements of these time-series in response to say, a change in economic fundamentals. Thus, the model specified for the Error Correction Model (ECM) based Granger causality test is as follows:

$$
\begin{aligned}
\Delta \ln PP_t = {} & \delta_0 + \sum_{i=1}^{p} \lambda_{1i} \Delta \ln PP_{t-1} + \sum_{i=1}^{q_1} \alpha_{1i} \Delta \ln CRD_{t-1} + \sum_{i=1}^{q_2} \beta_{1i} \Delta \ln EXR_{t-1} + \sum_{i=1}^{q_3} \chi_{1i} \Delta \ln INF_{t-1} \\
& \sigma_1 \mathrm{ECT}_{t-1} + \varepsilon_{1t}
\end{aligned}
\tag{3.21}
$$

$$
\begin{aligned}
\Delta \ln CRD_t = {} & \delta_0 + \sum_{i=1}^{p} \lambda_{2i} \Delta \ln CRD_{t-1} + \sum_{i=1}^{q_1} \alpha_{2i} \Delta \ln PP_{t-1} + \sum_{i=1}^{q_2} \beta_{2i} \Delta \ln EXR_{t-1} + \sum_{i=1}^{q_3} \chi_{2i} \Delta \ln INF_{t-1} \\
& \sigma_2 \mathrm{ECT}_{t-1} + \varepsilon_{2t}
\end{aligned}
\tag{3.22}
$$

$$
\begin{aligned}
\Delta \ln EXR_t = {} & \delta_0 + \sum_{i=1}^{p} \lambda_{3i} \Delta \ln EXR_{t-1} + \sum_{i=1}^{q_1} \alpha_{3i} \Delta \ln PP_{t-1} + \sum_{i=1}^{q_2} \beta_{3i} \Delta \ln CRD_{t-1} + \sum_{i=1}^{q_3} \chi_{3i} \Delta \ln INF_{t-1} \\
& \sigma_3 \mathrm{ECT}_{t-1} + \varepsilon_{3t}
\end{aligned}
\tag{3.23}
$$

$$
\begin{aligned}
\Delta \ln INF_t = {} & \delta_0 + \sum_{i=1}^{p} \lambda_{4i} \Delta \ln INF_{t-1} + \sum_{i=1}^{q_1} \alpha_{4i} \Delta \ln CRD_{t-1} + \sum_{i=1}^{q_2} \beta_{4i} \Delta \ln EXR_{t-1} + \sum_{i=1}^{q_3} \chi_{4i} \Delta \ln PP_{t-1} \\
& \sigma_4 \mathrm{ECT}_{t-1} + \varepsilon_{4t}
\end{aligned}
\tag{3.24}
$$

where ECT_{t-1} presents the lagged error correction term and Δ represents the first difference to examine the short-run dynamic. Additionally, $\varepsilon_{1t}, \varepsilon_{2t}, \varepsilon_{3t}$ and ε_{4t} represent the error terms and they should be white noise and serially uncorrelated. PP denotes petroleum product. Other variables are as previously explained. The ECM is an important model that differentiates the short-run and the long-run Granger causalities. The lag of the individual coefficients is utilised to test the significance of the short-run relationship.

3.7 Diagnostic test

For a model to be trusted, it must be robust. To check for the robustness of an estimated model, one needs to peruse various diagnostic tests. Regression diagnostics is a set of procedures available for regression analysis that seek to assess the validity of a model in any of a number of different ways. Engle's Autoregressive conditional heteroskedasticity test was used to test for the heteroskedasticity whiles the Lagrange Multiplier test was employed to test for serial correlation among the residuals of the model. The CUSUM test was also employed to test for the stability of the Error Correction Model (ECM).

3.7.1 Engle's Autoregressive conditional heteroskedasticity (ARCH) Test

Suppose there is a sequence of random variables $\{Y_t\}_{t=1}^{n}$ and a sequence of vectors of random variables, $\{X_t\}_{t=1}^{n}$. In dealing with conditional expectations of Y_t given X_t, the sequence $\{Y_t\}_{t=1}^{n}$ is said to be heteroscedastic if the conditional variance of Y_t given X_t, changes with t. The existence of heteroscedasticity is a major concern in the application of regression analysis, including the analysis of variance, as it can invalidate statistical tests of significance that assume that the modelling errors are uncorrelated and uniform hence that their variances do not vary with the effects being modeled. Because heteroscedasticity concerns expectations of the second moment of the errors, its presence is referred to as misspecification of the second order. An uncorrelated time series can still be serially dependent due to a dynamic conditional variance process.

A time series exhibiting conditional heteroscedasticity or autocorrelation in the squared series is said to have autoregressive conditional heteroscedastic (ARCH) effects. Engle's ARCH test is a Lagrange multiplier test used to assess the significance of ARCH effects

(Engle, 1982) and is similar to the Lagrange Multiplier (LM) test for autocorrelation. Consider a time series

$$y_t = \mu_t + \varepsilon_t \tag{3.25}$$

where μ_t is the conditional mean of the process, and ε_t is an innovation process with mean zero. Suppose the innovations are generated as $\varepsilon_t = \sigma_t z_t$, where z_t is an independent and identically distributed process with mean 0 and variance 1. Thus, $E(\varepsilon_t \varepsilon_{t+h}) = 0$ for all lags $h \neq 0$ and the innovations are uncorrelated. Let H_t denote the history of the process available at time t. The conditional variance of y_t is;

$Var(y_t \mid H_{t-1}) = Var(\varepsilon_t \mid H_{t-1}) = Var(\varepsilon_t^2 \mid H_{t-1}) = \sigma_t^2$

Thus, conditional heteroscedasticity in the variance process is equivalent to autocorrelation in the squared innovation process. If all autocorrelation in the original series, yt, is accounted for in the conditional mean model, then the residuals are uncorrelated with mean zero. However, the residuals can still be serially dependent.
The alternative hypothesis for Engle's ARCH test is autocorrelation in the squared residuals, given by the regression:

$$H_a : e_t^2 = \alpha_0 + \alpha_1 e_{t-1}^2 + \ldots + \alpha_m e_{t-m}^2 + \mu_t$$

Where μ_t is a white noise error process and $e_t = y_t - \hat{\mu}_t$. The null hypothesis is

$$H_0 : \alpha_0 = \alpha_1 = \ldots = \alpha_m = 0$$

3.7.2 Lagrange Multiplier (LM) test for serial correlation

Given a weakly stationary time series $\{y_t\}$, let μ denote its mean and $\gamma(.)$ denote its autocovariance function, where $\gamma(i) = \text{cov}(y_t, y_{t-i})$ for $i = 0, 1, 2, \ldots$. The autocorrelation function $\rho(.)$ is such that $\rho(i) = \gamma(i) / \gamma(0)$. The series is serially uncorrelated if, and only if, its autocorrelation function is identically zero.

The Breusch–Godfrey test, named after Trevor S. Breusch and Leslie G. Godfrey, is used to assess the validity of some of the modelling assumptions inherent in applying regression-like models to observed data series (Breusch (1978); Godfrey (1978)). It specifically tests for the presence of serial correlation that has not been included in a proposed model structure and which, if present, would mean that incorrect conclusions would be drawn from other tests, or that sub-optimal estimates of model parameters are obtained if it is not taken into account.

The regression models to which the test can be applied include cases where lagged values of the dependent variables are used as independent variables in the model's representation for later observations. Because the test is based on the idea of Lagrange multiplier testing, it is sometimes referred to as LM test for serial correlation. The Breusch–Godfrey serial correlation LM test is a test for autocorrelation in the errors in a regression model. It makes use of the residuals from the model being considered in a regression analysis, and a test statistic is derived from these. The null hypothesis is that there is no serial correlation of any order up to p.

Consider a linear regression of the form:

$$Y_t = \alpha_0 + \alpha_1 X_{t,1} + \alpha_2 X_{t,2} + \mu_t \tag{3.26}$$

Where the errors follow an AR(p) autoregressive as follows:

$$\mu_t = \rho_1 \mu_{t-1} + \rho_2 \mu_{t-2} + \ldots + \rho_p \mu_{t-p} + \varepsilon_t$$

The simple regression model is first fitted by ordinary least squares to obtain a set of sample residuals $\hat{\mu}_t$. Breusch and Godfrey (1980) proved that, if the auxiliary regression model (equation 3.23) is fitted, and if its R^2 statistic is calculated, then the following asymptotic approximation can be used for the distribution of the test statistic $nR^2 \sim \chi_p^2$, when the null hypothesis holds. Where $n = T - p$ the number of data points is available for the regression model in equation 3.23, T is the number of observations in the basic series and p the number of lags of the error term.

$$\hat{\mu}_t = \alpha_0 + \beta_1 X_{t,1} + \beta_2 X_{t,2} + \rho_1 \hat{\mu}_{t-1} + \rho_2 \hat{\mu}_{t-2} + \ldots + \rho_p \hat{\mu}_{t-p} + \varepsilon_t \tag{3.27}$$

3.7.3 Stability Test

To avoid functional form misspecification caused by the volatility of the time series data, the stability test for the parameters is required. The Cumulative Sum (CUSUM) test is employed to verify the stability of the parameters in the ECM model (Pesaran and Pesaran, 1997). In time series analysis, the CUSUM statistics use the sequence of residual deviations from a model to indicate whether the autoregressive model is misspecified.

CHAPTER 4

ANALYSIS AND DISCUSSIONS OF RESULTS

4.1 Overview

This chapter presents the analysis and discussions of results for the study. The chapter is divided into 4 sections. The description of the data is presented in Section 1. Section 2 accounts for the Unit Root tests and Cointegration test. Results for the Short and Long Run estimates from the Cointegration model is presented and discussed in Section 3. Section 4 deals with the Granger Causality test.

4.2 Preliminary Analysis

4.2.1 Descriptive Statistics

The descriptive statistics for all the seven variables are presented in Table 4.1. From the table, it can be seen that the distributions of the all the variables with the exception of crude oil are far from being normal. This is due to the fact that the values of the skewness and kurtosis for a normal distribution must be 0 and 3 respectively. Also, the Jarque-Bera probability values for all the variables with the exception of crude oil are below the 0.05 critical level. This suggests a rejection of the null hypothesis of normal distribution for all the prices of the petroleum products at 5 percent level of significance. Gasoline and Gas oil are yielding the highest prices, whereas Residual fuel oil and Premix fuel show the lowest values as expected. Although mean prices differ widely, the coefficients of variations (a measure of the deviation of a variable from its mean) are pretty similar to one another. The skewness statistics show that five of the variables: residual fuel oil prices, premix prices, crude oil prices, exchange rate and inflation rate are positively skewed, while the prices of gasoline and gas oil are negatively skewed.

A correlation analysis on the prices of Crude oil and its products is performed. It is observed from the table that the prices of Gasoline and Gas oil have a moderate positive relationship with Crude oil whiles Premix prices appears to have a very weak correlation with Crude oil. There is a high degree of co-movement between Gas oil and Gasoline. It can also be noted that Premix is less correlated with the other three Oil products which may be due to the fact that Premix faces a high degree of possible substitution to other Fuels in its use.

Figures 4.1 to 4.5 depict the prices of Crude oil and its corresponding four products during the period of 2009–2019. From the Figures 4.1 and 4.2, it is evident by inspection of the strong correlation between the prices of Gas oil and Gasoline. It is also clear that the prices of Premix have a weak correlation with the prices of Crude oil and the prices of the other three Crude oil products.

Table 4. 1 Descriptive Statistics

	GLN	GOIL	RFO	PREMIX	CRD	EXR	INF
Mean	0.906	0.902	0.406	0.364	211.474	2.971	13.039
Max.	1.120	1.130	0.649	0.574	414.747	5.815	20.740
Min.	0.590	0.456	0.195	0.270	53.249	1.226	8.390
S.D.	0.123	0.133	0.120	0.063	81.320	1.435	3.819
Obs.	125	125	125	125	125	125	125

Table 4. 2 Correlation Analysis

	CRUDE OIL	GASOLINE	GAS OIL	RFO	PREMIX
CRUDE OIL	1.00	0.49	0.40	-0.28	-0.03
GASOLINE	0.49	1.00	0.93	0.52	0.20
GAS OIL	0.40	0.93	1.00	0.57	0.19
RFO	-0.28	0.52	0.57	1.00	0.42
PREMIX	-0.30	0.20	0.19	0.42	1.00

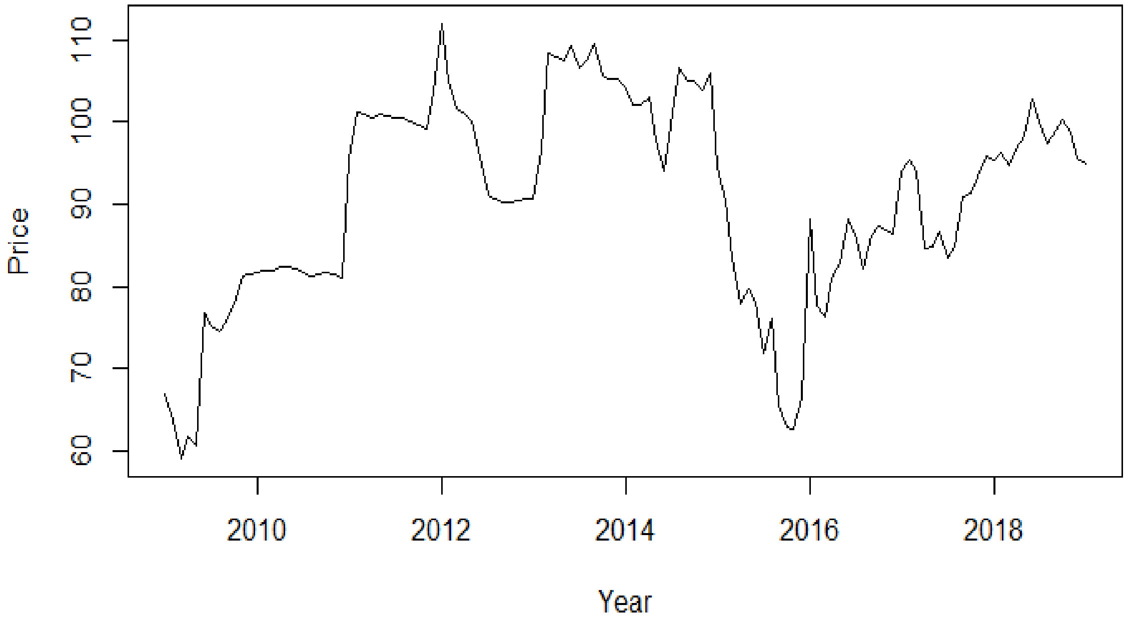

Figure 4. 1 Graph of Gasoline Prices

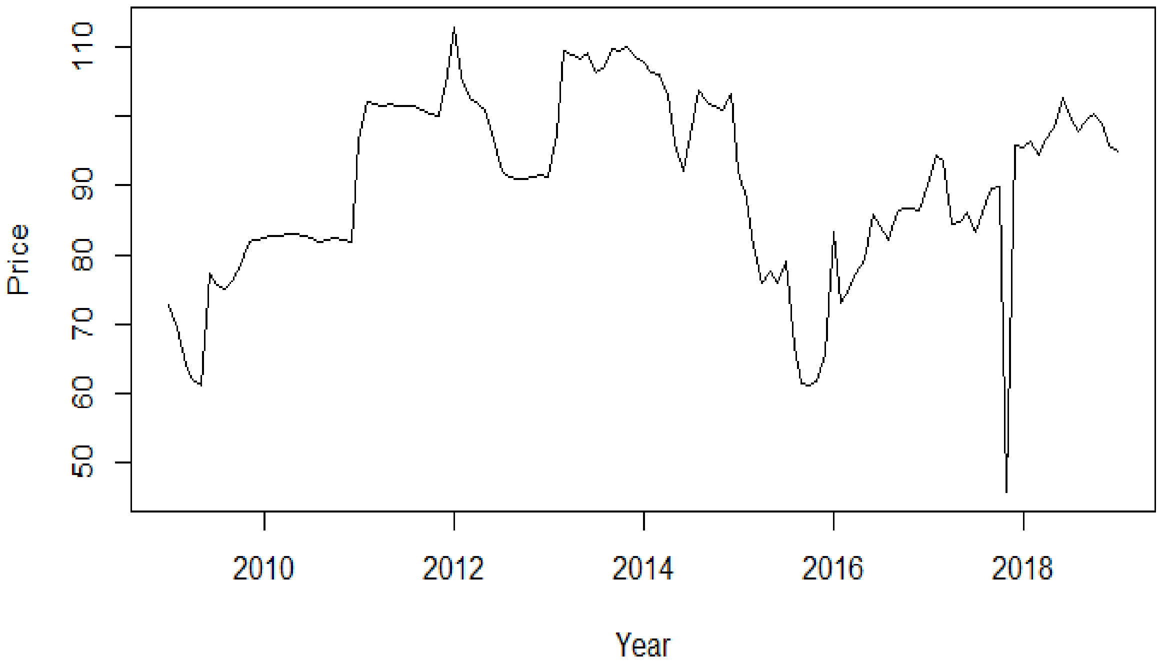

Figure 4. 2 Graph of Gas Oil Prices

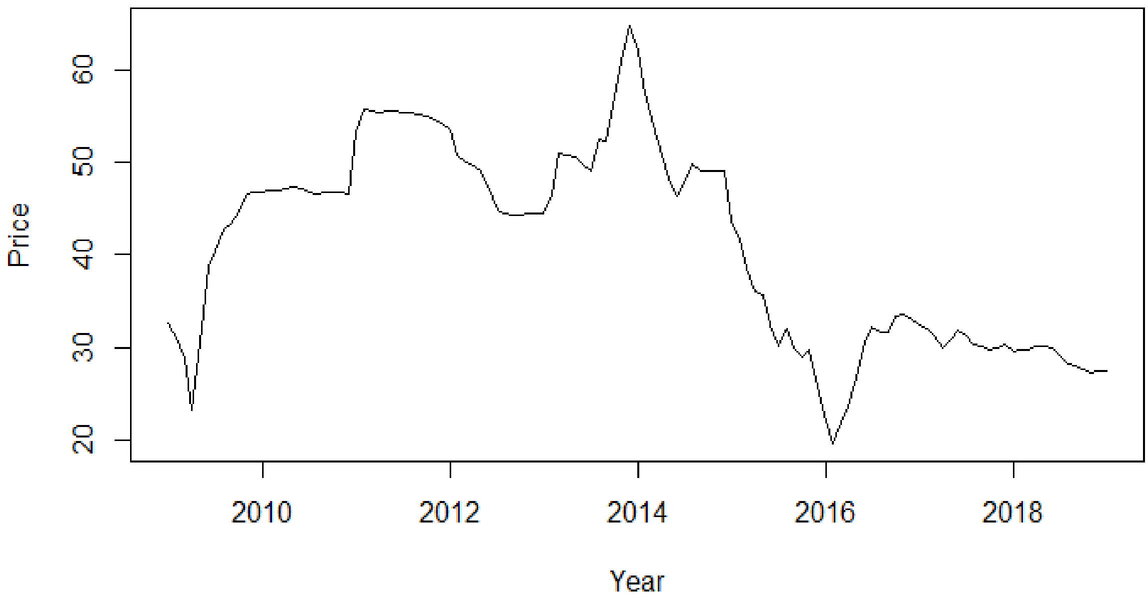

Figure 4. 1 Graph of RFO prices

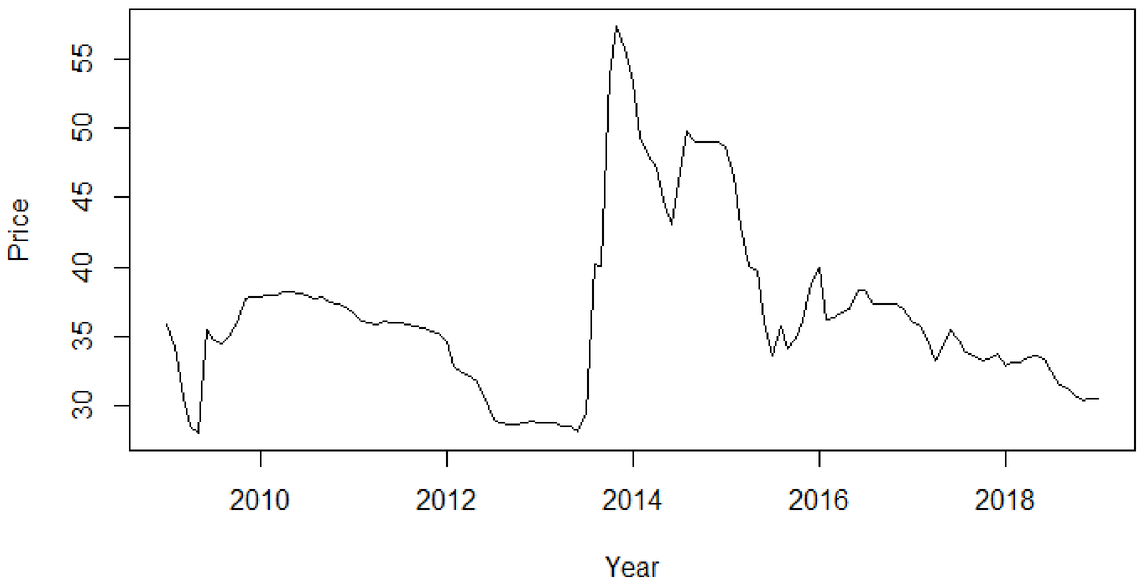

Figure 4. 4 Graph of Premix Prices

Figure 4. 5 Graph of Crude Oil Prices

4.3 Results and Discussions

4.3.1 Unit Root Test

A non-stationary time series can lead to statistically insignificant results due to a purely spurious correlation (Ghouse *et al.*, 2018). It is therefore necessary to test for the stationarity of the prices of Crude oil, Gasoline, Gas oil, Residual Fuel Oil and Premix and that of Exchange rate and Inflation rate before performing a cointegration test. Three tests were employed to check for the stationarity of the prices of Crude Oil, its products prices, Exchange rate and inflation rate. The tests employed include the Augmented Dickey Fuller (ADF) test, the Phillips Perron (PP) test, and the Kwiatkowski Phillips-Schmidt-Shin test (KPSS). The tests were conducted considering the constant term.

The null hypothesis for both the ADF and PP tests is that the series contains a unit root whiles that of the KPSS test is that the series has no unit root. From the Table 4.2 the sign ** denotes the rejection of null hypothesis of unit root at the 5% significance level.

The test statistics for the ADF is compared with simulated critical values from Elliott *et al.* (1996). The lag length in the test was selected based on the Schwarz information criterion (SIC). All the tests as indicated in Table 4.2 showed that the prices of Crude oil, Gasoline, Gas oil, Residual Fuel Oil and Premix are all not stationary at level but stationary at the first difference (that is, they are integrated of order 1).

Table 4. 3 Unit Root Test

	Level			First difference		
Variable	**ADF**	**PP**	**KPSS**	**ADF**	**PP**	**KPSS**
Crude oil	-1.874	-1.503	0.479**	8.124**	-7.978**	0.289
GASOLINE	-2.558	-2.596	0.192**	10.692**	10.684**	0.128
GAS OIL	-2.713	-3.079	0.156**	14.992**	15.745**	0.087
RFO	-1.490	-1.144	0.753**	-6.996**	-6.960**	0.246
Premix	-2.778	-2.177	0.148**	-5.912**	-8.687**	0.085
Exchange rate	-0.058	-0.304	1.312**	-7.393**	-7.311**	0.098
Inflation rate	0.808	0.828	1.299**	-8.258**	-8.258**	0.239

4.3.2 Optimal Lag Selection

In other to perform the Johansen cointegration test, an appropriate lag length must be selected in order not to lose degrees of freedom and not to obtain statistically insignificant coefficients as a result of selecting too many lags or too few lags. Among the 8 lag lengths selected by the Schwarz's Bayesian Information Criterion (SBIC), the information lost for the Premix was least at lag 1 which resulted in the selection of a lag length of 1 as the optimal lag length for Premix fuel. The least information lost for the RFO occurred at the lag 3, therefore the optimal lag length of RFO selected by the VAR lag order selection was 3. A lag length of 2 was finally selected as the optimal lag length of Gasoline and Gas oil. Table 4.3 shows the results for the VAR lag selection. The sign "*" on the table indicates the optimal lag order selected by the criterion.

Table 4. 4 VAR Lag Order Selection

	Schwarz's Bayesian Information Criterion (SBIC)			
Lag	GASOLINE	GAS OIL	RFO	PREMIX
0	-7.463614	-6.943632	-7.123182	-6.608263
1	-19.98262*	-18.48548*	-20.21562*	-20.06844*
2	-19.94021	-18.32252	-20.21259	-19.77368
3	-19.46667	-17.82790	-19.70312	-19.36468
4	-19.15853	-17.50102	-19.31162	-18.90320
5	-18.78430	-17.11636	-18.92486	-18.49624
6	-18.49124	-16.67345	-18.43850	-17.99979
7	-18.03957	-16.32693	-18.21306	-17.63372
8	-17.58983	-16.02017	-17.70570	-17.15064

4.3.3 Cointegration Test

To investigate the existence of a long-term relationship between the prices of Crude oil and its products prices, cointegration analysis was performed. The Johansen test and ARDL Bounds test approach were used to test for long run relationship between the prices of crude oil and its products and the results are presented in Table 4.3 and Table 4.4. Results from both the Trace test and the Maximum Eigen value test of the Johansen cointegration test rejected the null hypothesis of no cointegration equation among the prices of Crude oil and the prices of Gasoline, Gas oil, RFO and Premix at the 5% level. Both tests also failed to reject the null hypothesis of the existence of cointegration equations for the at least one, at least two, and at least three at the 5% level. From the two test it was inferred that there exist at least one cointegration equation among the prices of Crude oil and its products' prices. The ARDL bounds test used as a robust check for cointegration showed the presence of cointegration among the prices of Crude oil and the prices of Gasoline, Gas oil and RFO but failed to reject the null hypothesis of no cointegration between the prices of Crude oil and Premix fuel. From Table 4.6, the F-statistic (5.92, 11.24 and 5.27) of Gasoline, Gas Oil and RFO respectively clearly exceeds both the lower and upper bounds at the 5% significance level which confirms the existence of a long run relation among the prices of Crude oil and Gasoline, Gas Oil and RFO. The F-statistic (3.89) of Premix falls below the upper bound at the 5% significance level, nullifying the existence of a long run relationship among the prices of Crude oil and the prices of Premix. The results of the Johansen cointegration test (Trace test and Maximum Eigenvalue test) and the bounds test are displayed in tables 4.4, 4.5 and 4.6 respectively.

Table 4. 5 Trace Test

Null Hypothesis No. of Cointegration Equation(s)	GASOLINE	GAS OIL	RFO	Premix
None	57.69371 [0.273972] (47.85613)	59.32693 [0.253592] (47.85613)	58.41314 [0.246437] (47.85613)	56.63716 [0.266472] (47.85613)
At most 1	18.31322 [0.102743] (29.79707)	23.35148 [0.143921] (29.79707)	23.61118 [0.136290] (29.79707)	18.52081 [0.088545] (29.79707)
At most 2	4.978399 [0.037317] (15.49471)	4.238157 [0.031813] (15.49471)	5.589445 [0.039141] (15.49471)	7.117048 [0.045972] (15.49471)
At most 3	0.300610 [0.002441] (3.841466)	0.261510 [0.002124] (3.841466)	0.678386 [0.005500] (3.841466)	1.328364 [0.010742] (3.841466)

Table 4. 6 Maximum Eigen Value Test

Null Hypothesis No. of Cointegration Equation(s)	GASOLINE	GAS OIL	RFO	Premix
None *	39.38049 [0.273972] (27.58434)	35.97546 [0.253592] (27.58434)	34.80196 [0.246437] (27.58434)	38.11636 [0.266472] (27.58434)
At most 1	13.33482 [0.102743] (21.13162)	19.11332 [0.143921] (21.13162)	18.02173 [0.136290] (21.13162)	11.40376 [0.088545] (21.13162)
At most 2	4.677789 [0.037317] (14.26460)	3.976647 [0.031813] (14.26460)	4.911060 [0.039141] (14.26460)	5.788684 [0.045972] (14.26460)
At most 3	0.300610 [0.002441] (3.841466)	0.261510 [0.002124] (3.841466)	0.678386 [0.005500] (3.841466)	1.328364 [0.010742] (3.841466)

Table 4. 7 ARDL Bounds Test

	GASOLINE	GAS OIL	RFO	Premix
F-Statistics	5.92	11.24	5.27	3.89
5% lower bound	4.94	3.23	3.23	3.23
5% upper bound	5.73	4.35	4.35	4.35
Remark	Long run relationship exists	Long run relationship exists	Long run relationship exists	No long run relationship exists

4.3.4 Model Estimation

Since the results from both the Johansen and the ARDL Bounds cointegration tests are clearly depicting the presence of a long-run relationship between the prices Crude oil and Gasoline, Gas oil and RFO, equation 1 was estimated using ARDL-ECM. The short and long run equation could not be estimated for the prices of Premix fuel since the results from the ARDL bounds test could not provide enough evidence of long run relationship between the prices of Crude oil and Premix fuel.

Model selection criteria

The ARDL-ECM were selected based on the Schwarz Bayesian Criteria. The information criteria estimated 500 different ARDL models and out of the 500 models, the ARDL (1,0,1,0) ARDL (1,0,0,0) and the ARDL (2,0,2,0) were found to be the models with the least information lost thereby becoming the best models for Gasoline, Gas oil and RFO respectively. Figure 4.2 shows the graphical representation of the Schwarz Criteria selection focusing on the top 20 models with respect to the minimal information lost.

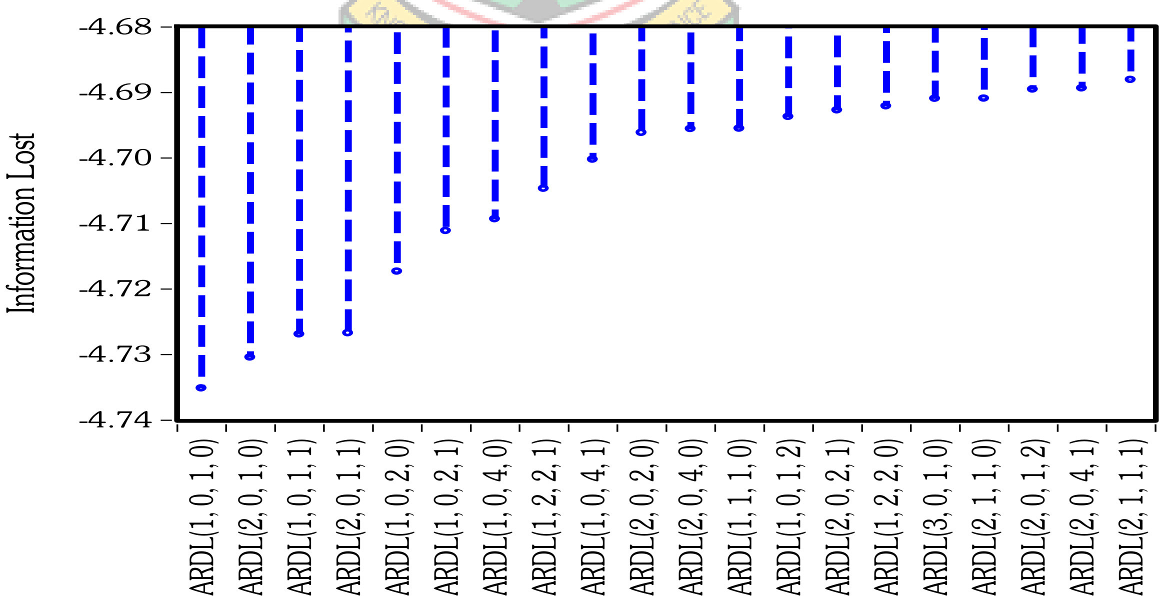

Figure 4. 2 Model for Gasoline

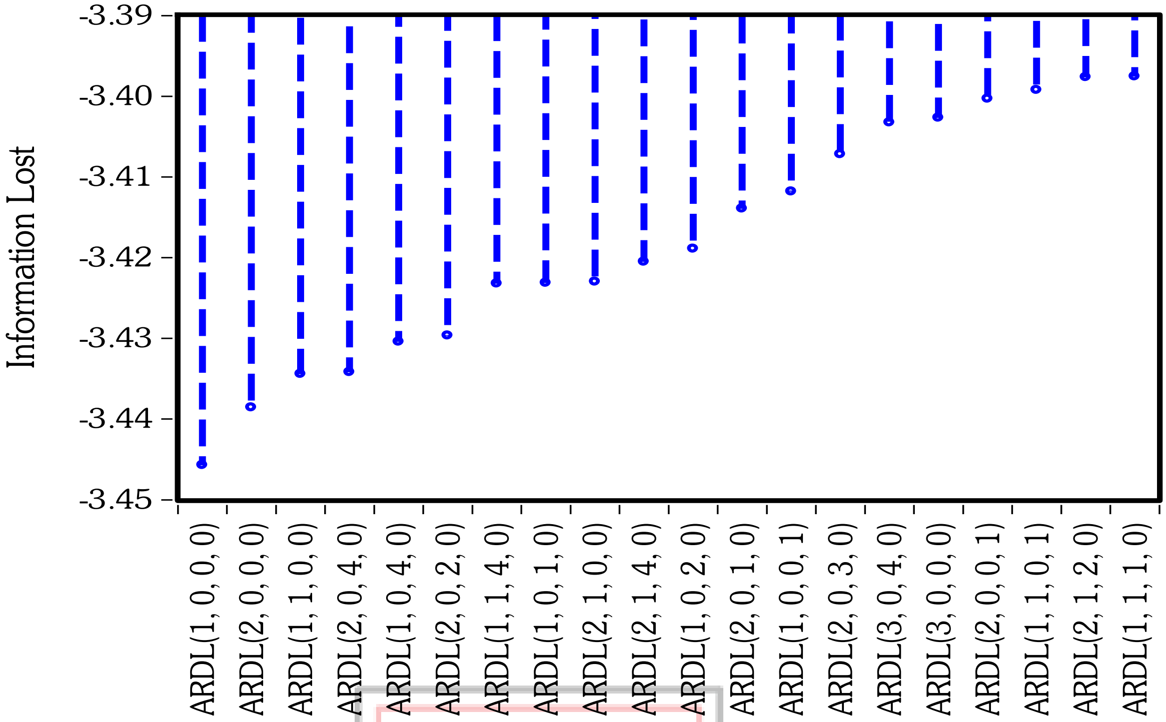

Figure 4. 3 Model for Gas oil

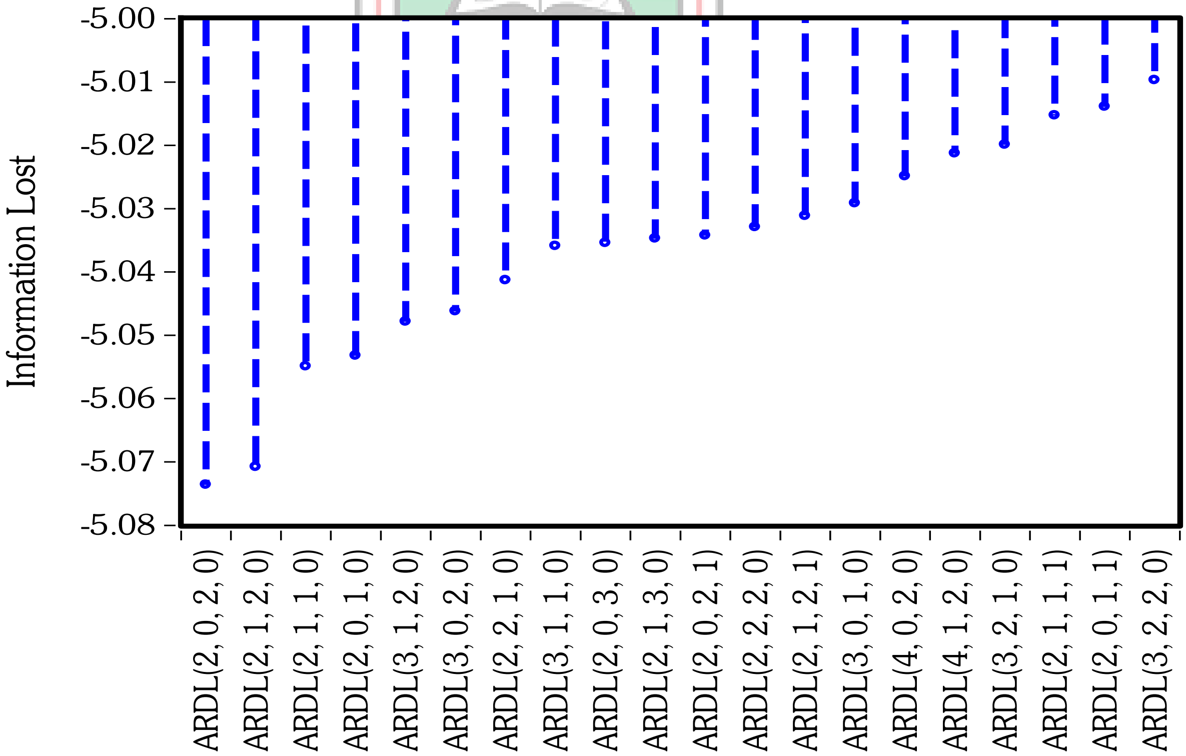

Figure 4. 4 Model for RFO

4.4 Long Run and Short Run Estimates

The results obtained from the Long run and the Short run estimation of the ARDL Error Correction Model (ECM) for the prices of Crude oil and petroleum products are presented in Table 4.7 and Table 4.8 respectively. The error correction coefficients were negative and significant as desired showing the direction and speed of adjustment towards the long run equilibrium. The negative sign implies that, in the absence of disparity in the independent variables, a shift of the previous months deviation from the long run is corrected in the current period at adjusted speeds of -0.172125, -0.488370 and -0.179091, representing error correction coefficients of Gasoline, Gas oil and RFO respectively.

The results from the estimates of the error correction model, the prices of Crude oil, exchange rate and inflation rate affect the prices of petroleum products in Ghana in a unique way in both the short run and the long run. It is evident from the results that the prices of crude oil have a positive and significant effect on the prices of Gasoline, Gas oil and RFO. Hence, an increment in the prices of crude oil increases the prices of Gasoline, Gas oil and RFO and thus a decrease in the prices of crude oil decreases the prices of Gasoline, Gas oil and RFO in both the long and the short run.

Exchange rate on the other hand has a negative and significant effect on the prices of Gasoline, Gas oil and RFO in both the short and the long run. This is so because, an increment in a country's exchange rate implies a high purchasing power of the country. Hence an increment in the exchange rate decreases the amount of money needed to be payed to purchase crude oil for the production of petroleum products in Ghana and the vice versa in both the short and the long run. Inflation rate has a significant and positive effect on only the prices of Residual fuel oil in both the short and long run since most of the RFO produced in the country is exported. Hence foreigners need to pay more when inflation goes up and less when inflation goes down. It can also be inferred that, RFO is affected the lag of itself and exchange rate in the short run.

The coefficient of inflation for the prices of Gasoline and Gas oil were positive and negative respectively but were however insignificant even at 10% level, implying that, all things being equal, changes in the rate of inflation does not affect the prices of Gasoline and Gas oil in Ghana.

Table 4. 8 Results for the Short Run Estimate

Variable	Model 1 (GASOLINE)	Model 2 (GAS OIL)	Model 3 (RFO)
D(PP(-1))	---	---	0.312434 (0.079291) [3.940328]
D(LNCRD)	0.085429* (0.027293) [3.130070]	0.178000* (0.046941) [3.791989]	0.133713* (0.030350) [4.405708]
D(LNEXR)	-0.876944* (0.170659) [-5.138571]	-0.122831* (0.034801) [0.034801]	-0.958431* (0.180677) [-5.304675]
D(LNEXR(-1))	---	---	0.303154 (0.198790) [1.524995]
D(LNINF)	0.015811 (0.020601) [0.767507]	-0.034775 (0.037981) [-0.915578]	0.066610* (0.022876) [2.911775]
CointEq(-1) ϕ	-0.172125* (0.051912) [-3.315680]	-0.488370* (0.077285) [-6.319067]	-0.179091* (0.032252) [-5.552807]

Table 4. 9 Results from the Long Run Estimates

Variable	Model 1 (GASOLINE)	Model 2 (GAS OIL)	Model 3 (RFO)
LNCRD	0.496323* (0.125394) [3.958124]	0.364479* (0.076352) [4.773654]	0.746618* (0.128562) [5.807475]
LNEXR	-0.338945* (0.102727) [-3.299486]	-0.251513* (0.060751) [-4.140072]	-0.956048* (0.100838) [-9.481029]
LNINF	0.091860 (0.128141) [0.716868]	-0.071205 (0.076927) [-0.925624]	0.371933* (0.124469) [2.988169]
C	-1.111401* (0.357072) [-3.112541]	-0.700362* (0.216763) [-3.231012]	-2.112110* (0.363466) [-5.811028]

4.5 Granger Causality Test

After confirming the long-run relationship between the prices of crude oil and gasoline prices, gas oil prices and residual fuel oil prices by applying the ARDL bounds test, the Granger causality can be applied to investigate the direction of causality among the variables. The Error Correction Model (ECM) based Granger causality test is applied to investigate the direction of causality between the dependent and the independent variables.

The null hypothesis that Crude oil does not Granger causes Gasoline; Gas oil; and RFO was rejected at the 5% level but the vice versa was not rejected which implies that there exists a uni-causal relationship running from Crude oil to Gasoline, Gas oil and RFO over the study period. Thus, the prices of Crude oil provide useful information in estimating the prices of Gasoline, Gas oil and RFO in Ghana.

The null hypothesis of exchange rate not causing Gasoline, Gas oil and RFO prices and the vice versa was rejected which implies a bi-causal relation between the prices of exchange rate the prices of Gasoline, Gas oil and RFO. Hence it can be inferred from the results that past information on exchange rate and the prices of the three petroleum products can be used to predict each other in Ghana. There was no evidence of causality between inflation and the prices of petroleum products in Ghana.

Table 4. 10 Granger Causality Test

Null Hypothesis	F-Statistic	Prob.
LNCRD does not Granger Causes LNGASOLINE	9.7973	0.0022
LNGASOLINE does not Granger Causes LNCRD	13.5853	0.1228
LNEXR does not Granger Causes LNGASOLINE	26.40491	0.0000
LNGASOLINE does not Granger Causes LNEXR	13.5854	0.0004
LNINF does not Granger Causes LNGASOLINE	0.5891	0.4443
LNGASOLINE does not Granger Causes LNINF	0.0678	0.7952
LNCRD does not Granger Causes LNGASOIL	14.3792	0.0002
LNGASOIL does not Granger Causes LNCRD	0.4997	0.4811
LNEXR does not Granger Causes LNGASOIL	12.4574	0.0006
LNGASOIL does not Granger Causes LNEXR	6.9829	0.0093
LNINF does not Granger Causes LNGASOIL	0.8383	0.3617
LNGASOIL does not Granger Causes LNINF	0.7413	0.3910
LNCRD does not Granger Causes LNRFO	19.4103	0.0000
LNRFO does not Granger Causes LNCRD	22.7039	0.2110
LNEXR does not Granger Causes LNRFO	28.1396	0.0000
LNRFO does not Granger Causes LNEXR	44.4070	0.0000
LNINF does not Granger Causes LNRFO	8.4784	0.0043
LNRFO does not Granger Causes LNINF	0.2667	0.6066

4.6 Diagnostic Test

In other to validate that the ARDL-ECM developed has a good predictive relationship, regression diagnostics are used. The ARDL-ECM Residual Serial Correlation LM tests indicated that there is no serial correlation problem in the estimation. The heteroskedasticity tests with the Chi-squared statistic also specified that heteroskedasticity is eliminated from the data. Results from serial correlation and heteroskedasticity tests are presented in Table 4.10.

Table 4. 11 Test for Serial Correlation and Heteroskedasticity

	Model 1 (Gasoline)	Model 2 (Gas oil)	Model 3 (RFO)
LM-Statistics	2.308815 (0.1313)	4.999141 (0.2480)	3.816142 (0.0532)
Chi-Square Statistics	0.077411 (0.7791)	1.169994 (0.3013)	0.451846 (0.8754)

4.7 Stability Test

It is required to perform a stability test to avoid functional form of misspecification caused by the volatility of the time series data, the stability test for the parameters is required. The Cumulative Sum (CUSUM) tests is employed to verify the stability of the parameters in the Error Correction Model (Pesaran and Pesaran, 1997). The result is shown in Figure 4.9. As shown in the Figure, the CUSUM plots lie within the critical bounds at the 5 percent significance level, which confirms the stability of the parameters. Accordingly, the models and their corresponding parameters for the prices of crude oil and its products in Ghana are reliable.

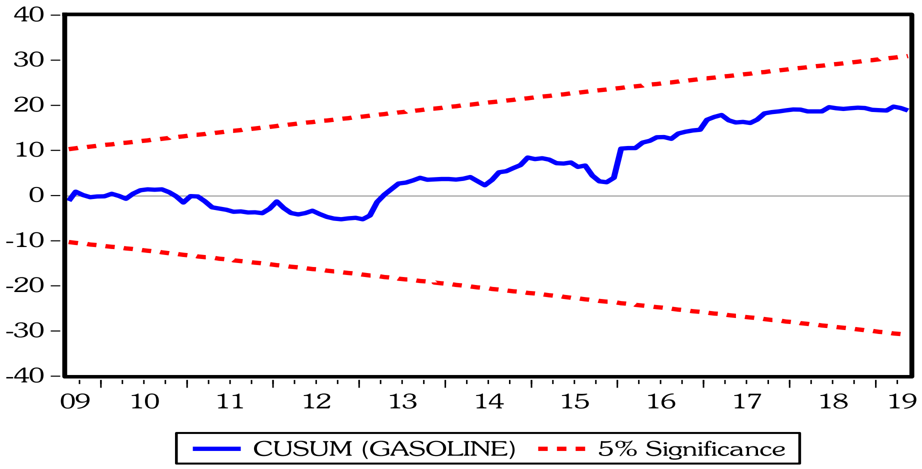

Figure 4. 5 CUSUM Plots of the Residuals of Gasoline Prices

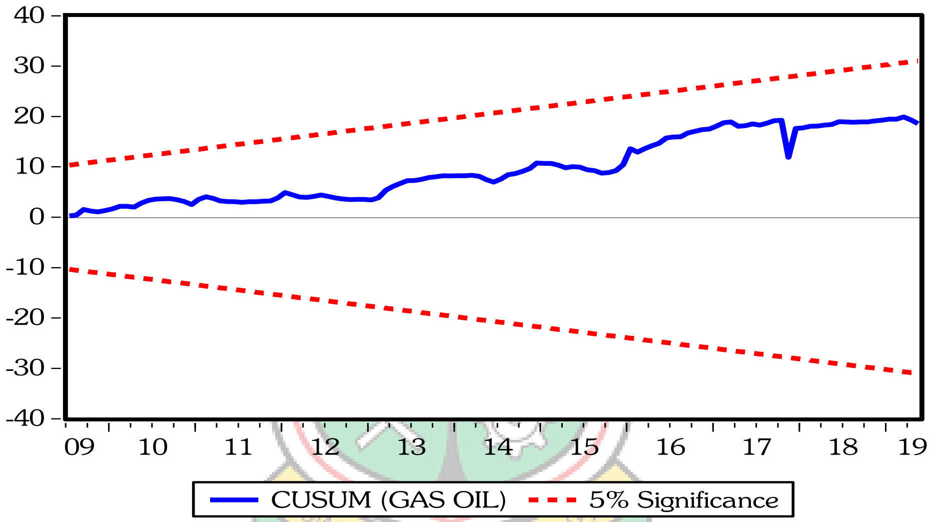

Figure 4. 6 CUSUM Plots of the Residuals of Gas Oil Prices

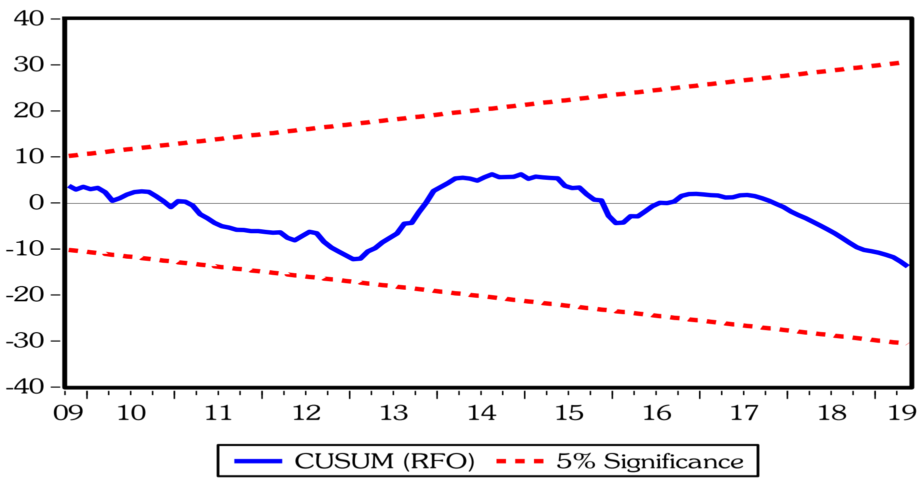

Figure 4. 7 CUSUM Plots of the Residuals of RFO Prices

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

This chapter presents the conclusions and recommendations derived from the results of the research.

5.2 Conclusions

This research examined the long run relationship between the prices of crude oil and petroleum products in Ghana. From Table 4.3, the unit root tests showed that all the series were integrated of order one. Results from the cointegration analysis showed evidence of long-run relationship between the prices of crude oil and Gasoline, Gas oil and Residual fuel oil. The prices of crude oil showed no long run relationship with the prices of Premix fuel. From the ARDL error correction model estimates evidenced on Tables 4.8 and 4.9, crude oil prices have a significant positive effect on the prices of Gasoline, Gas oil and Residual fuel oil in both the short and the long run. Exchange rate has a significant negative effect on the prices of Gasoline, Gasoil and Residual fuel oil in both the short and long run. Inflation has a significant positive effect on only the prices of Residual fuel oil in both the short and the long run. Results from the Wald's Granger Causality test indicated a uni-causal relationship running from Crude oil to Gasoline, Gas oil and RFO. There is a bi-causal relationship between Exchange rate and Gasoline, Gas oil and RFO. There is no causal relationship between Inflation rate and Gasoline, Gas oil. There is a uni-causal relationship running from Inflation rate to RFO.

5.2 Recommendations

This is a time series approach of estimating the relationship between the prices of crude oil and other petroleum products in Ghana. I therefore recommend that other techniques from various fields also be performed to establish the dependency of the prices of crude oil and its products in Ghana. The interdependencies of the prices of crude oil and its products in Ghana can also be researched into. Further research can be performed to investigate the relationship between the prices of crude oil and other petroleum products in Ghana.

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