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İçindekiler

LONG RUN EVALUATION OF CRUDE OIL PRICES: STRUCTURAL BREAKS, LONG MEMORY OR NONLINEARITY?[1]

ABSTRACT

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The crude oil is such an important energy type that forecasting its prices both in particular and in other types of energy prices in general over time has been widely discussed in the literature. Under the Hotelling modelling tradition, much of the controversy is linked to this choice of a stochastic process to represent the evolution of the exhaustible resource's price, and asks whether crude oil prices are best modelled in the long-run as a random walk or as mean reverting. With the thought that we could attain some useful inference about crude oil market and its supply and demand structure, the time-series properties of crude oil prices have been examined again in this paper by applying some tests, such as the standard linear parametric tests of stationarity with structural breaks (Zivot and Andrews; Bai and Perron), the standard linear parametric tests of stationarity without structural breaks (Augmented Dickey Fuller; Phillips and Perron; Kwiatkowski, Phillips, Shin and Schmidt; Dickey-Fuller with generalized least squares de-trending (DF-GLS) test; Elliot, Rothenberg, and Stock point optimal; Ng and Perron modified versions of the P-P and Ng and Perron ERS point optimal) fractional unit root tests (Geweke and Porter-Hudak; Robinson

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Gaussian Semi-parametric Estimator) and parametric non-linear tests (Caner and Hansen; Kapetanios, Shin and Snell), on a secular annual series of crude oil prices to identify their most useful properties. Because of testing the Hotelling model, it is significant to use an historical data set. I examine the long run behaviour of crude oil covering the 150-year period (1861-2010). According to linear unit root tests with and without structural break, crude oil has generally been found as a random walk process. Also, the endogenous structural breaks are significant but they have not affected the random walk process of these series. And yet, crude oil price series have also been found non-stationary with reference to fractional unit root test result. But integration order has been found smaller than one for crude oil prices. Moreover, I have found that we can reject the null hypothesis of linearity in favour of the alternative, that there is a threshold effect in the price series barring crude oil price case with intercept, indicating that simple linear models are inappropriate.

1. Introduction

The crude oil is such a fundamentally important commodity that it forms the basis of most modern production modes and life styles. It is considered one of the most important commodities in the world, whose consumption is about 87 million of barrels per day. The role of natural gas as a major source of energy has also increased. Nearly 55 per cent of the world energy consumption comes from crude oil and natural gas. World proved reserves are more or less the same for natural gas and oil, roughly one trillion barrels of oil equivalent for each. The world economy would decline without oil and natural gas on which we are dependent in several aspects in different stages of our life. The importance of these fuels requires an increased understanding of their market structures and price dynamics to assess the potential impacts of their shocks not only on importing countries but also on exporting countries whose budgets (e.g., Saudi Arabia, Russia, Venezuela, Mexico, and etc.) are strongly linked to actual and estimated crude oil and natural gas prices (Bernabe et al., 2004).

Globalization and liberalization have come to permeate every aspect of the oil industry, but also, more dramatically, the natural gas industry. "The world oil market, like the world ocean, is one great pool," said Adelman (1984) in order to emphasize the degree of integration of the world crude oil market, i.e., the existence of one single market. Contrary to Adelman, Weiner (1991) claims that the world oil market is far from completely unified. This issue has still been argued empirically by many researchers to determine which interpretation is the more consistent. But the general thinking is that crude oil has been bought and sold internationally by many different players—oil-producing nations, oil companies, individual refineries, oil importing nations and speculators. The crude oil market, historically, have undergone a structural transformation from the Rockefeller oil monopoly at the end of the nineteenth century in the USA to the Seven Sisters International Oil Cartel in 1928, leading to the several attempts by a number of European state-owned companies to break the Major's dominance after the Second World War, and finally to the OPEC leadership to determine oil prices (Bourbonnais and Geoffron, 2007; Chevalier, 2007). The regulation of prices conducted mainly by USA and OPEC countries also played an essential role in this scenery. Actually, in spite of much effort by OPEC to set production at a level low enough to stabilize crude oil prices, many of these attempts did not work as OPEC expected. Moreover, one must realize that the price series of crude oil is formed by cycles, some of which are caused by shocks related to the success of OPEC's policy for price stabilization, and others of which are caused by shocks related to OPEC's failure (Tabak and Cojueiro, 2007).

Crude oil market has been subject to various supply and demand shocks and consequently has been highly volatile. Examples of positive shocks are strikes, wars and conflicts; negative shocks are produced, for example, by announcements of oil discoveries or by the development of new technologies. Crude oil prices are also influenced by events like the weather, stock levels, and market sentiment. For example, the following events had considerable influence on energy consumption and expenditures and thereby crude oil prices the world over: The Yom Kippur War which started with an attack on Israel by Syria and Egypt in 1973; the 1978 Iranian revolution, accompanied by escalating oil prices and a period of high inflation during the late 1970s; the world-wide recession in the early 1980s; the 1985 crash in oil prices; the industrialized countries' moderate economic growth and low inflation periods in the late 1980s and early 1990s; the uncertainty associated to the Iraqi invasion of Kuwait in 1990 and the subsequent Gulf War; the 1997–1999 Asian financial crisis, in a period when most Asian countries were still developing, when news came from the oil-producing countries' agreement to lower production to raise oil prices; the beginning of USA military action in Iraq on March of 2003; and the "Fundamentals of Climate Change Convention" and the "Kyoto Protocol". These kinds of events, the more important of which are mentioned above, brought about structural change in the market condition. For example, oil prices have behaved radically differently after 1986 than before (Hamilton, 1996; Postali and Picchetti, 2006; Tabak and Cojueiro, 2007). This change, being toward the spot market, was expedited by the second oil shock accompanying the Iranian Revolution, rendering contract prices unreliable. Historically, crude oil has been traded on the world market mostly under long-term contracts at official prices of exporting countries. Although the spot markets for oil have existed since the 1960s, trading in spot markets accounted for only 3 to 5 percent of the total trade before 1980. This share, however, reached 50 percent internationally during the first half of the 1980s. Again, environmental concerns have become the major guidelines for the formulation of energy policy and business management plans in most countries, but yet not all. Increasingly, natural gas is the fuel of choice for consumers seeking its relatively low environmental impact, especially for electric power generation. In many, natural gas has gained further importance due to tighter environmental rules. It has also gained weight due to the fact that liberalization has created additional pressure to select the least cost options. A change in administration's energy policy results in an important impact on people's energy consumption habits, and these changes in the priorities also affect supply, demand and ultimately prices of crude oil (Victor, et al., 2006; Chen and Lee, 2007).

Economic agents including energy policy makers and private energy actors, such as energy firms, economic analysts, government, central banks, international companies, traders and speculators have been interested in a better understanding of the stochastic process of commodity prices, that is, crude oil prices, and predicting their behaviour. Conventional regression analysis and hypothesis testing cannot be correctly undertaken without first understanding characteristics of the time series. Otherwise, results from estimating regression models may be rendered invalid. As indicated by Borensztein and Reinhart (1994), both short-term fluctuations and the long-run trend in these prices have a nontrivial role in transmitting business cycle disturbances in industrial countries (Videgaray-Caso, 1998; Lee et al., 2006). Analysing supply and demand shocks affecting the time series properties of the prices is important for economic agents because, given that a significant fraction of world merchandise trade consists of crude oil, high prices and price volatility have real and notable consequences for all consumers and end users, but especially for those in nations and regions that rely heavily on imports to augment energy production. High crude oil prices and tight market conditions have raised fears about resource scarcity and concerns about energy security in many energy-importing countries. For planning and adjusting the timing of their energy policies, policymakers need to assess the future trends that energy prices may follow. Future values of oil prices in particular, and energy products in general, are also important ingredients of long-run forecasts for various macroeconomic variables. Indeed, the consequences of the oil price shock in terms of economic growth have highlighted the impact of energy price fluctuations. Since oil is the basic input for the production, its high prices have a bearing on macroeconomic conditions such as slowing economic growth, rising inflation and creating global imbalances. "Oil prices are ... generally more volatile than the prices of other commodities" Verleger (1993) has argued. The volatility in oil prices can also increase uncertainty and discourage much needed investment in the oil sector, since running energy price forecasts is also significant for producers in an attempt to motivate and evaluate investment decisions related to resource exploration or reserve development activities (Fattouh, 2007; Chardon, 2007).The stochastic properties of energy prices also have important implications for firms making investment decisions. Because investments in general, and energy investments in particular, are made in a long-run perspective, at least for twenty or thirty years, and are irreversible, energy prices behaviour have sizable effects on the profitability or riskiness of these typically irreversible investments and, hence, on firms' willingness to invest in physical or human capital. In this case, as Baker et al. (1998) and Dixit and Pindyck (1994) showed, different models of the pricing process carry important implications for investment and valuation decisions. Statistically

speaking, an investment decision based on a mean reverting process could turn out to be quite different from one based on a random walk, which I argue in the following sections in detail. Furthermore, examining whether crude oil spot and future prices contain a unit root has important implications for traders and speculators. For example, as mentioned clearly by Maslyuk and Smyth (2008), if crude oil spot and futures prices contain a random walk, the crude oil market is considered as efficient in the weak form, meaning future prices cannot be predicted using historical price data. This implies that an uninformed investor with a diversified portfolio will, on average, obtain a rate of return as good as an expert. If the random walk hypothesis is rejected, making profits using technical analysis would be possible for investors. Knowing the correct time series behaviour of crude oil prices can be vital to distinguish among theories that more accurately describe observed behaviour. The stochastic properties of crude oil prices have also important implications for proper econometric estimation. With an understanding of the stationarity properties of the real price of crude oil, structural econometric models with different variables that are specific to a relevant regime and more convenient to represent behaviour can be appropriately and properly constructed (Ahrens and Sharma, 1997; Maslyuk and Smyth, 2008). Then, it would be more valuable to account for the radically different behaviour of crude oil prices possibly across different regimes. Finally, given that good policymaking typically depends on profound economic forecasts, appropriately modelling the nature of the time series can be invaluable to forecasters. Information about the shock-persistence properties of the price of crude oil can also be helpful in formulating stabilisation and exchange rate policies, and setting the medium-run balance of payments guidelines in energy-exporting countries. If the commodity price series are better modelled as a trend stationary (TS) process, innovations in prices have no permanent effects. In such cases innovations are entirely cyclical, and at the risk of oversimplifying, stabilization policies and hedging are useful in dealing only with temporary and, preferably, short-lived shocks. On the other hand, if there is a unit root in the underlying data-generating process (DGP here after), shocks will have permanent effects, requiring adjustment and, possibly, the implementation of structural policies leaving very little room for any price stabilization scheme to work successfully (Reinhart and Wickham, 1994; Cashin et al., 2000; Jalali-Naini and Asali, 2004).

It is for this reason that it is necessary to choose a movement that reflects as likely as possible the dynamics of the world oil prices. While both academics and practitioners have been paying attention to the understanding and statistical valuation of crude oil prices in recent times, there is no uniform view about the

trajectory of their prices, over time. Even so, a consistent theme across much of this literature is that most natural resource prices are non-stationary. As will be seen in the section of literature review, classical unit root tests are likely to be inconclusive in the case of oil prices for time series spanning several times. While most researchers agree that exhaustible natural resource prices are non-stationary, they disagree as to whether the non-stationarity of prices takes the form of a deterministic trend, a stochastic trend, or whether there are structural breaks (Cashin et al., 2000; Postali and Picchetti, 2006). The literature reviews above clearly indicate that models more complex than conventional unit root tests should be used for a more accurate description of the dynamics of crude oil prices. The stochastic process of oil prices cannot be modelled correctly if both structural breaks and nonlinearities are not considered in the analysis. The motivation relies on the historical record of events in the international crude oil market. Differences in the economic systems and also extraordinary circumstances may cause structural changes in the variables. If there is such a structural change in the forecast period, the estimates will not be successful for the whole period. Some researchers tend to interpret the oil price behaviour in terms of cyclicality of exhaustible resource prices and give importance to high frequency (noise) factors, like weather etc., to explain this cyclicality. Theoretically speaking, Ahrens and Sharma (1997), for example, note that in regards to both a simple and more general Hotelling (1931) model, as described in Slade (1988), "price movement is still systematic and may be modelled appropriately as a deterministic trend." Instead, according to other researchers, some cause exhaustible resource prices to shift to a new path. In a world with uncertainty "in which speculative motives drive the behaviour of extracting firms or unanticipated events largely characterize the market, resource prices may be generated by a random walk process" (Ahrens and Sharma, 1997;Lee et al., 2006). In the oil case, these factors could be the erosion of spare capacity in the entire oil supply chain, the emergence of new producers (e.g. non-OPEC producers), the emergence of new large consumers (mainly China, and India), the geopolitical uncertainties in the Middle East, the re-emergence of oil nationalism in many oil-producing countries, investment and installed capacity, and binding producer agreements (OPEC cohesion) (Jalali-Naini and Asali, 2004; Fattouh, 2007). It is therefore important to analyze the long-standing issue of determining the source of the non-stationarity observed in crude oil prices: whether it is the result of innovations that are highly persistent or it appears as a consequence of the existence of rare and unexpected events that change the underlying structure of the series (breaks).

In the oil market case, the OPEC behaviour in 1973-74 may be one candidate for a structural break. For example, after decades of stability and relatively low prices, the price of a barrel of crude oil sky-rocketed in 1973-74, leading to a period of higher prices and volatility. Indeed, examining the long-run time series of real oil and natural gas prices spanning a century, requires taking into account the existence of several breaking points and nonlinearities to obtain a relevant statistical test and reach accurate conclusion. In the context of time series; Perron (1989) has firstly proved that the presence of structural breaks in the data may introduce a bias in the conclusion of unit root tests. But the empirical literature dealing explicitly with structural breaks in the oil price process is quite scarce. Even, Pindyck (1999) thinks that stochastic switching models increase the possibilities for "data snooping" (for any long time series, it is likely that one will always find one or more "structural change") and they provide no explanation for what such a structural change means or why it occurred. On the one hand, Pindyck expresses the dangers of data snooping and judges the entire series to be mean-reverting to a moving quadratic trend. On the other hand, Krichene (2002) examines the world markets for crude oil and natural gas over 1918–1999, thereby covering the periods prior to and following the oil shock occurred in 1973, with the thought that this division into sub-periods was necessary in order to account for structural changes that might have occurred in 1918–1999, but without applying any test. Krichene (2002) has claimed that the study of a truncated period, 1973–1999, would not enable us to uncover features of the oil and gas markets that prevailed prior to 1973 and that are essential for analyzing the market equilibria that existed hereafter. But then, there are numerous studies accepting structural breaks a priori and choosing the periods accordingly. After Pindyck (1999), a number of tests are developed considering structural breaks. For example Hamilton (2009) focuses his analysis on the period constructed only since the early 1970s.

Thus, I examine whether crude oil prices have a unit root over a much longer period, employing historical data. To realize this objective I employ several unit root tests as discussed in the methodology. My analysis extends the literature in crude oil prices in several important ways. Before starting, it is worth emphasizing that my intention is not to explain specific theories to explore the mechanics of DGP, nor to focus on the source of shocks to the crude oil market or even to analyze the structure of this very complex international oil market. Generally, I intend to characterize the underlying DGP as either trend stationary (TS) or difference stationary (DS)[1]by different techniques for the crude oil prices in this paper. Plus,

1 They will be explained in the Section 5 in detail.

one of the objectives of this paper is to look at the history of crude oil prices to obtain some insight as to whether or not some events introduce multiple structural breaks in the stochastic process of the oil prices which should be a feature of any complete univariate description of the process bearing in mind that modelling of their prices would be incorrect without considering structural breaks in the analysis. In other words, one of the purposes of this paper is to examine the time series behaviour of crude oil prices allowing for multiple structural breaks in the underlying DGP. To achieve this objective, I use the Zivot and Andrews (1992) (Z-A hereafter) method to test endogenous one structural break and Bai and Perron (1998, 2003) (B-P hereafter) method to test for endogenous multiple structural breaks and estimate the corresponding break dates. This is because the regime-wise stationarity could be established allowing for further structural breaks or using data over much longer periods, for which previous studies have found mean reversion.

In addition, conventional tests give ambiguous results when a near unit root process describes the data. Non-rejection of null hypothesis (unit root) does not necessarily mean that the Geometric Brownian Motion (GBM here after) is the correct modelling process, but it brings indications of a slow mean reverting. As Postali and Picchetti (2006) pointed out, GBM is used as a proxy for the evolution of oil prices since the speed of reversion of prices is low enough to do it. Indeed, the stochastic permanent shifts mimic the effect of a persistent shock. In this situation, I think that we should apply fractional unit root tests to bring out accurate properties of the crude oil prices, which allow the speed of reversion of prices to be low. In this paper, I investigate whether crude oil prices are non-stationary but mean-reverting with an order of integration smaller than one, using two different fractional unit root tests keeping in mind these models could be convenient alternatives to explain the strong persistence in those prices. I use Geweke and Porter-Hudak (1983) (GPH hereafter) (LP regression) and Robinson's (1995) Gaussian semi-parametric estimator (GSE hereafter) methods, extensively used in applied econometric research, because of their convenience, which stem from the simplicity of their construction as a linear regression estimator. After seeing that there are big changes to the crude oil market, bearing in mind model parameters may change from one sub-sample to another beyond a certain threshold, I also run nonlinear unit root tests, e.g., Caner and Hansen (2001) (C-H hereafter) and Kapetanios, Shin and Snell (2003) (KSS hereafter) methods, to see whether crude oil prices have undergone a shift in the parameters before and after the event. Only univariate techniques are used in this paper. In the subsequent studies, structural breaks in the co-integrated relations can be detected by multivariate techniques.

In this paper, I also examine the long run behaviour of crude oil prices, using 150 years of data for crude oil (1861-2010) only by focusing on alternative stochastic processes that might be consistent with this long-run behaviour. Because the Hotelling model on which this paper is based on the claims that exhaustible resources will run out in the long term, this premise should only be tested by long-term data. Thus my analysis is based on historical annual data for crude oil prices for the world market. Instead of trying to explain and predict the behaviour of the real price of crude oil in terms of the underlying supply and demand structures, as done in structural modelling, forecasts can be realized using stochastic processes that might be consistent with oil price long-run behaviour over more than a century in order to draw conclusion about the law of motion. The issue as to how the supply and demand of crude oil can be modelled seems to be discussed more among economists. Actually this paper is written after some efforts to model crude oil supply and demand. Rather than fixing all modelling issues in a structural model, I continue my research of crude oil prices in the framework of continuously shifting levels and slopes of trend lines started by Pindyck (1999). The nature of the trend, however, can only be discerned through empirical testing (Ahrens and Sharma, 1997; Videgaray-Caso, 1998). In other words, with the thought that we can attain some useful inference about crude oil market and its supply and demand structure by examining the behaviour of result variable (e.g. prices), the time-series properties of crude oil prices are examined. Without taking any theoretical side, I aim to take part in the discussion in terms of time series properties of those prices using techniques known in statistics. Specifically, I will try to show whether oil prices are mean reverting or not, the rate of mean reversion is slow, so that the trends to which prices revert also fluctuate over time by following Pindyck's (1999) tracks. I will also take structural breaks, nonlinearity and long memory structure into consideration in the long-run stochastic process of the price of crude oil.

The paper proceeds as follows. Section 2 provides the theoretical rationale for examining the stationarity of crude oil prices. I present the original Hotelling model and its extension done by Pindyck (1999). I allocate Section 3 to explanation by presenting the importance of stationarity or non-stationarity of crude oil prices. Section 4 is for a literature review of studies of unit root tests applied to crude oil prices. Section 5 provides a methodological overview of the unit root tests that I apply in this paper. We will see in this section the specific econometric techniques to be implemented in this long-run context. Section 6 gives an overview of the data as well as containing a discussion of the potential break points. Section 7 presents the results. The final section concludes with a discussion of the implications of the findings, and considers some of the limitations of the research and provides suggestions for future research.

2. Theoretical Explanation about Exhaustible Resource Prices: The Hotelling Model and its Extensions

Sustainability of economic growth in a finite natural world is one of the earliest and most enduring questions in the economic literature. The idea that limited raw materials and commodities confine economic growth started at least as far back as the early nineteenth century when the British classical economists, particularly Malthus, Ricardo, and Mill, suggested that the long-run trend of raw materials and commodity prices was rising because of limited supplies of natural resources in the face of diminishing returns to commodity production and growing populations (Cashinet al., 2000; Krautkraemer, 2005). Raw materials and commodities can be regarded as limited, non-renewable or exhaustible if the resource is no longer available for use or extraction within a reasonable time horizon once it is used or extracted. This is because the supply of that resource is not replaceable or else replaced at a very slow rate and is limited relative to demand. This feature of non-renewable energies, then, introduces an inter-temporal dimension in the use decision: the choice of using it now or later. Oil, which could be regarded as a classic example of exhaustible resources, has both these features (Fattouh, 2007).

Generally, commodity price behaviour has been explained in two different ways, depending on whether that commodity is considered to be exhaustible or not. Some theorists, such as Prebisch (1950) and Singer (1950), pointed out a declining long-term trend in some commodity prices relative to manufactured goods because of the deterioration in the terms of trade of commodity caused by a competitive market structure, low income elasticity of demand for commodities and rapid increases in supply. The evidence in support of a persistent downward trend in relative commodity prices is rather mixed (Cashin et al., 2000; Jalali-Naini and Asali, 2004). Despite this historical background, materials shortages, especially related to world wars, led to a renewed interest in the subject of natural-resource adequacy and the optimal use of exhaustible resources as a response to the problems facing many of the industrial countries. The seminal paper on the economics of exhaustible resources was that of Hotelling (1931)and since then it has formed the basis of the literature on exhaustible resources. After that, the assumption derived from Hotelling (1931) has been contested, both on theoretical and on empirical grounds(Krautkraemer, 2005). After sketching out the other theories explaining exhaustible resource prices below, the Hotelling model will be discussed in detail.

There is an extensive literature on long-term trends in the exhaustible resource prices, especially, in the price of crude oil. But the evolution of exhaustible resource prices is not an easy task, rather, forecasting them can be quite challenging. Several approaches have been reported in the literature regarding the structure and behaviour of exhaustible resource markets. A first review of crude oil market models was provided by Gately (1986). Fattouh (2007) has sorted them for crude oil prices very successfully into three groups, each of which emphasizes a certain set of drivers of oil prices and is useful in improving our understanding of how the different elements of the oil market function: structural models using the supply-demand framework, the informal approach and non-structural models[2].

The price behaviour of any exhaustible resource in the long term is generally determined by interaction between supply and demand. But, to be able to explain exhaustible resource prices in structural terms, i.e, in terms of movement in supply and demand and variables affecting them, some more advanced theoretical and empirical studies using behavioural equations are necessary (Pindyck, 1999).Market specific features of exhaustible resources such as oil render this modelling difficult and complex. Some of the market specific features come from uncertainties. These uncertainties, some of which are due to unknown future events such as geopolitical factors, supply disruptions, environmental disasters and technological breakthroughs and others of which are due to the lack of knowledge about factors such as the long run price and income elasticity of demand, the response of supply, affect the reliability of forecasting future values of oil prices in particular, and energy products in general. In oil demand analysis, price and income can be taken as explanatory variables. But supply models are somewhat problematic due to the role of suppliers and hence market structure, reserves, technology, discovery, depletion, some regulatory factors (the fiscal system) and political factors (sanctions and political turmoil). These largely unpredictable non – market-related aspects present the biggest challenges for the forecaster. The informal approach, used to identify economic, geopolitical and incidental factors affecting demand and supply within specific economic and political contexts and episodes of market history, such as the role

2 But there are some other models developed just for crude oil market dynamics. The poor performance of the OPEC as a cartel has led some researchers to show increased interest in alternative explanations. For example, Cremer and Salehi-Isfahani (1989) developed a competitive theory to describe the behaviour of crude oil markets since OPEC's foundation in 1973. They explained that the backward bending supply curve could account for the presence of multiple equilibria. In fact, several players, such as oil companies, refineries, and speculators have introduced additional dynamics into the market although the OPEC has tried to control the oil prices by manipulating the production and stock rates. So, the crude oil prices vary widely with apparent unpredictable behaviour (see Bernabe et al. 2004 for details).

of OPEC, the erosion of spare capacity, the role of speculation and inventories, can only provide a qualitative assessment as to whether the market has witnessed structural changes with a lasting impact on oil price behaviour or whether the recent strength in the oil prices has been mainly caused by temporary drivers and about how the oil market and its prices might develop in the future, and hence is of limited use to making projections (Fattouh, 2007).

The third group is non-structural models about exhaustible resources. There is still no consensus among economists as to whether natural-resource commodities are becoming scarce relative to other factors of production, being indicated by an increase in the real price of natural-resource commodities. In the theoretical literature, the basic model of the extraction of exhaustible resources initially proposed by Hotelling (1931) predicts an exponential increase in price net of marginal extraction cost over time (Slade, 1982). As Fattouh (2007) noticed, this theory about exhaustible resources has had an influence on many energy economists' view of oil price behaviour. Given demand and the initial stock of the non-renewable resource, the problem handled in the Hotelling (1931) paper is to find the optimal depletion path of a firm that seeks to extract such resources to maximize its profit and then he mainly asks how much of the resource should be extracted every period in order to maximize the profit for the owner of the resource. There is a vast body of academic literature on this subject.[3]The inter-temporal aspect of exhaustible resources (oil here) can be analysed using a simple framework. The basic model is based on the following assumptions: (a) the size of the resource stock is known, (b) the entire reserve is exhausted during the project life, (c) the real interest rate is presumed to remain constant (Fattouh, 2007; Bhattacharyya, 2011).Firms use information about the quantity of oil, its cost of extraction, the demand curve for oil, etc. to maximise the net present value of rents (the price of oil minus its marginal extraction cost).

$$W = B(q(0)) + B(q(1))\left(\frac{1}{(1+r)}\right) + B(q(2))\left(\frac{1}{(1+r)}\right)^2 + \cdots + B(q(T))\left(\frac{1}{(1+r)}\right)^T$$
$$q(0) + q(1) + q(2) + \cdots + q(T) \leq S$$

in which $B(q(t))$ is the sum of consumer and producer surplus in period t generated by the extraction of quantity $q(t)$, r is the discount rate, and S is the total quantity of oil to be extracted. If we make some assumptions about the costs of extraction (for example, they are constant over time), and take into account

3 See Fisher (1979), Devarajan and Fisher (1982) and Krautkraemer (1998) for further details.

the size of the oil resource base, maximising total social welfare generates a very simple two-period case:

$$p(t) - c = [p(t+1) - c]\left(\frac{1}{1+r}\right)$$

in which p is the price of oil and c is the cost of extraction. Solving for r generates the following(Kaufmann et al., 2008):

$$\frac{[p(t+1-c) - (p(t) - c)]}{[p(t) - c]} = r$$

This is Hotelling's rule, i.e., assuming no or negligible extraction costs, and given a market price per unit of resource and real risk free interest rate on investment in the economy r, that in a competitive market, the price of the extracted resource should rise with the rate of interest, r. The above equation shows the Hotelling's rule in the presence of extraction costs, which is a more general case. If marginal extraction cost is constant for a given stock and does not depend on the remaining stock in situ, then the scarcity rent (the difference between price and marginal cost) increases at the real rate of interest (Ahrens and Sharma, 1997; Fattouh, 2007). This rule hints that exhaustible resources have a value over and above their cost of production, which is due to their scarcity. This extra value is considered as scarcity rent. The owner of the resource has two options: either to extract the oil today or to keep it in the ground for future extraction. Why will the resource owner not empty everything now? Any amount extracted today is not available for extraction in the future and any resource left in the ground can fetch a higher price in the future. If the supplier produces one unit now and invests the money in the capital market he earns rp_1. If he supplies one unit in period 2, he earns p_2, which is $p_1 + (p_2 - p_1)$, which is equal to $p_1 + rp_1$. Thus by waiting for one period, the producer makes the same profit, which makes him indifferent. The expectation of better prices in the future will ensure that not the entire amount is produced in one period. If the price of oil is expected to rise faster than r, then the owner has the incentive to hold on to the resource. If all suppliers behave in a similar manner, the supply would go down causing the current market price to rise (Fattouh, 2007; Bhattacharyya, 2011). So, given this equilibrating mechanism, this rule can be used to generate optimal price and production paths. Anticipating changes indicated by these paths allows firms to schedule investment required to produce alternative fuels in a timely fashion (Kaufmann et.al, 2008).

To sum up, Hotelling (1931) predicts that price does not revert to a fixed mean in such a model. It is clear that, under certain assumptions, such a model implies systematic increases in the real price of an exhaustible resource at the rate of interest over time. This theory has stark predictions on the time pattern of resource prices. Earlier tests of the Hotelling Principle, generally based on time series of resource prices, have yet to provide convincing support. Although this gradually rising price trend continued to dominate forecasting models even in the 1980s and 1990s, there existed also some other literature having found quite the opposite, showing relative natural-resource commodity prices to have declined and to be trendless over time (Ahrens and Sharma, 1997; Fattouh, 2007). For example this hypothesis puts down that resource prices increase was first systematically examined by Barnett and Morse (1963).They found that there is no sign of an upturn in either real cost or relative price of the output of the extractive industries. After that, Barnett (1979) updating Barnett and Morse (1963) maintained that the original Barnett and Morse judgment still holds (Slade, 1982). Although intellectually attractive, they observed this seemingly anomalous pattern and concluded that scarcity was not a real problem. Then, interest in the descriptive and especially the predictive ability of the Hotelling Principle was excited by the marked upward drift in the prices of energy beginning in the early 1970s. Although these particular results are evidence against the original hypothesis of Hotelling, theoretical extensions of the underlying Hotelling model (a notable contribution being that of Pindyck (1978)) by adding real-world complexities, such as the difficulties of the exploration process, constraints on investment and capacity, ore quality and a host of market imperfections, can produce predictions of falling or stagnant prices over time (Miller and Upton, 1985; Lee et.al, 2006). For example, from a theoretical point of view, the presence of significant potential for exploration and reserve additions can make unclear the shape of the trajectory of the price of energy. Indeed, using a simple competitive Hotelling model, Pindyck (1999) shows that how this elementary model of extraction of exhaustible resources can produce great variability in the trend and in the level of an unobservable long-term marginal cost which resource prices revert to (Videgaray-Caso, 1998; Postali and Picchetti, 2006). Then, Pindyck (1999) is widely argued and cited in terms of how to use the Hotelling model in an attempt to construct forecasting models of energy prices.

In this model, the price trajectory is dP/dt=r(P-c), with the constant marginal cost (c) and the interest rate (r).It can be set that $P_t = P_0 . e^{rt} + c$. If the demand function is isoelastic with unitary elasticity, that is to say a demand function of the form $Q_t = AP_t^{-1}$, the rate of production is given by $Q_t = A(c + P_0 e^{rt})^{-1}$. The cumulative production over the life of the resource must equal the initial reserve

level, R_0: $R_0 = \int_0^{\propto} A(c + P_0 e^{rt})^{-1}\, dt$. Performing the integration: $R_0 = \frac{A}{rc}\log\left(\frac{c+P_0}{P_0}\right)$, so that the price level at any time t (Chardon, 2007) is found by,

$$p_t = c + \left(\frac{ce^{rt}}{e^{rcR_0/A} - 1}\right)$$

where A is a level of demand. The last equation presents an idea of which factors exhaustible resource price depends on. First, the level of reservoirs: the higher the initial level of reservoir, the lower the price and new discoveries generate pressures toward lower prices. In this sense, any uncertainty about available and/or recoverable reservoirs tends to bring about oscillation in the prices. Uncertainty over the parameter A, the level of demand, has impacts on prices. The more volatile and subject to shocks the demand is, the higher the variability in oil prices. The other uncertainties are the ones about the evolution in extraction cost. In this sense, exhaustible resource prices are subject to a set of uncertainties linked to asymmetric information about stocks, recoverable reserves, probable reserves, alternative technology and demand. It is the interaction of all uncertainties that causes great variability in the price of the unit, making it sensitive to an extensive set of variables, which are not always available to all agents (Postali and Picchetti, 2006).

As highlighted in Pindyck (1999), not only the level, but also the slope of oil price is stochastic. Differentiating the last equation with respect to t, the slope of the price trajectory can then be written as,

$$\frac{dP_t}{dt} = \frac{rce^{rt}}{(e^{rcR_0/A} - 1)}$$

Thus, change in demand, extraction costs, and reserves all affect this slope. That is, the slope of the price is also stochastic and depends on the same sources of uncertainty as the level. For example, an increase in A causes this slope to increase; while increases in c or R_0 cause the slope to decrease (Chardon, 2007). In Pindyck's words: "for most depletable resources, one would expect demand, extraction, costs, and reserves all to fluctuate continuously and unpredictably over time. Whether or not the processes that these variables follow are stationary is an open matter. But in either case, we would expect price to revert to a trend line with a level and slope that likewise fluctuate over time." According to Pindyck (1999) if demand, extraction costs, and reserves change very infrequently but by large, discrete amounts, then a switching model of the sort estimated by Perron (1989) is

appropriate as a description of price although he thinks that there is little evidence or reason to believe that this is the case for virtually any resource. Instead, Pindyck (1999) argues that a model of long-run energy price evolution should incorporate both a reversion to the trend of long-run total marginal cost, and continuous random fluctuations in the level and the slope of that trend. These two characteristics correspond to a general version of the multivariate Ornstein-Uhlenbeck (O-U) process. He proposes discrete versions of multivariate O-U processes integrating the desired features for these prices (Bernard et al., 2004; Chardon, 2007).

Apart from Pindyck (1999) explanation above resuming Hotelling's theory of exhaustible resources which was intended to show that, even assuming mean reverting, trend and level of oil prices are stochastic, raising questions about the variability and uncertainty about the price of the exhaustible resource, there are also some other studies extending the theory of exhaustible resources in which a number of simplifying initial assumptions have been relaxed to make models of exhaustible resources more realistic through showing how exhaustible resource prices can follow a declining or a U-shaped path. Any combination of these arguments would lead to declining or stagnant real-price paths for resource products (Fattouh, 2007). These extensions improve the ability of Hotelling's model to account for the historical record in the industry, but the resulting complexity makes the price paths specific to the assumptions and produce behavioural implications for price that are more complex than the simple model (Kaufmann et al., 2008).

As shown by Pindyck (1978), exploration and reserves additions can result in a U-shaped time pattern instead of the always path predicted in the Hotelling modelling tradition. Afterwards, Slade (1982), among many others, has tried to reconcile the theoretical predictions of an increase in prices over time with the empirical findings of falling real prices and explained in her ore-grade selection model how the exogenous technical change and an endogenous change in extraction and processing, possibly along with depletion of grade, can offset the increase in resource rents and lead to declining or a U-shaped product price path (Berck and Roberts, 1996; Videgaray-Caso, 1998). Basically, technological change lowering extraction cost will generate a declining price path. But continuous resource depletion with diminishing return to technological innovation will cause the price to shift to an upward path. Resource prices may also decrease when a backstop technology is introduced, causing an inward shift in the demand for natural resources. Moreover, there are some other studies pointing out that environmental constraints and natural resource abundance may induce price declinations (Berck and Roberts, 1996; Lee et al., 2006; Fattouh, 2007).

Population and resource consumption have steadily risen but humans have generally been quite resourceful at finding solutions to the natural resources scarcity problem, particularly in response to signals of increased scarcity. In accordance with this notion of Slade (1982), Adelman (1990) has criticized the fixed stock view of the Hotelling model. Rather than assuming a fixed stock of the resource, Adelman (1990) thought that the world oil price changes since 1973 cannot possibly be explained by scarcity or by changes in scarcity. To verify his idea he showed that reserve additions have played a major role in the determination of the price of crude oil, in particular in preventing the oil price from rising steadily after the oil price crash of 1986. According to Adelman (1990) oil reserves have been continuously depleted through extraction but continuously augmented through exploration and development like inventories. Then, the issue in this idea now turns from exhaustibility to investment in accumulating inventories and the costs involved in finding new reserves. Mabro (1991) takes a stance between these two extreme positions in terms of exhaustibility of resources. There have been few instances in history where natural resources have been perceived to be in limited supply. That's why Adelman's main argument generally holds in view of the fact that resources are perceived to be abundant (Slade, 1982; Videgaray-Caso, 1998; Fattouh, 2007). Proven world resource reserves, such as oil, have been increasing in recent decades through technological advances in exploration and utilization, in spite of ever increasing production (Dvir and Rogoff, 2010). So, it can be said that the exhaustibility of resources is not of first order significance in explaining resource price behaviour and the size of reserves should be kept in mind while modelling.

As noted by Lynch (1994), this Hotelling modelling tradition has been the theoretical foundation for the majority of oil price forecasts published since the late 1970s. But many economists consider that not only the original Hotelling model but also any combination of these arguments in the literature on resource exhaustibility above, does not have the final say in the resource price issue. According to Fattouh (2007), Hotelling's original model was not intended and did not provide a framework for predicting prices or analysing the time series properties of prices of an exhaustible resource. But, as widely explained above, Pindyck (1999) modified the Hotelling model to construct forecasting models of energy prices. He suggests that rather than use structural models that take into account a wide array of factors including supply and demand factors, OPEC and non-OPEC behaviour, technological advances and regulatory factors, it might be preferable to use simple non-structural models that examine the stochastic behaviour of exhaustible resource prices because these models are quite flexible and allow exhaustible resource prices to be modelled as GBM, or mean reverting process or related process with jumps (Fattouh, 2007).

3. Emprical Explanation: Stationary or Non-Stationary of Crude Oil

Ideally, it would be better to be able to explain crude oil prices in structural terms because it is the movements in demand and supply, and the factors that determine demand and supply, that cause prices to fluctuate. Different approaches are frequently used to make projections about prices and/or global demand and supply either for the short term or for the very long-term horizon, often over twenty years. This supply-demand framework is better suited to provide understanding of the causes of short or intermediate-run fluctuations of prices and other variables. However, the determinants of the movements (e.g., inventory levels, production capacity and demand growth etc.) in supply and demand are not so easy to anticipate. So, as Fattouh (2007) mentioned, all the approaches suffer from major limitations and any attempt to use them to predict prices or project market conditions in years to come would certainly result in errors especially when used to make long-term projections. For example, according to Huntington (1994), the oil forecasting models based on the supply and demand approach have over-predicted the oil prices in 1990 by thirty percent. As Pindyck (1999) pointed out, structural models are not always useful for long-run forecasting and would certainly lead to rather fragile results because of not capturing the impact of unexpected shocks. To sum up, the supply-demand approach cannot adequately capture the various shocks that influence the oil market and change behavioural equations reflecting the underlying assumptions of the model (Radchenko, 2005; Fattouh, 2007). Instead of trying to explain and predict the behaviour of the real price of crude oil in terms of the underlying supply and demand structures as done in structural modelling, forecasts can be realized using stochastic processes that might be consistent with oil price long-run behaviour over more than a century in order to draw conclusion about the law of motion. The issue ~~as to~~ how the supply and demand of crude oil can be modelled seems to be discussed more among economists. The nature of the trend can be discerned through empirical testing (Ahrens and Sharma, 1997; Videgaray-Caso, 1998). In other words, some useful inference can be attained about crude oil markets and their supply and demand structure by examining the behaviour of result variable (e.g. prices).

Actually, time series properties of crude oil prices related to the debate have centred on the issue of whether natural resources, especially exhaustible resources, have become more or less scarce in time.Such stochastic fluctuations, both in the level and slope of the trend, are also consistent with a basic model of exhaustible resource production (Hotelling, 1931) explained in detail in the previous section. As mentioned, Hotelling's (1931) paper moulded the forthcoming thinking on the theory of the long-run price path for exhaustible resources, e.g. crude oil.

Indeed, oil is considered scarce when its supply falls short of a specified level of demand and this scarcity is reflected in the market price. In general, oil price rising are interpreted as an indicator of increase in the scarcity, meaning that these exhaustible resources will be less available on the market. In practice, it is important to distinguish between scarcity and other reasons for high oil prices. There can also be large cyclical fluctuations in oil prices, which largely reflect the interaction between cyclical (including some financial) factors and low short-term price elasticities of demand and supply (Ahrens and Sharma, 1997; IMF, 2011).There is a legitimate interest in differentiating between long-term trends and short-term cyclical fluctuations in oil prices and in determining whether the factors, such as speculation, contango, increase in inventories etc. mentioned above, are cyclical or structural. For example according to Fattouh et al. (2012) there is no structural change caused by speculation in the oil market.

Industry forecasts of exhaustible resource prices over long time periods often assume that prices grow in real terms at some fixed rate. The rate of growth might reflect some notion of resource depletion and/or technological change. One possibility is that prices follow a random walk with drift. Another possibility is that prices revert to a trend line, intimating that shocks to exhaustible resource prices are temporary. Much of the controversy is linked to this choice of a stochastic process to represent the evolution of the exhaustible resource's price, whether the observed trend is stochastic or deterministic? By asking this question we will already be inclined to examine if the shock is a temporary phenomenon that largely reflects short-lived variability or a permanent phenomenon that largely reflects long-lived enduring effects causing exhaustible resource prices to shift to a new path. The type of trend, stochastic or deterministic, exhibited by the price of an exhaustible resource commodity should play a critical role in the development and empirical verification of theories which may explain its long run behaviour (Ahrens and Sharma, 1997; Maslyuk and Smyth, 2008).

In recent years, the search for an upward price path for crude oil has been replaced with the search for other time-series properties, including the stationarity of the crude oil price-series. Also, important literature has developed that empirically examines oil price paths to determine which process modelling its prices is the most suitable and investigates whether they are TS or DS (Lee et al., 2006). Under this framework, the main issue of interest has been whether a unit root is present or not in the process, i.e, the crude oil prices are best modelled in the long-run as a random walk or as mean reverting. If crude oil price series are mean-reverting (i.e., TS), then these series should return to their trend path over time meaning that price fluctuations are purely cyclical in nature. Price shocks tend to have finite persistence and it should be possible to predict future movements in these prices based

on past behaviour. Conversely, if the crude oil price-series are modelled as a random walk characterised by the most popular of price processes, the GBM and the Black-Scholes option pricing model, then shocks to crude oil price series are likely to be permanent (Hsu et al, 2008). This kind of DS series has infinite persistence.

Early works in this literature widely assumed that crude oil prices follow a Brownian motion with drift. As mentioned above, the justification for this assumption is largely theoretical and related to the Hotelling (1931) model[4] although it is not always declared explicitly. There are different modifications of the Hotelling model in the literature, outlined before. Despite being simple, these models are flexible, allowing prices to grow from their current level (i.e., prices follow a random-walk process with drift) and/or from a changing trend line (i.e., prices revert to a possibly moving mean). Such differences reflect differences in assumptions regarding resource depletion and technological change (Videgaray-Caso, 1998; Bernard et al., 2004). If we consider the usual results from the theory of non-renewable resources (Hotelling, 1931), we would expect that equilibrium price shows a drift reflecting the progressive tendency to exhaustion of crude oil. Exhaustion tends to produce shifts in the equilibrium price. From this perspective, the higher prices may reflect a shift in the equilibrium level. So, the entire observed price changes are considered to be permanent shifts of the base from which the price is expected to increase. Moreover, its modelling as a GBM may incorporate an unusual high level of uncertainty on this variable, meaning a serious lack of knowledge on the global availability of reservoirs and alternative technologies. In an uncertain world in which speculative motives drive the behaviour of extracting firms or unanticipated events largely characterize the market, resource prices may be generated by a random walk process (Ahrens and Sharma, 1997; Postali and Picchetti, 2006). Properly speaking, the 'random walk' used to model prices under GBM is based on the assumption that price changes are independent of one-another, following a freely flexible path based on the information available. Put differently, the historical path that the price followed to achieve its current price is irrelevant for predicting the future price path, i.e., prices follow a Markov process. With the processing of the new information provided by the shock, price moves along an entirely different path. Therefore, the Hotelling modelling tradition predicts the oil price should follow a random walk with trend, or its continuous-time equivalent, a GBM with drift (Blanco and Soronow, 2001; Videgaray-Caso, 1998). Expressed clearly, the GBM hypothesis

4 As explained in detail in the previous section, Hotelling predicts that the margin of price over marginal cost of a unit of a resource in limited supply should rise over time at the discount rate under competitive equilibrium; if suppliers have some degree of monopoly power, it is the difference between marginal revenue and marginal cost which should rise at the discount rate (Videgaray-Caso, 1998).

implies a constant rate of growth in the crude oil price and a constant volatility of futures price returns (Mirantes et al., 2007): $dP = \mu Pdt + \sigma PdW$, where P is the resource price, the drift μ is the expected return per unit time, σ is the price volatility and W is a Wiener process. This assumption implies that relative changes in the price behave as a normally distributed random variable. The events measured are independent and identically distributed. Physically, this means that the events must not influence one another and they must all be equally likely to occur.

Other authors, like Laughton and Jacoby (1995) and Schwartz (1997), argue that commodity prices show mean reversion (i.e., TS), which incorporates the tendency of commodity prices to gravitate towards a 'normal' equilibrium price level that is usually governed by the cost of production and level of demand, and the volatility of future price returns is a decreasing function of time. Unlike the GBM, the mean reverting process does not have a constant expected growing rate. In this framework,As Pindyck (1999) noted, even if sharp rises are observed during short periods for specific shocks, crude oil prices generally tend to revert to 'normal level' over a long period since the resource is produced and sold in a competitive market, so that price should converge to its unobservable trending long-run marginal cost, which is likely to change only slowly, as the effects of shocks disappear. Pindyck (1999) interprets the trend line economically as a proxy for long-run marginal costs, according to the Hotelling model. This would imply that price shocks are temporary, i.e., prices are mean-reverting rather than random walks over sufficiently long horizons. This process is realistic in the extent that the growing rate responds to deviations of prices from their average levels: if the price is above the equilibrium level, the component of reversion reduces the growth rate down, or even becomes it negative (Pindyck, 1999; Postali and Picchetti, 2006).

The GBM and the mean reverting model each represent extreme case in the degree of uncertainty and prediction: while the first one contains the highest level of risk, the second one is compatible with a higher level of certainty since it embeds a reference which price fluctuates around. Apart from these extreme cases, Postali and Picchetti (2006) explained three types of model with intermediate levels of uncertainty mimicing better the stylized facts of oil markets: a) one factor (price) with mean reverting; b) two factors (price and convenience yield) with mean reverting and c) three factors, including the volatility of interest rates (see Postali and Picchetti, 2006 for details). As Lee et al. (2006) stated, without an appropriate understanding of the dynamics of a time series, empirical verification of theories, forecasting, and proper inference are potentially misleading. That's why in an attempt to see accurate properties of crude oil prices, both academics and practitioners have been paying attention to the understanding and statistical valuation of their prices in recent times.

4. Literatur Review

In recent years, most effort has been devoted to testing for the stationarity properties of crude oil prices. Exploring the stochastic properties of time series has become a standard implication prior to other econometric analysis. Most findings about time series properties of crude oil prices in the literature are the results of these kinds of implications. These studies use a variety of unit root tests to examine the time paths of crude oil prices. But as seen below, there has been an expansiveness of studies using different techniques, time periods, and different sample countries, with most studies employing univariate unit root tests[5] that reach mixed conclusions.

Subsequent research has shown that even the most competitive and complex markets do not always strictly follow a random walk. Rather, the mean reversion of commodity prices, such as crude oil prices, to a marginal cost of production has been demonstrated a number of times in the literature (Bernabe et al., 2004; Chardon, 2007). On looking at the long-term data in detail, one might expect that oil prices would be stationary because of market dynamics, time lags between price changes and demand/supply imbalances. Theoretically speaking, as discussed above in the context of Pindyck (1999) explanation, crude oil prices exhibit large upward or downward swings due to fluctuations in demand, extraction costs, and reserves. According to Pindyck (1999) any upward shifts in demand for oil or a rise in extraction costs will cause the crude oil prices to increase and this might lead to a change in the slope of the price trajectories (Maslyuk and Smyth, 2008).

Worth mentioning firstly, Pindyck (1999) dealt successfully with the issue of unit root test in the context of energy commodities (oil, gas, coal) by applying the O-U process to the energy price long-run evolution which could take into account that the marginal cost may fluctuate in slope and level over time. After the analysis, based on oil prices using 127 years of data (1870-1996) on crude oil and coal as well as 78 years of data (1919-1996) on natural gas, Pindyck (1999) concluded that the price mean reverted to stochastically fluctuating trend lines that represented long-run total marginal costs but were themselves unobservable. So a modelling as a mean reverting to a stochastic trend had a better performance for purposes of prediction in general. But Pindyck (1999) also showed that during the time period of analysis, the random walk distribution for log-prices, i.e., the

5 Basically, rejection of the unit root null supports the alternative hypothesis of a mean or trend reverting stationary series, implying that shock effects are transitory. Alternatively, failure to reject the unit root null implies a non-stationary series in which shocks have permanent effects; following a shock there is no tendency for crude oil or natural gas prices to revert to a stable mean or trend (Lee et al., 2006).

GBM for spot prices, was a much better approximation for coal and gas than oil (Geman, 2007; Chardon, 2007). It should be pointed out here that Pindyck (1999) has not taken into account the possibility of jumps or non-constant volatility in his unit root tests, even he criticizes to take into account structural breaks with the thought of increasing the possibilities for data snooping.

Apart from Pindyck (1999), some of the other studies analysing the long-run properties of crude oil prices based on unit root tests applied to long spans of data are Slade (1988), Dixit and Pindyck (1994), Jalali-Naini and Asali (2004) and Krichene (2002).Slade (1988) used data from 1906 to 1973 and was not able to reject the unit root hypothesis for the oil price. AlsoKrichene (2002) employed annual data spanning 1918 to 1999 for crude oil and natural gas.He examined the time series properties of not only natural gas and crude oil production but also prices. Krichene (2002) divided the sample into two sub-samples spanning 1918-1973 and 1973-1999 and he could not reject the unit root null with standard Dickey and Fuller (1979, 1981) (D-F hereafter) and Augmented Dickey Fuller (ADF hereafter) tests for the whole period but could reject for sub-samples. Jalali-Naini and Asali (2004) tested the unit root hypothesis for the annual data of crude oil prices with both the Phillips and Perron (1988) (P-P hereafter) and ADF tests for two different periods (1861-2002) and (1925-2002). The null hypothesis that the logarithm of the price of oil has a unit root was not rejected at the conventional confidence levels. However, the null hypothesis was rejected for the 1925–2002 period. For the quarterly data, the null hypothesis was not rejected for the nominal price of crude oil for the 1957.1–2003.2 period, but it was rejected for the 1972.1–2003.2 period. ADF and P-P tests of the quarterly data had similar results. They pointed out that the P-P and ADF tests indicated that the value of the autoregressive term, whether the unit root hypothesis has been rejected or not, depended on the sample period.

Lund (1993) argued that the GBM with drift has been hardly an equilibrium price process if resource deposits have had different extraction costs and each resource owner has followed an optimal extraction strategy. However, stationarity of crude oil prices has not been confirmed by the majority of studies. In fact, the literature on crude oil price behaviour seems to indicate that these exhaustible resources exhibit shock-persistence, meaning that exhaustible resource prices have a stochastic trend. Most papers have applied conventional unit root tests such as the ADF,P-P and stationarity test, i.e., the Kwiatkowski, Phillips, Shin and Schmidt (1992) (KPSS hereafter).The failure of many of these studies to find that oil prices are mean-reverting processes might reflect the low power of conventional unit root tests (Videgaray-Caso, 1998; Maslyuk and Smyth, 2008).

This result obtained by previous time series analysis is worth measuring and arguing by new techniques.

Silvapulle and Moosa (1999) used the data sample consisting of daily observations of spot and futures prices of WTI crude oil covering the period between 2 January 1985 and 11 July 1996 and applied the ADF, P-P and KPSS unit root tests. The results showed that these conventional tests confirmed the crude oil price series to be non-stationary. Differently, Cashin et al., (2000) used the median-unbiased estimation procedure to determine the persistence of a shock to commodity prices. They found that shocks to commodity prices were generally long-lasting, but the degree of persistence of price shocks differed significantly for different commodities. They also found that, for crude oil, the price shock was permanent and highly persistent. In order to study the inter-relationships of international crude oil markets Ewing and Harter (2000) studied co-movement of Alaskan North Slope and UK Brent crude oil prices using monthly data from 1974 to 1996. Based on the P-P unit root test, they could not reject the null of a unit root in either Alaskan or UK Brent crude oil prices and concluded that these oil markets shared a long-run common trend. Papapetrou (2001) used also P-P and KPSS tests to investigate the degree of integration of the real oil price. The empirical analysis was carried out using monthly data for the period 1989:1 to 1999:6 for Greece. He found that the variable of real oil price was I(1) according to the P-P and KPSS statistics. Again, Alizadeh and Nomikos (2004) tested for a unit root by ADF, P-P and KPSS tests in weekly closing prices of WTI, Brent and Nigerian Bonny Light spanning January 1, 1993 to August 10, 2001. They could not reject the unit root null hypothesis as well (Maslyuk and Smyth, 2008). The other paper is Tang and Hammoudeh (2002) using the monthly spot crude oil prices data spanning January 1988 to December 1999, which are the average basket price of seven types of crude oil produced by OPEC's member countries. According to D-F, ADF and P-P test results, they came through the same result that the oil price was non-stationary. Thereafter, Tabak (2003) used the Brent Crude futures contracts traded at the International Petroleum Exchange (IPE) data spanning the period from January 1990 to December 2000 in his paper dealing with the efficiency of the Brent Crude oil future contracts and testing whether futures could be used to predict realized oil spot prices. He could not reject the null of non-stationary time series for the one and two-months series. However, he rejected the null for the three-months contract.

Furthermore, Coimbra and Esteves (2004) used the Brent crude oil spot and futures prices spanning the period from January 1989 to December 2003 as well as for a shorter period, which omitted the Gulf War, from January 1992 to December

2003 to test the stationarity by applying the ADF test. For both timeframes, the null hypothesis of a unit root for crude oil prices could not be rejected. According to Coimbra and Esteves (2004), it was very difficult to identify any kind of systematic behaviour in oil prices, as they tended to follow a random walk process or a very short memory process (Maslyuk and Smyth, 2008). Mobert (2007) performed the ADF test as well as the test namely Hylleberg, Engle, Granger, Yoo to test for unit root. According to both test results, the monthly WTI crude oil price series spanning between December 1995 and January 2006 was found as non-stationary. Recently, Askari and Krichene (2008) applied ADF unit root test to daily crude oil prices spanning January 2, 2002 to July 7, 2006 containing 1,130 daily observations. Their results clearly showed that oil prices were moving upward, and became forecastable. After each peak, oil prices seemed to retreat temporarily then returned toward higher peaks. He was unable to reject the unit root hypothesis for crude oil price series showing no sign for mean reversion. Al-Salman et al. (2008) studied on G-7 countries by using quarterly data spanning 1970:1 to 2006:4. ADF test showed that oil price data representing by average of the OPEC crude oil price on quarterly base was I(1). Again, Cologni and Manera (2008) using quarterly international average crude oil price (Brent dated) data spanning the period from 1980:1 to 2003:4 applied ADF test and found oil prices were I(1) for all countries.

More recently, Miller and Ratti (2009) analyzed the long-run relationship between the price of crude oil and international stock markets from January 1971 to March 2008 using a vector error correction model. They conducted standard P-P coefficient and t-tests as well as KPSS tests. They firmly rejected stationarity of the crude oil price series using the KPSS tests, and failed to reject a unit root anywhere using the P-P tests, indicating the presence of non-stationarity. In order to test the stationarity of the WTI crude oil prices and Henry Hub natural gas prices Ramberg (2010) employed the ADF and P-P test using weekly data starting 25 January 1991. Both the logged WTI crude oil and the Henry Hub natural gas prices failed to reject the null hypothesis that there was a unit root and that data were non-stationary.

Classical unit root tests are likely to be inconclusive in the case of oil and natural gas prices, for time series spanning several times. The other modelling principle is allowing for structural change to take place over time. The empirical literature that deals explicitly with structural breaks in the oil price process is quite scarce although taking structural break into account is crucial for long term time series. Since the seminal work of Perron (1989), it is well known that ignoring structural change in unit root tests will lead to a bias against rejecting

the unit root null hypothesis when it should in fact be rejected. The motivation relies on the historical record of events in the international crude oil market. To many observers it appears that the workings of the international crude oil market, for example, were significantly altered in the decade of the 1970s, when market control shifted early in the decade from oil companies to producing nations, who eventually raised prices. These kinds of events introduce structural breaks in the stochastic process of the oil prices, which should be a feature of any complete univariate description of the process. Numerous previous empirical studies on natural resource prices typically neglect possible structural change in the time series (Videgaray-Caso, 1998; Lee et al., 2006).

Serletis (1992), to the best of my knowledge, is the first study testing for a unit root in oil prices with a single endogenous structural break by applying the Z-A test to a sample of daily NYMEX energy futures prices, including crude oil, heating oil and unleaded gasoline, over the period July 1983 to July 1990. He firstly applied the ADF and P-P tests and found all series contained a unit root. Then, he used the Z-A test and showed that the unit root hypothesis can be rejected if allowance is made for the possibility of a one-time break in the intercept and the slope of the trend function at an unknown point in time (Serletis, 1992; Maslyuk and Smyth, 2008).

Akarca and Andrianacos (1995) conducted tests of structural change on a second order autoregressive model (AR(2)) using monthly data for the 1974-1996 period. They found evidence that the stochastic process changed after January 1986, resulting in a more volatile process in which shocks were less persistent. Berck and Roberts (1996) and Ahrens and Sharma (1997) also discussed the notion that exogenous shocks can affect the time path of natural resource prices. Ahrens and Sharma (1997) assumed one known or exogenously given structural break common to all commodity price series in 1929, 1939, or 1945(Lee et al., 2006). They found 6 of the 11 resource commodity price series, (aluminium, bituminous coal, lead, nickel, petroleum, and zinc), having TS processes. However, copper, iron, natural gas, silver, and tin and prices were found to be DS.

Gulen (1997) applied Perron's (1989) ADF-type unit root test with one exogenous structural break to spot and contract prices for US and non-US crudes of different gravity while testing Weiner's main hypothesis which is "prices in all regions move together in a completely unified market". The likely effects of the crash in 1986 were selected as the exogenous structural break because it corresponded to the largest drop in oil prices over the entire sample period.

According to Gulen (1997) conventional unit root tests were not appropriate in the case of the oil market. He found that two of the fifteen spot price series and three of the thirteen contract price series were stationary at the 5 percent level of significance (Maslyuk and Smyth, 2008).In a second study Gulen (1998) applied Perron's (1989) ADF-type unit root test to NYMEX monthly crude oil futures at one, three and six months to maturity from 1983:3 to 1995:10 (except for one-month-ahead contracts which starts at 1983:5) and treated 1986:2 as the exogenous break point. He was unable to reject the unit root hypothesis for any of the oil price series (Maslyuk and Smyth, 2008).

Videgaray-Caso (1998) examined the possibility of a structural change in the context of the price of crude oil. Working with about 120 years of data, he applied Perron's method to the estimation of stochastic switching models of price, and found a structural change around 1973. Sadorsky (1999) used the US monthly real oil prices data measured using the producer price index for fuels covering the period 1947:1-1996:4. According to P-P results the real crude oil price had unit root. He also applied the Z-A test and found that at the 1 percent level of significance, crude oil price series are not TS around a broken trend. Cunado and Perez de Garcia (2003) also used two tests (P-P and Z-A) for unit root and found that as in the P-P case, the Z-A test results suggested that the null hypothesis of a unit root in oil prices could not be rejected using this approach.

Lee et al. (2006) used five different unit root tests (no break LM unit root test of Schmidt and Phillips (1992) with an added quadratic time trend, two break LM unit root test of Lee and Strazicich (2003), one-break minimum LM unit root test of Lee and Strazicich (2004), two-break LM unit root test to include a quadratic time trend, one-break LM test to include a quadratic trend) to analyze each of eleven natural resource price series. They tested two specifications: a unit root test with linear trend and a unit toot test with a quadratic trend. Their results provided the strongest evidence to date against the unit root hypothesis and suggested that natural resource price series were stationary around deterministic trends with occasional structural changes in intercept and trend slope, their findings were at odds with those in previous studies. In particular while natural gas was found stationary in every five test, petroleum was only stationary according to the results of two Break Minimum LM Unit Root Test and One Break Minimum LM Unit Root Test with Quadratic Trend. Postali and Picchetti (2006) also applied the Lee and Stazicich (2003, 2004) LM unit root tests with one and two endogenous structural breaks to international oil prices. Similar to Pindyck (1999), Postali and Picchetti (2006) found that the length of the sample period was the most important factor in determining whether the series had

at least one unit root. They divided the sample that covered 1861 to 1999 into several sub-samples. Although ADF and P-P tests were only able to reject the unit root null for the entire sample, conventional tests and LM unit root tests with two breaks in the intercept could not reject the unit root null for the sub-samples. But, the unit root null hypothesis could be rejected for the period 1861-1999 and the sub-periods when allowing for two breaks in the intercept and trend (Maslyuk and Smyth, 2008).

Bentzen (2007) used daily spot price data covering the time period from April 1987 to December 2004 from the Middle East, North America and the North Sea measured in US dollars per barrel. He first performed the ADF unit root test, Dickey-Fuller with generalized least squares de-trending (DF-GLS hereafter) test (Elliott et al., 1996) and the KPSS test and crude oil prices are found to be non-stationary in levels according to these test results. Additionally, he applied the Perron (1997) test for unit roots allowing for a structural break (in the intercept) and the unit root hypothesis was not rejected in any of the cases when including this type of break.

It can be generalized that the length of the sample period seems the most important factor in determining whether the series had unit root. For this reason, all the academic studies aiming at testing the time series properties of crude oil prices should use similar periods so that comparing the results makes sense. After all, the previous studies that have found mean or trend reversion in crude oil prices have typically used annual data over periods ranging from 50 years to 140 years. In other words, only tests on very long series have enough power to reject the null. Moreover, studies that have found evidence of stationarity in crude oil prices have typically applied ADF-type or LM unit root tests with structural breaks to annual data spanning 50 to 140 years (Maslyuk and Smyth, 2008). Rejection of the unit root null hypothesis with tests taking structural breaks into account would lay weight on the important role of structural breaks plays in tests for unit roots. That's why, prior to crude oil prices being treated as either TS or DS, it is important to determine whether such trend breaks should be treated like any other, or differently (Serletis, 1992). Indeed, examining the long-run time series of real oil prices spanning a century, suggests non-linearity because of the existence of several breaking points.

There is both anecdotal and econometric evidence about the presence of non-linearities in the process. Green et al. (1994) applied an extended version of variance-change and outlier-search techniques to oil price annual data for the 1860-1989 period. They found that movements in the price of crude oil were not all of the same kind: while "normal" changes were well described by a stationary

AR(1) model, some infrequent changes were larger than usual but quite persistent (Videgaray-Caso, 1998). Videgaray-Caso (1998) applied Hamilton's Markov regime switching model on the USA's 127 years long series of the real price of oil. He found presence of changes in regime according to this model. He indicated that the price of oil has switched back and forth between two AR(1) regimes. The model suggested that in "normal" times including more than 80 percent of the sample, the price moved around a relatively low mean, volatility was low and the persistence of disturbance was high; however, there were recurrent episodes (every 11 years on average) in which the price moved around a much higher mean, volatility was very high but persistence of disturbances was relatively low. He found these episodes lasting on average between 4 and 5 years.

Fattouh (2008) analyzed 10 pairs of crude oils whether a price differential is stationary using standard unit root tests, such as the ADF, P-P and DF-GLS and TAR model suggested by Caner and Hansen (2001). He used weekly data for the period 1/1/1997 to 26/10/2007. With the thought that standard unit root tests are inconclusive on whether oil price differentials follow a stationary process, he modelled crude oil price differentials as a two-regime threshold autoregressive (TAR) process using C-H method and found that that oil price differentials follow a stationary process even for pairs of crude oil with very different qualities.

Instead of trying to decide whether the series as a whole or in part exhibits a unit root, Dvir and Rogoff (2010) determined whether it showed transitions from a stochastic trend to a deterministic one, and vice versa. In order to do that, they employed a series of tests proposed by Harvey, Leybourne, and Taylor (2006), modified version of tests for change in persistence proposed earlier by Kim (2000), Kim et al. (2002), and Busetti and Taylor (2004), all of whom build on the unit root testing method of KPSS. They found that the real price of oil has tended to be highly persistent and volatile whenever rapid industrialization has coincided with uncertainty regarding access to supply. They therefore conducted a test for multiple breaks in oil price volatility, using the methods of Bai and Perron (1998, 2003). They identified three potential breakpoints: 1878, 1933, and 1972. They concluded that the real oil price from 1861-1877 (or 1878) was highly persistent and volatile, from 1878-1933 was not as persistent and less volatile, from 1934-1972 (or 1973) it was still not very persistent and displayed even lower volatility. Finally, from 1973 on the real price of oil returned to being highly persistent and volatile, though not as volatile as in the pre-1878 period. Fractional unit root tests are rarely used to understand the stochastic process of crude oil prices. Gil-Alana (2001, 2003) could be cited as an example. He found that the real price of oil is a fractional integrated process.

5. Econometric Methodology

Time series are often described as being composed of a trend and a cycle. Before the study of Nelson and Plosser (1982), an important stimulant in this time-series renaissance, it was commonplace to assume that the trend was linear. Recent years have witnessed an explosion of research examining the time series properties of economic and financial data and focusing on the search for the best way to characterize or model the dynamic properties of them. Classical methods of estimation, which are usually used in applied econometric works, are based on the assumptions that the mean and variance of a stochastic process are independent of the time. Nelson and Plosser (1982) applied unit root analysis to test for the stationarity of many widely used aggregate macroeconomic time series and provided evidence that the trend could be characterized as a random walk. That is, instead of being a fixed trend to which the time series would revert over the business cycle, the trend would be moved by random shocks and then would stay at the new level until disturbed by another random shock (Hansen, 2001). To sum up Nelson and Plosser (1982) argue that almost all macroeconomic time series have a unit root. Since this seminal study[6], the distinction between stationary processes and unit root has become a dominant topic in time series econometrics and many authors have analyzed data ranging from stock prices to air pollutant emissions (Lee et al., 2006).

Due to its far-reaching economical implications, it has also become a central issue in empirical research, where it has been concluded that many economic and financial time series and particularly price series, rarely result from stationary stochastic process. A variable in which the mean changes with time is known as non-stationary or having a unit root. In other words, the non-stationarity of the process can involve the first order moment (mathematical expectation) as well as the second order moment (variance and covariance of the process). Studies on the theory of unit roots have shown that the utilization of classical methods to estimate relations with variables that possess unit roots can lead to erroneous inferences. This is known as spurious regression, i.e. if the mean and variance change with time, all the statistics computed in the regression model are also time dependent and do not converge to their true values as the sample size increases. Moreover, conventional hypothesis tests will be seriously biased through the rejection of the null hypothesis of non-relation between the dependent and the independent variables. That's why in order

6 Actually, as mentioned by Hendry and Juselius (2000), the unit-root literature is a recent phenomenon. Udny Yule analyzed the hazards of regressing a trending variable on another unrelated trending variable – the so-called `nonsense regression' problem in 1926.

to draw any statistical inference about the temporal behaviour of an indicator; the particular series under scrutiny must be stationary in a statistical sense. The number of differences needed for a series to be stationary is known as the integration order (Franco et al., 2006, Westerlund, 2006).

Following the empirical work of Nelson and Plosser (1982), a common motivation for testing for a unit root is to test the hypothesis that a series is DS against the alternative that it is TS (Schmidt and Phillips, 1992). The TS process can be written as $x_t = f_t + \varepsilon_t$. Here, f_t is a linear or non-linear polynomial function of time and ε_t is a stationary process. The simplest and the most widely used TS process is represented by a polynomial function of degree 1. The TS process is then called linear and is expressed $x_t = a_0 + a_1 t + \varepsilon_t$. This TS process is non-stationary because $E[x_t]$ is a function of time. Knowing $\hat{a}_0$ and $\hat{a}_1$, the x_t process can be stationarised by removing, from the value of x_t in t, the estimated value $\hat{a}_0 + \hat{a}_1 t$. In this type of modelling, the effect produced by a shock (or by several stochastic shocks) at a time t is transitory. The model being deterministic, the time series resumes its long-term movement on the trend line. It is possible to generalize this example to polynomial functions of any degree (Bourbonnais and Meritet, 2007).

The DS processes are the ones that can be made stationary by the use of a difference filter:

$$(1-L)^d x_t = \beta + \varepsilon_t$$

where ε_t is a stationary process β is a real intercept, L is the lag operator and d is the order of the difference filter. The macro econometric literature stresses the cases d = 0 and d = 1, and $(1 - L)^d$ can be defined for all real d by the expansion

$$(1-L)^d = 1 + \sum_{j=1}^{\infty} \frac{\Gamma(d+1)(1-L)^j}{\Gamma(d-j\mp 1)\Gamma(j+1)}$$

The process is then said to be a first order process and is written:

$$(1-L)x_t = \beta + \varepsilon_t \leftrightarrow x_{t-1} + \beta + \varepsilon_t$$

This introduction of intercept β in the DS process makes it possible to define two different processes:

$\beta = 0$: The DS process is said to be without trend. It is written $x_t = x_{t-1} + \varepsilon_t$. Since ε_t is white noise, this process is called a Random Walk Model. To stationarize the random walk, it is only necessary to apply the first order difference filter to the process $x_t = x_{t-1} + \varepsilon_t \leftrightarrow (1 - L)x_t =$. A random walk process containing an intercept term is called random walk with drift.

$\beta \neq 0$: The process is then called a DS process with trend. It is written as follow:

$$x_t = x_{t-1} + \beta + \varepsilon_t$$

This process can be stationarised using the following first order difference filter(Bourbonnais and Meritet, 2007):

$$x_t = x_{t-1} + \beta + \varepsilon_t \leftrightarrow (1 - L)x_t = \beta + \varepsilon_t$$

To sum up, the presence or absence of unit roots helps to identify some features of the underlying DGP of a series. In the absence of unit root, a stationary series fluctuates around a constant long-run mean and reverts to this mean after a random shock; implying that the series has a finite variance which does not depend on time. On the other hand, a series may exhibit non-stationarity if it contains either a deterministic trend or stochastic trend. In the DS type processes, a shock may or may not have significant effects on the trends over short spans of time but their cumulative effects may be significant and cannot be ignored, i.e., a shock at a given time affects, to infinity, the future value of the series; the effect of the shock is therefore permanent and decreasing and thus these series follow a random walk. Typically, the stochastic trend is characterized as a unit root process with a drift which consists of the accumulation of random, or stochastic, events over time while the deterministic one is represented as the sum of a stochastic short-memory component and some deterministic trends (Mayoral, 2012). For the deterministic one, the mean of the series is trended. With appropriate de-trending, the series will become stationary around a fixed mean and is referred to as TS. A stochastic trend process is neither mean nor trend-reverting. These models typically imply that the mean and variance increase without bound over time, the precision of the forecast error is unbounded, and the effect of shocks persists. In other words, these kinds of series have no tendency to return to a long-run deterministic path and the variance of the series is time dependent. A unit root process must be differenced in order to achieve stationarity. The number of unit roots indicates the number of differences that must be undertaken. A unit root process appropriately differenced is said to be DS (Ahrens and Sharma, 1997).

Shortly, to stationarize a TS process, the preferred method is that of ordinary least squares; for a DS process, it is necessary to employ the difference filter.

The appropriate treatment of trends in economic time series is important. There is evidence that removal of estimated (typically linear) deterministic trend from time series that are in fact integrated could lead to spurious cyclical behaviour in the de-trended series. Chan et al. (1977) studied both inappropriate de-trending of integrated series and inappropriate differencing of trending series, and showed that the former produced spurious variation in the de-trended series, while the latter produced spurious variation in the differenced series at high frequencies. These results have been confirmed by Nelson and Kang (1981, 1984) and Durlauf and Phillips (1988).

The issue of stochastic versus deterministic trend models has considerable implications for our understanding of the economy and economic planning. First, the unit root is transferred to other macroeconomic variables due to existence of interrelation between them. Secondly, if shocks to these economic series are temporary, then a stabilization of energy policy has no long-lasting effects. When any economic series temporarily deviates from the trend path, therefore there exists less need for policy action, since the series will in any case return to its trend sometime in the future. But in the context of stochastic trends, any shock to the economic system will have a permanent effect, so a policy action will be required to bring the variable back to its original long-term projection. Finally, any series exhibits stationarity, making it possible for the series to forecast future movements established on past behaviour (Hsu et al., 2008).

Despite the interest aroused in unit-root models by Box and Jenkins (1970) and Dickey and Fuller (1979), no test has been shown analytically to be uniformly most powerful. In addition, the empirical size of a unit root test can differ substantially from the nominal size under certain conditions. Last, different unit root tests impose different restrictions on the series under the null and alternative hypotheses (Ahrens and Sharma, 1997, Gil-Alana and Robinson, 1997). Below, the unit root tests used in this paper are explained shortly.

5.1. Linear Unit Root Tests without Structural Breaks

As stressed above, the unit root literature concentrates on whether time series are affected by transitory or permanent shocks. As mentioned before, rejection of the unit root null supports the alternative hypothesis of a mean or trend reverting stationary series, implying that shock effects are transitory. Alternatively, failure

to reject the unit root null implies a non-stationary series in which shocks have permanent effects; following a shock there is no tendency for any time series to revert to a stable mean or trend (Lee et al., 2006). This implication has profound consequences for business cycle theories. It runs counter to the prevailing view that business cycles are transitory fluctuations around a more or less stable trend path. It is therefore of importance to assess carefully the reliability of the unit root hypothesis as an empirical fact (Perron, 1989). So there emerged a considerable literature to reveal time series properties of economic and financial data and to assess them accurately.

I begin through applying commonly used methods, the D-F, ADF, P-P, KPSS, DF-GLS, Elliot, Rothenberg, and Stock (1996) (ERS hereafter) point optimal, Ng and Perron modified versions of the P-P (N-P MZ_t hereafter) and Ng and Perron ERS point optimal (N-P MP_T hereafter) to provide a benchmark for other unit root tests such as Z-A, B-P, GPH, GSE, C-H and KSS. The D-F test is developed for simple Gaussian random walks and makes it possible to display the stationary or non-stationary character of a time series by the determination of a deterministic or stochastic trend. In D-F models, the process ε_t is, by hypothesis, white noise. However, there is no reason, a priori, for the error to be non-correlated; tests that take into account this hypothesis are called ADF tests (Dickey and Fuller, 1981). This test is performed in a manner similar to that of a simple D-F test; only the statistical tables are different. There are also derivative procedures (notably Said and Dickey (1984), Phillips (1987) and Phillips and Perron (1988)) intending to detect the presence of a unit root in a general integrated process of order one (I(1)). In these tests the null hypothesis of a unit root is tested against a TS alternative. The P-P test being extension of the D-F test, but without the lagged differences, is built on a non-parametric correction of D-F statistics to take into account the heteroskedastic errors. While the ADF test corrects for higher-order serial correlation by adding lagged difference terms to the right-hand side, the P-P unit root test makes a non-parametric correction to account for residual serial correlation. Its statistics are to be compared with the critical values in MacKinnon table as well[7]. Kwiatkowski et al. (1992) propose the use of the Lagrange multiplier test (LM) based on the null hypothesis of stationarity. This test has generally been used to confirm results from the ADF and P-P tests in literature. But according to Maddala and Kim (1998) the KPSS test is also plagued by the poor power and size properties, as

7 The available evidence from Monte Carlo studies suggests that the P-P unit root test generally has greater power than the ADF test (see Banerjee et al., 1993).

are the other conventional ADF and P-P tests. Since these tests have been widely used in various applications of detecting stationarity, the mathematical details of these tests have been suppressed to avoid unnecessary lengthening of the paper (Bourbonnais and Meriet, 2007).

The ADF and P-P unit root tests are known (from Monte Carlo simulations) to suffer potentially severe finite sample power and size problems and to have severe size distortion (in the direction of over-rejecting the null) when the series has a large negative moving average root. In general, the ADF and P-P tests have very low power against I(0) alternatives that are close to being I(1). That is, unit root tests cannot distinguish highly persistent stationary processes from non-stationary processes very well. Also, the power of unit root tests diminishes as deterministic terms are added to the test regressions. That is, tests that include an intercept and trend in the test regression have less power than tests that only include an intercept in the test regression. For maximum power against very persistent alternatives the recent tests proposed by DF-GLS, ERS point optimal and Ng and Perron (2001) (N-P hereafter) should be used. These tests are described below.

5.1.1. Dickey-Fuller Generalised Least Squares (DF-GLS)

This test is particularly appropriate for highly trending data; furthermore, Maddala and Kim (1998) argue that DF-GLS tests are more powerful than the ADF and P-P tests.In the ADF test regression, either an intercept or an intercept with a linear time trend is included to take account of the deterministic components of data. ERS propose a simple modification of the ADF tests in which the data are de-trended so that explanatory variables are "taken out" of the data prior to running the test regression. The DF-GLS has also called de-trending test because the order of integration of variable y_t is calculated from de-trending procedure developed. The following equation is then estimated to test for a unit root in the variable:

$$\Delta y_t^d = \alpha y_{t-1}^d + \beta_t \Delta y_{t-1}^d + \cdots + \beta_p \Delta y_{t-p}^d + v_t$$

where Δ is the difference operator, y_t^d is the generalized least squares de-trended value of the variable, α, βt and βp are coefficients to be estimated and v_t is the independently and identically distributed error term. As in the case of the ADF test, a test for a unit root of the variable y involves examination of whether the coefficient of the AR(1) term, in this case α, in equation above is zero against the alternative of a $\neq 0$. In other words, the null hypothesis of this test is that y_t has a random walk trend,

possibly with drift. Basically it proposed two hypotheses. Firstly, y_t is stationary about a linear time trend and secondly it is stationary with a non-zero mean with no linear time trend. Considering the second hypotheses, the DF-GLS test is performed by estimating the intercept and trend utilizing the generalized least square technique. In this hypothesis, t value is the same as the ADF test, and its critical value is as the ADF test. But if DF-GLS test contains both trend and intercept, its distribution is different from the ADF test, the critical values tabulated in Elliot et al. (1996) are used.

5.1.2. Elliott, Rothenberg and Stock (ERS) Point Optimal Test

When a time series has an unknown mean or a linear trend the ERS point optimal test dominates other conventional unit root tests. This test is based on the following quasi-differencing regression:

$$d(y_t|a) = d(x_t|a)'\delta(a) + \eta_t$$

where $d(y_t|a)$ and $d(x_t|a)$ are quasi-differenced data for y_t and x_t respectively and η_t the error that is independently and identically distributed. Details on computing quasi differences are given in Elliot et al. (1996). In this equation, y_t is the variable whose time series properties are tested, x_t may contain an intercept only or both an intercept and time trend and $\delta(a)$ is the coefficient to be estimated. ERS recommend the use of $\bar{a}$for ain equation above that is computed as $\bar{a} = 1 - 7/T$when x_t contains an intercept and $\bar{a} = 1 - 13.5/T$when x_t contains an intercept and time trend. In the ERS point optimal test, the null and alternative hypotheses tested are α=1 and α=$\bar{a}$respectively. The relevant test statistic (P_T) to test the above null hypothesis is:

$$P_T = (SSR(\bar{a}) - (\bar{a})SSR(1))/f_0$$

where SSR is the sum of squared residuals from equation above and $f_0$is an estimator for the residual at frequency zero. In making inferences, the test statistic calculated is compared with the simulation based critical values of ERS (Cooray and Wickremasinghe, 2007).

5.1.3. Ng and Perron (2001) Test

N-P (2001) construct four M-test statistics based on the GLS de-trended data y_t^d. These test statistics are modified forms of P-PZ_α and Z_t statistics, the Bhargava (1986) R_1 statistic, and the ERS point optimal statistic. First, one will define the term.

$$\kappa = \sum_{t=2}^{T} \left(y_{t-1}^d\right)^2 / T^2$$

The GLS-de-trended modified statistics may then be written as

$$MZ_{\alpha}^{d} = \left(T^{-1}\left(Y_T^d\right)^2 - f_0\right)/(2\kappa)$$

$$MZ_{t}^{d} = MZ_{\alpha} x MSB$$

$$MSB^{d} = (\kappa/f_0)^{1/2}$$

$$MP_T^d = \begin{cases} \dfrac{\left(\bar{c}^2\kappa - \bar{c}T^{-1}\left(Y_T^d\right)^2\right)}{f_0} if x_t = \{1\} \\ \dfrac{\left(\bar{c}^2\kappa + (1-\bar{c})T^{-1}\left(Y_T^d\right)^2\right)}{f_0} if x_t = \{1, t\} \end{cases}$$

$$\text{where } \bar{c} = \begin{cases} -7 if x_t = \{1\} \\ -13.5 if x_t = \{1, t\} \end{cases}$$

These tests have similar size and power properties. First, the time series is de-meaned or de-trended by applying a GLS estimator. This step turns out to improve the power of the tests when there is a large AR root and reduces size distortions when there is a large negative MA root in the differenced series. The second feature of the NP tests is a modified lag selection (or truncation selection) criteria. They also address the problem of sensitivity of unit root testing to choice of lag and hence propose the modified information criteria, which takes into account the bias in the sum of the autoregressive coefficients being highly dependent on the number of lags that the general Akaike and the Schwartz Bayesian criteria do not. They also formulate the null hypothesis that the series has unit root.

5.2. Linear Unit Root Test with Structural Break

Because a wide range of political and economic factors can cause the relationships among economic variables to change over time, essentially testing for structural change has always been an important issue in econometrics, see Stock and Watson (1996) for a persuasive empirical analysis. There are huge econometric literatures on testing for structural change, and on estimating models of structural change and stochastic regime switching. Structural break tests can be divided into three categories. The first and classical test for structural break is typically attributed to Chow (1960). He tests whether the series has a break in the tested date by splitting the sample into two sub-periods, estimating the parameters for each sub-period, and then testing the equality of two sets of parameters using F statistic. The tests in the second category look for the presence of a break in the series, which may exist at any time within the sample

period. Some tests in this category also reveal the most possible break date as a by-product. The tests in the last category are in fact estimators, they first estimate the "unknown" date of the break, then test it (see Hansen, 2001; Eksi, 2009).

As discussed above, the most important implication under the unit root hypothesis sparked by Nelson and Plosser (1982) is that the random shocks have permanent effects on the long-run level of macroeconomics; that is the fluctuations are not transitory. These findings were challenged by Perron (1989, 1990) and Rappoport and Reichlin (1989) independently, who argue that in the presence of a structural break, the standard ADF tests are biased towards the non rejection of the null hypothesis and the failure of the ADF test to reject the unit-root hypothesis reflects not the presence of the unit root but instead that the data are TS about a broken trend. For example, Perron (1989) carries out standard tests of the unit-root hypothesis against TS alternatives with a break in the trend occurring at the Great Depression of 1929 or at the OilPrice Shock of 1973 using the Nelson and Plosser macroeconomic data series as well as a post-war quarterly real gross national product series (John et al., 2007; Onel, 2005). These two shocks are rather different in nature. According to Perron (1989), the Great Depression created a dramatic drop in the mean of most aggregate variables on one hand and the 1973 oil price shock was followed by a change in the slope of the trend for most aggregates, i.e., a slowdown in growth, on the other. Perron (1989) concludes that a unit root does not characterize most macroeconomic series but rather that persistence arises only from certain big and infrequent shocks, and that the economy returns to deterministic trend after small and frequent shocks. Insum, Perron's argument was that only certain "big shocks" have had permanent effects on the various macroeconomic time series and that these shocks were exogenous, i.e., not a realization of the underlying DGP of the various series. Modelling such shocks as exogenous removes the influence of these shocks from the noise function and, in general, leads to a rejection of the null hypothesis of a unit root. So, he found that fluctuations were indeed stationary around a deterministic trend function that contains a one-time break, a single change in the intercept of the trend function after 1929 or a single change in the slope of the trend function after 1973 (Perron, 1989, Serletis, 1992). These results seem to suggest that failure to account for breaks can produce misleading tests and result in incorrect inference, i.e., apparent persistence in macroeconomic data could be the result of unmodelled structural breaks in the underlying DGP and above all the long-term properties of output are determined not by unit-root dynamics, but rather by rare events with lasting implications for mean long-term growth,

such as the Great Depression, the Second World War and the subsequent shift to more activist governmental economic policy, or the oil shock and productivity slowdown of the mid-1970's (Stock, 1994).

This explanation is plausible, since a trend break produces serial correlation properties that are similar to those of a random walk. After that, researchers have become well informed about the potential hazards of falsely imposing parameter stability and the importance of allowing for a structural break when testing for a unit root. Perron (1989, 1990) show that the standard unit root tests, such as the ADF and the P-P, have low power against the alternative hypothesis of mean reversion to the random walk hypothesis and propose a modification to the ADF test. His procedure is characterized by a single exogenous (known) break in accordance with the underlying asymptotic distribution theory. He tabulated a set of critical values for his test statistic that make it possible to distinguish between a unit root process and stationary fluctuations around a mean or trend function which contains a one-time break (Chardon, 2007, John et al., 2007).

Perron's research provoked considerable interest in both detection of structural breaks, and inference about the order of integration in the possible presence of such breaks (Lee et al., 2006). The assumption that the location of break is known a priori has been criticized by a number of studies, such as those by Christiano (1992), Banerjee et al. (1992), Perron and Vogelsang (1992), Zivot and Andrews (1992), Perron (1997), Lumsdaine and Papell (1997), and Vogelsang and Perron (1998). For example according to Christiano (1992) the break point must be unknown. He criticized Perron by arguing that the break point is in most cases correlated with the data, e.g., the practitioner may determine the location of the break-date by visually inspecting a plot of the time series and this leads to inaccurate inferences and accusations of data mining (Buranakunaporn, 2006). Also the unit-root null is rejected too often according to Perron (1989) test because this methodology does not account for this pre-test examination of data. These papers above have urged the importance of endogenous rather than exogenous selection of a break date and proposed extensions for unit-root tests that do not require the practitioner to pre-specify the location of break. These studies have shown that bias in the conventional unit root tests can be reduced by endogenously determining the time of structural breaks. The strategy adopted by these studies is to apply Perron's methodology for each possible break-date in the sample, which yields a sequence of the statistic. These unit root tests accounting for structural breaks allow one to detect structural change in the variable under consideration that results in a shift in the mean, or in the growth rate or both,

thereby determining whether the series is a TS process with a one-time break occurring at an unknown point in time. After all these papers, it can be seen that all shocks, except one or two (possibly the Great Depression, the Second World War or the first oil shock) have had transitory effects (Mehl, 2000; John et al., 2007). Consequently, it can be said that the distinction between a random walk and a trend break largely concerns the frequency of permanent shocks to the trend. In a random walk process, such shocks occur frequently, while in a trend-break process, they occur infrequently (once or twice in a sample). Future work may attempt to find alternative ways to narrow the difference between these models.

Several tests for structural change have been proposed in the econometrics literature. These tests can be classified in two groups: a) tests for a single structural change and b) tests for multiple structural breaks. Macroeconomic time series can contain more than one structural break (Onel, 2005; Carrion-i Silvestre and Sanso, 2006). Especially if the historical time series are used in the analysis, it is important to be aware that the larger the sample period covering the time series, the more likely it is that there will be a structural change.

5.2.1. Unit Root Test with Endogenous-One-Structural-Break (Zivot and Andrews)

Subsequent studies have modified the test so that it allows for one unknown breakpoint that can be determined endogenously from the data. Zivot and Andrews (1992) (Z-A) argued that selection of the structural break a priori could lead to an over rejection of the unit root hypothesis. Therefore Z-A consider a variation of Perron's tests but they use a data-dependant algorithm to determine endogenously the date of the break, i.e., the break date is estimated rather than fixed. This endogenous structural break test is a sequential test that utilizes the full sample and uses a different dummy variable for each possible break date. Here, the null hypothesis is that the series is integrated without an exogenous structural break against the alternative that a TS process can represent the series with a once only breakpoint occurring at some unknown time. They considered the following three different characterizations of the trend-break alternative, respectively: (A) The Crash model that allows a break in the intercept; (B) The Changing Growth model that allows for a break in the slope with the two segments joined at the breakpoint; and (C) The Mixed model that allows for a simultaneous break in the intercept and the slope as follow (Balcilar et al., 2011).

$$\Delta y_t = \mu_1^A + \gamma_1^A t + \mu_2^A DU_t + \alpha^A y_{t-1} + \sum_{J=1}^{k} \beta_j \Delta y_{t-j} + \varepsilon_t$$

$$\Delta y_t = \mu_1^B + \gamma_1^B t + \gamma_2^B DT^*{}_t + \alpha^B y_{t-1} + \sum_{J=1}^{k} \beta_j \Delta y_{t-j} + \varepsilon_t$$

$$\Delta y_t = \mu_1^C + \gamma_1^C t + \mu_2^C DU_t + \gamma_2^C DT^*{}_t + \alpha^C y_{t-1} + \sum_{J=1}^{k-1} \beta_j \Delta y_{t-j} + \varepsilon_t$$

Where DU_t is 1 and $DT^*{}_t = t - TB \text{if } t > TB$, 0 otherwise. Where DU_t is an indicator dummy variable for mean shift occurring at each possible break date (TB) and $DT^*{}_t$ is a trend variable. Here,

H_0 : α=0 (series $\{y_t\}$ contains a unit root with a drift that excludes any structural break,

H_1 : α<0 (series $\{y_t\}$ is a TS process with a one-time break occurring at an unknown point in time.

The aim of the procedure is to sequentially test breakpoint candidates and select that which gives the most weight to the TS alternative. For the three models, Z-A estimate the testing equation by allowing the break to take place beginning successively in the second, third, fourth, and so on, observation, up to observation T - 1, where T stands for the total sample size used in the estimation. The break date is selected where the t-statistic from the ADF test of unit root is at a minimum (most negative). Consequently a break date will be chosen where the evidence is least favourable for the unit root null. In order to test the unit root hypothesis, this minimum t-value is compared with a set of asymptotic critical values from the work of Z-A (see Table 2, 3 and 4 of Zivot and Andrews, 1992, pp.256-257). The critical values in Z-A are different to the critical values in Perron (1989). The difference is due to the fact that the selecting of the time of the break is treated as the outcome of an estimation procedure, rather than predetermined exogenously (John et al., 2007).

5.2.2. Unit Root Test with Endogenous-Multiple-Structural-Break (Bai and Perron)

The econometric literature has witnessed an upsurge of interest in extending procedures to various models with an unknown change point after Christiano (1992), Banerjee et al. (1992), Perron and Vogelsang (1992) and Zivot and Andrews (1992). Despite a vast amount of study on issues related to structural change, as Bai and Perron (1998) pointed out, most of them specifically designed for the case of a single change. But it is far from obvious that one break is a good

characteristic of long-term macroeconomic time series. These unit root tests taking one-break into account only capture the single most significant break in each variable, raising the question: what if there are multiple breaks in each individual variable? (Bai and Perron, 1998; John et al., 2007). Also, according to several studies such as Lumsdaine and Papell (1997), Lee and Strazicich (2003), Ben-David et al. (2003) and Maddala and Kim (1998), given a loss of power when ignoring one structural break in standard unit root tests, it is logical to expect a similar loss of power when ignoring two, or more, breaks in the one-break tests.

The multiple structural changes case has received an increasing attention because recent research indicates that many economic time series might contain more than one structural break. For example, Ben-David and Papell (1998) and Papell et al. (2000) find evidence of more than one structural break in real GDP, per capita real GDP, and unemployment rates among OECD countries. Therefore, it may be necessary to allow for more than one break when testing for a unit root. For example, Lumsdaine and Papell (1997) introduce a procedure by extending the Z-A model to capture two structural breaks and re-examine the unit root hypothesis for the Nelson and Plosser data by considering the possibility that two break points occurred over the relevant time period. They find more evidence against the unit root hypothesis than Z-A (1992), but less than Perron (1989) and argue that unit roots tests accounting for two significant structural breaks under the alternative hypothesis of the unit root test are more powerful than those allowing for a single break. Others, having considered multiple breaks, are Clemente et al. (1998), who base their approach on Perron and Vogelsang (1992) but allow for two breaks, Ohara (1999) whose approach based on sequential t-tests of Z-A to examine the case on m breaks with unknown break dates, Papell and Prodan (2004) whose test based on restricted structural change, which explicitly allows for two offsetting structural changes and Lee and Strazicich (2003, 2004) whose test developed as a version of the LM unit root test to accommodate two endogenous structural break (John et al., 2007; Maslyuk and Smyth, 2008).

The literature addressing the issue of multiple structural changes is relatively sparse. Bai and Perron (1998) consider the estimation of multiple structural shifts in a linear model estimated by least squares. They propose some tests for structural changes for the case with no trending regressors and a selection procedure based on a sequence of tests to estimate consistently the number of changes, starting by testing for a single structural break. If the test rejects the null hypothesis that there is no structural break, the sample is split in two (based

on the break date estimate) and the test is reapplied to each subsample. The sequence continues until each subsample test fails to find evidence of a break (Hansen, 2001; Ben-Aissa et al., 2004).

Using their notation, a linear regression model with m structural breaks and therefore m+1 regime can be expressed as

$$y_t = x_t'\beta + z_t'\delta_j + u_t,\ t = T_{j-1} + 1, \dots, T_j$$

for j=1,...,m+1, where m is the number of breaks, y_t is the variable being explained. The vector x_t is the column vector of the explanatory variables at time t whose vector of coefficients β is not subject to breaks, meaning that their effects are invariant with time, in such a way that the vector x'_t is a line vector. The vector z_t is the column vector of the explanatory variables at time t whose coefficients δ_j are allowed to change, meaning that their effects vary over time, in such a way that the vector z'_t is a line vector. Given a sample of T observations of (y_t, x_t, z_t) and a particular m, the goal is to determine the coefficient estimates $(\beta, \delta_1, .., \delta_{m+1})$ and the break points $(T_1, .., T_m)$ (Peñaranda, and Micola, 2009).

For locating the breaks, as mentioned above, B-P propose two approaches using the equation above. In the first, each partition m is obtained as the one that minimizes the sum of square residuals (SSR). In other words, the break locations T_i,i =1,...,m , are determined so as to minimize $\sum_{i=1}^{m+1}\sum_{t=T_{t-1}}^{T_i}\left[y_t - x_t'\beta - z_t'\delta_J\right]^2$. B-P use a dynamic programming algorithm in order to optimize the computational time when finding the global SSR-minimizing breaks. In the second approach, breaks are determined sequentially, starting with the single break that minimizes the SSR. Then, for each resulting partition, the single break that minimizes the SSR is determined. The second break is the one with the minimum SSR between the two. This process is repeated sequentially to find further breaks. The search for the breaks that minimize SSR is implemented regardless of whether these breaks are statistically significant or not. Once the breaks have been identified, B-P propose a series of statistics to test for the statistical significance of these breaks, using asymptotic critical values (Antoshin et al., 2008). B-P (1998) develop three tests as follows.

A. Test of Structural Stability versus a Fixed Number of Breaks (Sup F)

In the first test, B-P (1998) consider the sup F type test of structural stability (no breaks, i.e. m=0) against the alternative hypothesis that there is a known number of breaks, i.e., m=k. The test is calculated as the usual F-ratio

between the SSE for the null ('unrestricted' SSE) and the SSE for the alternative hypothesis ('restricted' SSE). In other words, the null hypothesis corresponds to the estimation of the model over the full sample whereas the alternative hypothesis corresponds to the estimation of the coefficients on each sub-sample of dimension. This test of no break versus k breaks are denoted by sup F(k) and consist of F-tests of the $\delta_1-\delta_2,..,\delta_k-\delta_{k+1}$ coefficient differences. Different versions of these tests can be obtained depending on the assumptions made with respect to the distribution of the regressors and the errors across segments (Bai and Perron, 1998, Onel, 2005).

B. Test of Structural Stability versus an Unknown Number of Breaks (UDMax and WDMax)

The number of breaks is often not known, and the standard F-statistic becomes insufficient for testing for the existence of breaks (Antoshin et al., 2008). In this case, B-P (1998) also consider tests of no structural change against an unknown number of breaks given some upper limit. The following new class of tests is called double maximum tests and is defined for some fixed weights.

$$D_{max} = \max_{n=1,\ldots,m}(a_n \sup F(0,n))$$

The weights reflect the imposition of some priors on the likelihood of various numbers of structural breaks. Firstly, they set all weights equal to unit, that is a_n can be equal to 1, for all n<01,...,m, and they label this version of the test as UDmax. Then, they consider a set of weights such that the marginal p-values are equal across values of n, in which case the Dmax statistics is labelled WDmax (see Bai and Perron, 1998, p. 59 for details). The double maximum tests, UDmax and WDmax, allow us to test the null hypothesis of no structural break versus an unknown number of changes given the upper bound of breaks. The significance of these tests does not provide enough information about the exact number of breaks but means that one break is at least present. (Ben Aissa et al., 2003; Antoshin et al., 2008).

C. Sequential Test of ℓ versus ℓ + 1 Breaks (Sup F(ℓ + 1 | ℓ))

The last test developed by B-P (1998) is a sequential test of ℓ versus ℓ+1 structural changes to determine m. Similarly to the sup F (k) ratio, the F(ℓ+1| ℓ) ratio also relates the 'unrestricted' SSE (for ℓ breaks) to the 'restricted' SSE(for ℓ+1 breaks). Each of the intervals defined by the ℓ breaks is then analyzed for an additional structural break. From all of the intervals, the partition allowing for an additional break that results in the largest reduction in the SSR is treated as the

model with ℓ+1 breaks. The Sup F (ℓ+1 | ℓ) statistic is used to test whether the additional break leads to a significant reduction in the SSR (Rapach and Wohar, 2005). Indeed, while the first two tests described so far show the existence of the break, F (ℓ +1 | ℓ) test statistic indicates the presence of more than one break date.

D. The Selection Procedure

B-P (1998) recommend the following strategy to identify the number of breaks on the basis of extensive Monte Carlo simulations. First, the UDmax or the WDmax tests are examined to see if, at least, a structural break exists. If these double maximum statistics are significant, then the number of breaks is chosen in terms of examination of the sup F(ℓ+1|ℓ) statistics constructed using the break date estimates obtained from a global minimization of the SSR (i.e. we select m breaks such that the tests sup F(ℓ+1|ℓ) are non-significant for any 1≥m) (Onel, 2005). Also according to Bai and Perron (2003) the number of breaks in a series can be chosen via information criteria, such as Bayesian Information Criteria (BIC), proposed by Yao (1988); and the modified Schwarz criterion (Liu, Wu, Zidek (LWZ)), proposed by Liu et al. (1997). But in deciding how many breakpoints there are, the various criteria explored by B-P may not agree. Given the documented facts the information criteria are biased and the sequential procedure performs better. For example the LWZ information criterion is known to perform badly when breaks are present (i.e. the alternative is true). As Bai and Perron (2003) recognize (pp. 15-16), the sequential procedure can be improved upon: the number of breaks should be chosen according to the last significant test statistic, instead of the usual practice of choosing according to the first insignificant test statistic (Dvir and Rogoff, 2010). Finally, to ensure an adequate number of observations for each regression, it is standard to use "trimming" such that breaks do not occur at the very beginning or end of the sample. The percentage "trimming" constraint ε is used to construct a minimal length of a segment: h = ε T. This minimal length is defined as a proportion of the total sample size so that Bai and Perron (2003) show that the size of this trimming factor depends upon the number of maximum breaks, m, and derive critical values based upon this statistic. Bai and Perron (2006) recommend using a trimming parameter of at least 0.15 (corresponding to M =5) such that breaks are assumed to occur only within the middle 70 percent of the sample when allowing for heteroskedasticity and serial correlation. But also Bai and Perron (2003) report on Monte Carlo simulations of the finite sample properties of this distribution for various tests in terms of a "trimming parameter" ε = h /T. In Monte Carlo simulations, Bai

and Perron find that the maximal value of m for ε=0.15 is 5. They find that the accuracy of the tests depend upon this trimming parameter (Lewis, 2006).

Bai and Perron (2006) also assess via simulations the adequacy of these methods. They study the size and power of tests for structural change, the coverage rates of the confidence intervals for the break dates and the relative merits and drawbacks of model selection procedures. They demonstrate that their approach for testing for multiple structural breaks in time series works well in large samples, but they found substantial deviations in both the size and power of their tests in smaller samples. They conclude that this method leads to the best results and is recommended for empirical applications. While B-P methods are powerful techniques for discovering breakpoints ex post, they do not make ex ante predictions about future regime shifts.

5.3. Unit Root Test for Long Memory

As argued above, most studies of the spurious regression concentrate on the non-stationary I(1) processes. This reflects the widely held belief that many data series in economics are I(1) processes, or near I(1) processes, as argued by Nelson and Plosser (1982). All conventional unit root tests based on the autoregressive integrated moving average (ARIMA) (p,d,q) process represent short memory and the order of integration, d, takes on the values zero and unity. However, these ARIMA models imply an extreme form of long memory, since the impact of a shock does not die out even in the infinite horizon. Specifically, the impulse response function of an I(0) process decays exponentially, while the impulse response function of an I(1) process approaches to a positive intercept in the long run and never dies out. In other words, all conventional unit root tests based on an ARIMA model as a specific form of long-memory are capable of detecting if a series was sufficiently differenced to become stationary.

In fact, these limitations may cause a process to be considered having `unit root` improperly while it could actually be mean-reverting in the long run. The series whose first differences are stationary, in fact, are likely to have a long memory. Long memory leads to bias in favour of finding unit root in the conventional unit root tests. As shown by Diebold and Rudebusch (1991), and Hassler and Wolters (1994), the tests possess less power when the series are mean-revertible, but are not I(0) (Franco et al., 2006).

It is important to study the case in which the order of integration can assume a non-integer value. This kind of analysis can be obtained through fractional

processes, also known as long-memory models. In recent years, increasing interest has been devoted to the research of long range dependence (long memory) in time series data, such as the autoregressive fractionally integrated moving average (ARFIMA) as a feasible alternative method in modelling macroeconomic time series. The use of fractional integration permits us to avoid the strong dichotomy between the I(0) stationary and the non-stationary unit root (I(1)) models (Franco et al., 2006; Gil-Alana, 2008). In this alternative to this dichotomic framework, it is supposed that a series is integrated of order d, where d need not be an integer. Fractionally integrated (I(d)) processes encompass both short-memory (I(0)) and unit root (I(1)) processes but also offer other interesting possibilities to model the persistence of shocks (Mayoral, 2012). Such models implying hyperbolic rate of decay better describe the dependence between increasingly distant observations in time than the ARIMA models implying exponential rate of decay. The impulse response function of an I(d) process with 0<d<1 decays at a slow hyperbolic rate, k^{d-1}. The order of integration, d, determines the decay rate of autocorrelations and the impulse response function. The implied slow decay of shocks and the very slow but eventual adjustment to equilibrium prove fractionally integrated models attractive in modelling long-memory time series (Okimo and Shimotsu, 2007; Ozdemir et al., 2011).

A time series y_t is said to follow an ARFIMA process of order (p, d, q) with mean μ if

$$\phi(L)(1-L)^d(y_t-\mu)=\theta(L)\varepsilon_t\varepsilon_t iid(0,\sigma_\mu^2)$$

where $\phi(L)$ is an autoregressive coefficient of order p and $\theta(L)$ is a moving average coefficient of order q and ε_t is a white noise process. A process y_t is said to be an I(d) process if its fractional difference, $(1-L)^d y_t$, is an I(0) process. The fractional difference operator $(1-L)^d$ is defined by means of the gamma function

$$(1-L)^d=\sum_{k=0}^{\infty}\frac{\Gamma(k-d)L^k}{\Gamma(-d)\Gamma(k+1)}$$

The value of d is the major interest in this case and is allowed to take any real value. More specifically, the I(d) processes can be either stationary or non-stationary, depending on the value of the fractional differencing parameter as seen in Table 1 (Okimo and Shimotsu, 2007).

Table 1: Memory Features Regarding the Fractional Integration Parameter Values

d	Mean (or trend) and variance	Shock duration	Stationarity
d=0	Short-run mean-reversion Finite variance	Short-lived	Stationary
0 <d < 0.5	Long-run mean-reversion Finite Variance	Long-lived	Stationary
0.5≤d<1	Long-run mean-reversion Infinite variance	Long-lived	Non-stationary
d=1	No mean-reversion Infinite variance	Infinite	Non-stationary
d≥1	No mean-reversion Infinite variance	Infinite; effect increases astime moves forward	Non-stationary

Source: *Tkacz, 2001: 23.*

As widely argued above, many economists and econometricians took part in the debate on whether economic time series are TS or DS. In the context of I(d) processes, these questions are translated into whether d ≥ ½ or d < ½ ; because I(d) processes become non-stationary when d ≥ ½. Long memory implies that shocks have a long-lasting effect, but the underlying process is mean reverting. Furthermore, long memory is not the property of only non-stationary processes; the stationary processes may as well have long memory. Long memory can be captured by a fractionally integrated, I(d), model as seen in Table (Balcilar 2003; Franco et al., 2006; Shimotsu, 2007; Ozdemir et al., 2011). An I(d) process is covariance stationary and invertible when −0.5<d<0.5. For −0.5<d<0, all the autocorrelations are negative and tend hyperbolically towards zero. In this case, the process is considered anti-persistent or with intermediate memory. When d≤-0.5, y_t is covariance stationary but not invertible. For a time series to be mean-revertible, it does not necessarily need to be integrated of order zero, I(0), but smaller than one. If 0<d<0.5, all the autocorrelations are positive and also decline hyperbolically. They are persistent and the process has, therefore, a long memory. An I(d) process with d≥0.5is non-stationary, but is still mean reverting if 0.5≤d<1 since an innovation will have no permanent effect on its value. The last interval for d, 0.5<d<1, is especially interesting for macroeconomic applications, displaying strong persistence, but mean reverting in the sense that the impulse response function is decaying. To sum up, an I(d) process with 0<d<1 can accommodate slowly decaying autocorrelations (when stationary) and slowly decaying impulse response function that are inconsistent with either an I(0) or an I(1) process. When y_t is mean reverting, it will eventually return to its mean in the face of a shock, although this may take a long time due to the presence of long-memory (Granger and Joyeux, 1980; Hosking, 1981).

Actually, it is usually difficult to justify infinite memory on theoretical grounds for many economic time series. Based on this observation, researchers especially for the last three decades have looked for alternative ways of modelling strong persistence in macroeconomic time series, such as inflation, interest rates or exhaustible resource prices examined in this paper[8]. The growing interest in long-memory models has been partly due to low power of unit root and co-integration tests in the presence of long-memory. Strong persistence can be modelled using the long-memory models without abandoning the mean reversion and equilibrium properties of most economic models. Furthermore, the non-stationary nature of many series that is usually solved by means of first differences might also be better described by using fractional integration (Balcilar 2003; Ozdemir et al., 2011).

There are several sources that may produce fractional integration: the aggregation of heterogeneous AR processes (Robinson, 1978; Granger, 1980), error duration models (Parke, 1999) or regime-switching and structural break models (Diebold and Inoue, 2001) as briefly explained in Gil-Alana, 2008. For example Robinson (1978) and Granger (1980) show that the very act of aggregating data that measure heterogeneous individual-level behaviour produces fractional dynamics in aggregate time series. The essence of Granger's argument is that the aggregate series is generated by different micro-level autoregressive and moving average processes among individuals, thereby introducing fractional dynamics. Since the existence of this type of behaviour at the disaggregate level is widely documented, fractionally integrated processes at the aggregate level are likely to arise in practice (Lebo et al., 2000; Mayoral, 2012). Parke (1999) presents an error duration model that leads to a long-memory process. Besides, the existence of breaks may lead to spurious findings of long memory.

Empirical research continues to find evidence that I(d) processes can provide a suitable description of certain long range characteristics of economic and financial data. Most recent studies preferred long memory models as an alternative to ARIMA models. Several estimators have been proposed in the literature to estimate the fractional memory parameter d. Most of them belong to either the semi-parametric or the parametric class. While Li and McLeod (1986) and Fox and Taqqu (1986) Approximate Maximum Likelihood and Sowell (1992) Exact Maximum Likelihoodmethods are some of parametric methods, log periodogram (LP) regression (GPH, 1983), local Whittle (LW) estimation (Künsch, 1986) and GSE(Robinson,

8 See for instance Haubrich (1993), Baillie (1996), Michelacci and Zaffaroni (2000) and Mayoral (2006) among others showing that the behaviour of many macroeconomic variables can be better captured by fractional to explain the strong persistence as opposed to integer integration orders in most economic time series.

1995) can be mentioned as most commonly used semi-parametric methods. Semi-parametric estimation of the parameter d in fractionally integrated (I(d)) time series has received much recent study because it is agnostic about the short-run dynamics of the process, that is to say without making any delimiting assumptions about the short memory components in the DGP and hence is robust to its misspecification. Gil-Alana and Robinson (1997) applied Robinson's (1994) LM test to macroeconomic time series to test the null hypothesis that $d = d_0$ for various values of d_0; including d = ½ ; and found that the results depend on how the short-run dynamics of the data is specified. Therefore, it is of great interest to investigate this issue using the semi-parametric approach that is agnostic about short-run dynamics (Philipps, 2007; Shimotsu, 2009). I explain GPH (LP regression) and Robinson's GSE below which are extensively used in applied econometric research and also used in this paper.

5.3.1. Geweke Porter-Hudak (1983) Test

Generally, fractional processes can be seen as an extension of the ARIMA models proposed by Box and Jenkins (1970). I have already defined an ARFIMA process of order (p, d, q) and the fractional differencing operator before. For reasons of space, I do not propose to repeat them again. Here, brief discussions of the basic setup of the procedure fo1lows. GPH suggests a semi-parametric procedure to obtain an estimate of the fractional differencing parameter d based on the slope of the spectral density function. This procedure requires no explicit parameterization of the autoregressive moving average (ARMA) dynamics, which are generally not known a priori. They show that the differencing parameter d can be consistently estimated from the least squares regression (Cheung, 1993; Andrews and Guggenberger, 2003; Kuswanto and Sibbertsen, 2007):

$$\ln\left(I(\omega_j)\right) = c - d\ln\left(4sin^2(\omega_j/2)\right) + \eta_j, \quad j = 1, \dots, n$$

where $\omega_j = \frac{2\pi j}{T(j=1,\dots,T-1)}, n = g(T) \ll T,$ and $I(\omega_j)$ is the periodogram of X at frequency ω_j defined by

$$I(\omega) = \frac{1}{2\pi T}\left|\sum_{t=1}^{T} e^{it\omega}(X_t - \overline{X})\right|^2$$

There is evidence of long memory if the least squares estimate of $d(\hat{d}_{GPH})$is significantly larger than 0. With a proper choice of n, the asymptotic distribution of $\hat{d}_{GPH}$ depends on neither the order of the ARMA component nor the distribution of the error term of the ARFIMA process. It is suggested to set $n = T^{0.5}$ and to use the known variance of $\eta_j, \pi^2/6$, to compute the estimated variance of $\hat{d}_{GPH}$. If the

errors behave like *iid* random variables, then the regression estimator $\hat{d}_{GPH}$ is a reasonable estimation procedure.

The GPH test can be used as a test for unit roots. Under the unit root hypothesis, the first differenced data follow a stationary ARMA process with d = 0. Hence the unit root hypothesis can be tested by determining whether the $\hat{d}_{GPH}$ from the first differenced data is significantly different from 0. The estimated d values can be interpreted as Table 1 above. Non-rejection of the null hypothesis in the GPH test means that the series do not have long memory, i.e., they have unit root process.

5.3.2. Robinson (1995) Gaussian Semi-Parametric Estimator

The other semi parametric test is the Gaussian semi-parametric estimator (GSE) suggested by Robinson (1995). This method is based on the periodogram, specifying the parametric from of the spectral density using $f(\lambda) \sim c\lambda^{-2d} as \lambda \to 0^{+}$. Similar to GPH estimator this estimator involves the introduction of an additional parameter m being taken less than or equal to ((T-1)/2) and satisfying 1/m+m/T→∞. The following function needs to be minimized to obtain the GSE estimator of d:

$$r(d) = q(\hat{q}, d) - 1 = logm^{-1} \sum_{j=1}^{m} \frac{I(\lambda_j)}{\lambda_j^{-2d}} - 2dm^{-1} \sum_{j=1}^{m} log\lambda_j$$

where

$$q(\hat{q}, d) = m^{-1} \sum_{j=1}^{m} \left(\frac{I(\lambda_j)}{\hat{g}\lambda_j^{-2d}} + log\hat{g}\lambda_j^{-2d} \right)$$

with $\hat{g} = m^{-1} \sum_{j=1}^{m} \lambda_j^{-2d} I(\lambda_j)$. Here, Robinson (1995) indicated that the value of $\hat{d}$ minimizing r(d) converges in probability to the actual d value and $m^{\frac{1}{2}}(\hat{d} - d) \to_d N(0,1/4)$ as T→∞. Then the asymptotic variance of $\hat{d}$ is equal to 1/4m. Like GPH, the choice of bandwidth parameter is also very important in this estimator. As explained by Balcilar (2002), if the time series is not ideal, in other words if it is an ARFIMA (p,d,q) with not both p=0 and q=0, then small values of m should be used, since the short run behaviour of the series will affect the form of the spectral density at higher frequencies.

5.4. Non Linear Unit Root Tests

Empirical researchers are faced with the fact that the conventional unit root tests are unable to reject the hypothesis that the variable is non-stationary because these methods cannot disentangle non-stationarity from nonlinearity because of the joint modelling problem of unit roots and threshold. Because the power of unit root tests is considerably reduced in the presence of nonlinearities and as such standard unit root tests that do not take into account the possibility of a threshold effect and asymmetric adjustment in time series may reach erroneous conclusions, recently a number of studies have focused on the interactions between nonlinearity and nonstationarity, especially when the (possible) nonlinearity is of the TAR or STAR form. For example the threshold approach decomposes the model into different regimes and thus allows the related series to follow different dynamics, depending on being above or below a certain threshold.

5.4.1. Caner and Hansen (2001) Test

An early and seminal contribution to this literature is Enders and Granger (1998), who propose a two-step procedure to test the null hypothesis of a linear unit root against the alternative of a stationary two-regime threshold model. Then, C-H (2001) study TAR models by allowing the deterministic terms, autoregressive root and the short-run dynamics to switch between the two states and accordingly propose a nonlinear based test. With this model, they study Wald tests for a threshold effect (for nonlinearity) and Wald and t tests for unit roots (for nonstationarity). For nonlinearity case, this Wald test is used for the null of two roots, one governs the upper regime and the other the lower regime, against the stationary alternative that both roots are negative by accommodating the nuisance parameter problem. For a threshold and for a unit root, the joint application of the two tests allows a researcher to distinguish nonlinearity from non-stationary processes (Caner and Hansen, 2001). They allow for general autoregressive orders, and do not artificially restrict the coefficients across regimes. Following Caner and Hansen (2001), the two-regime TAR model with k lags can be written as (Balcilar et al.,2011):

$$\Delta y_t = \theta_1 x_{t-1} I(z_t < \lambda) + \theta_2 x_{t-2} I(z_t \geq \lambda) + \varepsilon_t$$

where $x_t = (y_{t-1}, 1, \Delta y_{t-1}, \Delta y_{t-2}, \dots, \Delta y_{t-k})'$, $\theta_i = (\rho_i, \beta_i, \alpha_{1i}, \alpha_{2i}, \dots, \alpha_{ki})'$, $i = 1,2$ and $Z_{t-1} = y_{t-m} - y_{t-(m-1)}$, the threshold variable with some m ≥ 1.

The two parameters ρ_1 and ρ_2 control the stationarity of the process y_t.

The null hypothesis is

$H_0 : \rho_1 = \rho_2 = 0.$

Non-rejection of null hypothesis means that the process y_t can be described as having a unit root and can be expressed in terms of the DS, Δy_t. There are two alternative hypotheses. The first alternative hypothesis is specified as follows,

$H_1 : \rho_1 < 0$ and $\rho_2 < 0.$

This means that y_t is stationary and an ergodic process in both regimes. The second one,shown below as H_2, is the intermediate case of a partial unit root,

$$H_2 = \begin{cases} \rho_1 < 0 \text{ and } \rho_2 = 0 \\ \text{or} \\ \rho_1 = 0 \text{ and } \rho_2 < 0 \end{cases}$$

When H_2 is accepted, the process y_t shows stationary mean reverting behaviour in one regime and has a unit root in the other regime, meaning that the process is non-stationary, but it is not a classical unit root process.

Both one sided and two sided Wald tests are used to test the null hypothesis H_0 against the two alternatives H_1 and H_2. While the one-sided Wald test against the unrestricted alternative $\rho_1 \neq 0$ or $\rho_2 \neq 0$ is given by $R_{1T} = t_1^2 I(\hat{\rho}_1 < 0) + t_2^2 I(\hat{\rho}_2 < 0)$, the two-sided Wald test against the alternative $\rho_1 < 0$ or $\rho_2 < 0$ is given by $R_{2T} = t_1^2 + t_2^2$. Here, t_1 and t_2 are the t statistics for $\hat{\rho}_1$ and $\hat{\rho}_2$, respectively. Both tests R_{1T} and R_{2T} will have power against both alternatives H_1 and H_2.It is true that a significant test statistic can justify the rejection of the unit root hypothesis, but it cannot discriminate between the stationary case H_1 and the partial unit root case H_2. When one of the Wald tests is rejected, C-H suggest examining the individual t statistics t_1 and t_2, that is, considering the negative of the t-statistics ($-t_1$ and $-t_2$) to determine which regime has a unit root and which one is stationary. The rejection of $-t_1$ implies that the first regime is stationary. Analogously if $-t_2$is rejected, then the second regime is stationary (Balcilar, et al., 2011).

C-H (2001) claim that their threshold unit root tests have better power than the conventional ADF unit root test (Said and Dickey (1984)) when the true process is nonlinear. The difficulty is that the null of a unit root ($\rho_1 = \rho_2 = 0$) is compatible with both the existence of a threshold ($\theta_1 \neq \theta_2$) and the nonexistence of a threshold ($\theta_1 = \theta_2$). But C-H (2001) determine that the assumptions of these two situations are different and hence we can simultaneously distinguish between nonstationarity and nonlinearity. The distinction between linearity and nonlinearity lies in the

identification of the threshold parameter λ. With no threshold effects, λ is not identified, and so its estimate $\hat{\lambda}$ is random and so is R_T. With threshold effects, λ is identified, and with no randomness in R_T, it is equivalent to the case where λ_0 is known. C-H (2001) recommend (with caution) the implementation of bootstraps since both the identified and unidentified effects can be imposed. The unidentified threshold bootstrap imposes the restriction $\theta = \theta_1 = \theta_2$ (no thresholds) and $\rho = 0$ (unit root). In this case the bootstrap p-value is the percentage of simulated test statistic ξ_T^b that exceeds R_T. The identified threshold bootstrap requires simulation of the TAR process and calculating ξ_T^b. Again the bootstrap p-value is the percentage of simulated ξ_T^b that exceeds R_T. From all reason above, Ghosh and Dutt (2008) conclude that in the presence of nonlinearity, the C-H threshold unit root tests have more power than the standard ADF tests.

5.4.2. Kapetanios, Shin and Snell (2003) Test

KSS extend the standard ADF test and introduce a new test in which the null hypothesis is still unit root but the alternative hypothesis is a nonlinear globally stationary exponential smooth transition autoregressive (ESTAR) process, where the inner regime is allowed to have a unit root. This new test, as they show, is more powerful than the standard ADF test and for a time-series variable y,

$$\Delta y_t = \alpha y_{t-1} + [1 - \exp(-\vartheta y_{t-1}^2)] + \mu_t$$

where y_t is raw, de-meaned or a de-trended series under consideration, $\exp(-\vartheta y_{t-1}^2)$ is the exponential transition function ($\vartheta \geq 0$) and μ is an error term with usual properties. Note that this regression implies that the autoregressive parameter changes smoothly depending on the values of the variable y_t. The test focuses on the parameter ϑ, which equals zero under the null and is positive under the alternative. KSS(2003) demonstrate that testing the null hypothesis of $\vartheta = 0$against the alternative of a globally ESTAR process, H_1: $\vartheta > 0$ is not feasible because α is not identifiable under the null[9]. They, then, use a Taylor series to approximate first equation by the following, given that the coefficient γ cannot be identified under H_0. The second one below is the estimable auxiliary regression model in the presence of serially correlated errors with m augmentations:

$$\Delta y_t = \delta y_{t-1}^3 + \varepsilon_t, \quad \text{or}$$

$$\Delta y_t = \delta y_{t-1}^3 + \sum_{k=1}^{m} \rho_k \Delta y_{t-k} + \varepsilon_t$$

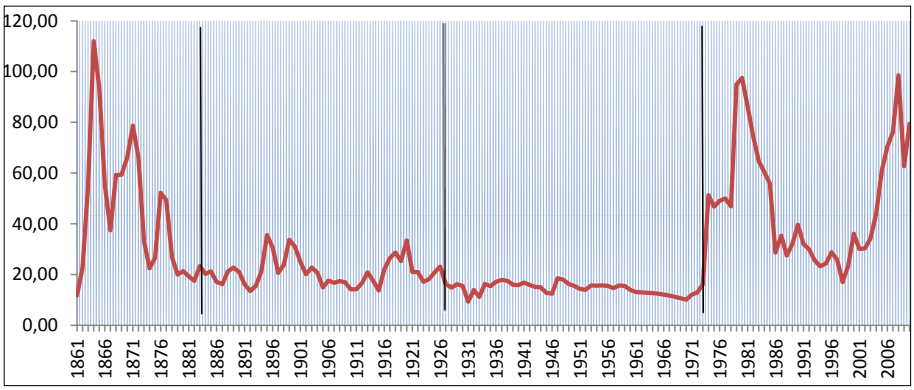
9 See KSS (2003) for mathematical details.

As can be seen, the above equation is similar to the standard ADF test with the difference that the lagged value of the time-series variable is raised to power three rather than to power one. The augmentations $\sum_{k=1}^{n} \rho_k \Delta y_{t-k}$ are included to correct for serially correlated errors.As for selecting the lag length (m) in the above equation, KSS (2003) recommend a procedure to choose lag order by assessing the significance of the augmented coefficients. It is now possible to apply a t-statistic to test whether y_t is a unit root process. Here, H_0: $\delta = 0$, or is a unit root process, is tested against the alternative of $\delta < 0$ by familiar t ratio obtained for δ with new asymptotic critical values tabulated by KSS via stochastic simulations for the raw, de-meaned and de-trended data series, depending on the deterministic terms in the auxiliary regression model above. Since this t ratio is for a nonlinear model, it is derived by dividing the estimated δ by its standard error in the equation and is denoted by t_{NL} (KSS, 2003, p. 365; Bahmani-Oskooee and Gelan, 2006; Cuestas and Regis, 2010).

6. Data and Potential Structural Breaks

For the data used in this paper for univariate time series analysis, I examine the price of crude oil over the 150-year period 1861-2010. The crude oil price series come from British Petroleum's Statistical Review of World Energy (2011)[10]. The crude oil price series is formed of three sequential price series: From 1861 to 1944 the data were obtained from US average prices, and from 1945 to 1983 the Arabian Light price, posted at Ras Tanura, was used to construct the series and from 1985 onwards Brent prices were used as benchmark of crude oil price. This crude oil prices are measured in US$/barrel. Thus prices are in constant 2010 $US. I take the logarithm of the series. The data sets of crude oil are similar to those used by Pindyck (1999). The usage of historical annual data set seems essential to reflect long run developments in the energy sector more accurately while working with the Hotelling (1931) model.

Figure 1: Crude Oil Price, 1861-2010 (2010 dollars)



Source: *British Petroleum, Statistical Review of World Energy (2011).*

To get an idea about the dynamics of crude oil prices, I present the graphs of the series in Figure 1 for the period 1861 – 2010.From the beginning to the end of this long period, oil prices could change their trajectories and behaviour with respect to the economic situation. Even a cursory look reveals these differences in the behaviour of the crude oil series at different periods. Visual inspection of the time series in Figure 1 suggests that there are different regimes caused by abrupt changes, such as the 1970s and the 1870s, and each regime may have a different stochastic process. But formal econometric tests are necessary to determine the structural breaks, non-linearity and also long memory (fractional integration)

10 Crude oil price statistics are published by specialized organizations. For example, methods of establishing international prices of oil have often varied. See more information in Desbrosses and Girod (2007).

process in the time series under consideration (Lee et al., 2006). A different kind of trend can be extracted to describe the long-run movements of time series. In this case, considering the whole range of data available we can fit the series, for example, to a quadratic U-shaped time trend. When the market was affected by decisions of OPEC more in the period between 1973 and 2010, there were higher annual amplitudes of price fluctuations and greater frequencies of price cycle; still, there were shorter durations of price cycles in the boom and slump periods and for the whole cycle. Furthermore, it can be realized that the price series of crude oil is formed by cycles. The success or failure of OPEC's price stabilization policy may cause these cycles (Jalali-Naini and Asali, 2004; Tabak and Cajueiro, 2007).

Crude oil prices have presented large variations in times of shortage or oversupply. Different kinds of shocks can be seen in the market. Kilian (2009) classified these shocks as supply and demand shocks in general: oil supply shocks driven by political events in OPEC countries; other oil supply shocks; aggregate shocks to the demand for industrial commodities; and demand shocks that are specific to the crude oil market. For example, oil prices rise when important political decisions related to the Middle East appear on the political agenda. Particularly, some events seem primarily concerning the supply side of the crude oil market, such as the Yom Kippur War and the Arab oil embargo of 1973/74, the Iranian Revolution of 1978/79 and the outbreak of the Persian Gulf War in 1990. Sizable increases in the real price of oil are observed after these supply shocks. There are also much smaller increases after the outbreak of the Iran-Iraq War in late 1980, the war in Afghanistan in 2001 and during the months leading up to 2003 Iraq War. The Asian crisis and the date of Hurricanes Rita and Katrina, causing the loss of US refining capacity, are examples of exogenous demand shock. The main argument is whether these geological, economic, institutional and technological conditions affecting supply and demand of crude oil, such as wars, embargoes, revolutions, speculation, spare capacity, contango, increase in inventories etc. are cyclical or structural in nature. At any time, analysts are split on whether such changes will persist or reverse, and if so by how much (Kilian, 2009). Before conducting econometric tests, I summarize these changes below to have an overview idea of the evolution of the market.

It can be observed in Figure 1 graphing the annual oil price from 1861 to 2010 that prices in the 19th century were highly volatile as there was much speculation, demand grew rapidly, new discoveries were made and thus the production of oil developed on a large scale. But, as noted by Dvir and Rogoff (2010), oil demand

was uncertain especially until 1878 because of economic shocks emanating from the industrializing US. In 1865, only three railroads served western Pennsylvania where most oil was produced. They were using this oligopolistic position to limit the supply of crude to the markets in the interest of rent extraction. So, access to spare capacity was limited by this oligopolistic structure of the railroad industry. The firms distributing most oil to their eventual users in the days before oil pipelines could charge high prices by limiting the provision of oil transportation services caused the oligopolistic structure of the railroad industry (Foote and Little, 2011).By the development of the first long distance oil pipeline in 1879 and by the completion of Rockefeller's network of long-distance pipelines in 1884, access to spare capacity was enhanced. Standard Oil owned the vast majority of long-distance pipelines in this period. After this period through to the oil shock, a much less volatile period can be seen in Figure 1, at which oil prices continued to fluctuate but stayed an average value. This might suggest that the oil price exhibits mean-reverting characteristics. If scrutinizing, one may see that prices were lower especially after any year between 1926 and 1933, insinuating a new path. In other words, short-term fluctuations in crude oil prices were fairly limited in those days (Jalali-Naini and Asali, 2004). Especially these approximately 40 years saw oil prices at their most stability.

Other important events occurred in the mid1920s. For example, in 1924, the Nash dome in Texas and Inglewood in California, were discovered in the US, the first well in Lake Maracaibo was drilled in Venezuela, the first long-distance crude pipeline to serve the Rocky Mountain area was constructed by Sinclair Pipeline Company; in 1926, St. Louis and the Bowlegs fields in Oklahoma, Mount Poso field in California, Hendricks and Yates fields in Texas, McCallum field in Colorado, La Cira field in Colombia and Seal Beach field were discovered regarding the supply side of the market. Development of mass-marketing methods and utilization of equipment for liquefied petroleum gases was started by Phillips Petroleum Corp. in 1926. From a demand side perspective these years could also be considered as important years regarding increasing use of petroleum.

Meanwhile, as a consequence of technological changes that took place, actually more producers existed and several new areas were discovered and investigated at decreasing cost. Prices were at their lowest real levels in the early 1930s as demand was low and production had increased owing to the discovery of the massive East Texas Oil Field in 1930 in particular (Chardon, 2007; Foote and Little, 2011). It can be said that the major peak of production in the first seven decades of the 20th century was towards the end of the First World War and

the period immediately afterwards. This development created an oil abundance reducing its prices that threatened the entire industry. Then the US government effectively issued production quotas to control supplies to individual states (Dvir and Rogoff, 2010). In particular, to maintain the balance between supply and demand the production at the East Texas field was kept much lower than full capacity by these controls. This quota system led to a more stable period of oil prices. Also, during the 1950s and 1960s, an abundance of large oil fields generated considerable excess capacity. Despite continuous industrialization in the US and other countries, and the considerable effects of two world wars and other international crises, this stability seen in Figure 1 continued owing to the specific regulatory structure of the oil industry especially over 1948-72. All in all, any shocks to the oil market could be offset by changes in the US production, enabling demand and supply of crude oil to move in harmony. In Texas, operators were allowed to pump oil from their fields for around nine days monthly by the Texas Railroad Commission that was one of the most significant government organisations. Unless a member country of the OPEC consented to lower prices or if any other facts affecting oil prices occurred, they could rapidly open the remaining amount in order to control the prices. Several facts are chronologically important in this context: the Iranian nationalization in 1951-52, the Suez Crisis of 1956-57, formation of the OPEC in 1960, the secular decline in US reserves toward the end of the 1960s. In the midst of the 1960s, owners were allowed to operate at an ever-higher capacity by the Texas Railroad Commission. As a case in point, the capacity utilisation was increased to 70 percent and over (it was less than 30 percent before) during the 1965-1970 period, even, it was increased to 100 percent in 1971. In doing so, the US market control of production ended in 1971, which reduced its power to influence oil prices and the power to control crude oil prices shifted from the USA to the OPEC. There were higher utilisation rates in Texas than other OPEC countries in 1973. This means that there was less spare capacity in the US and other non-OPEC countries than in the member countries of the OPEC. The OPEC started to control the marginal supply of oil as a result of the loss of spare capacity in the US (Kaufmann et al., 2008). In addition to this, prior to the early 1970s, the major international oil companies largely set crude oil prices. Besides, these oil companies essentially controlled the crude oil supplies in Arab oil producing countries as well. The companies' objective was to keep the price of oil low, while increasing supplies. After the period of domination by international oil companies when they controlled the entire oil market, in 1972, some ownership rights of the oil resources located on their land transferred from those companies to the governments under a

participation agreement with the oil producers (Plourde and Watkins, 1998; Dvir and Rogoff, 2010). These developments were so important that the nature of the market fundamentally changed, meaning that the oil producing countries (and their national oil companies) now controlled the marginal supply of oil and the producing countries progressively took control of oil at the source. Then, OPEC was able from 1973 to unilaterally fix the official selling price. The first world oil price shock proved that OPEC emerged as price setter.

After the non-competitive non-volatile crude oil market condition mentioned above, the cartelization among the member countries of OPEC took place. After the cartelization, a series of oil price shocks were witnessed. For example, this cartelization triggered the first oil price shock and increased price persistence and volatility thereafter. Real oil prices were fairly constant up to the early 1970s after which time they exhibit an upward trend. Only the production increases from existing OPEC capacity could meet the short-term increases in demand in the 1970s and in the beginning of 1980s. Likewise, the member countries of the OPEC could decrease short-term oil supply by cutting off the production and the non-OPEC countries were not able to increase production to compensate for these decreases (Mobert, 2007; Kaufmann et al., 2008). Following to the Yom Kippur War which started with an attack on Israel by Syria and Egypt in 1973, the OPEC member countries acted to dramatically restrict some OECD countries' access to oil supplies in response to their support of Israel in the 1973 war. There were three conceptually perceptible components during the 1973-74 oil shock: one is the unexpected shortage of production as a result of the military action during the October 1973 Arab-Israeli War; the second one is the oil export embargo that was implemented on the members of the OECD countries, such as the US and the Netherlands, thought to be supporters of Israel, by Arab oil producers; and the third one is the intentional deductions in production by some Arab oil producers at the end of 1973 (Kilian, 2009).They curtailed the production of crude oil, for example, by 5 million barrels per day. The resultant panic and reallocation of supply caused prices of the barrel to greatly increase more than three-fold between 1973 and 1974 (from $16.15 to $51.23 (in 2010 dollars)).

After declining slightly in 1975-78, the second oil price shock happened in 1979-80 when the Iranian Revolution (1979) and the start of the Iran-Iraq War (1980) both led to cuts in production, which caused further large increases in prices. This reduction in production represented about 10 percent of world oil demand. Rather than increasing production to offset the shortfall, other OPEC

countries reduced production. This action helped to sweep excess supply and maintain prices above the long-run level observed before 1973. So, the price of crude oil doubled in 1979 (from $46.89 to $94.94 (in 2010 dollars)). Price hikes culminated in 1980 at $97.5 in 2010 dollars. After the price increased dramatically (in 2010 dollars again) from 1973 to 1980, it returned to levels not much higher than those of thirty to eighty years earlier (Gately, 1986; Chardon, 2007). A major turning point occurred in 1982 with the beginning of a persistent downturn in crude oil prices, reflecting the impact of the cumulative adjustment in demand.

Basically, the production rate of the OPEC and many major events determined oil prices before the 1980s. At the time of second oil shock, large volumes that had been sold under long-term contracts before, due to tight restrictions in supply, started to be sold in the spot markets. Thus, from 1973-1974 to the end of 1985, the coexistence of two crude oil markets could be seen: the bigger one traded on the world market and was sold under long term contracts at the OPEC official prices. These prices were adjusted only infrequently. The other one is the smaller but increasingly market traded at market-determined spot prices. OPEC's capacity importantly declined, the effect of OPEC lessened and competitive market forces have gained great importance in determining the prices of crude oil since the early 1980s. 1983 was a significant year that left its mark on the introduction by NYMEX of crude oil futures contract trading, namely, that for WTI. Instruments for several other crude types and products have been introduced in the market which shows that there has been an increase in trust in market mechanisms. Then there has also been an increase in oil price volatility (Plourde and Watkins, 1998; Desbrosses and Girod, 2007).The price collapse in 1986, the first time there has been a major oil price decrease, was generally the result of a decision by Saudi Arabia and some of its neighbours to increase their share of the oil market. They did not bear large losses in revenue, dissimilar to other producers. The main reason for this is the offset of price declines by their output increases (Gately, 1986).

Some researcher believed that raising its price to an unsustainably high level was not a true policy for the OPEC's long-run interest. In response to higher prices in the following years, demand reducing policies, in the form of extremely high energy taxes and energy substitution, together with an increased supply outside of the OPEC, have tended to depress real oil prices, both of which weakened the OPEC's control over the marginal supply. Also, because prices remained at almost the same levels despite the ending of the embargo in March 1974, some

researchers have come to view the 1973-74 price increase as sustainable, but as a one-time event, corresponding to the OPEC's successful cartelization of the world oil market (Gately, 1986). But after that, it can be observed in Figure 1 that crude oil prices reduced throughout much of the 1980s and 1990s. This reduction can be ascribed to higher prices that increased the non-OPEC oil production and reduced demand. Both the increase of the non-OPEC oil production and reduction of demand weakened the control of the OPEC on marginal supply. More new oil fields and proved reserves were discovered since as a result of higher prices, incentives increased to drill wells, and the viability of fields, which were thought to be uneconomic before, were improved. The Non-OPEC oil production rates, like the former Soviet Union, Norway, Mexico, China and the United Kingdom, increased significantly as a result of the increase in proved reserves. Besides, technology used in oil production was improved in the wake of higher prices. In the 1980s, there was a decline in oil demand in the OECD countries and some structural issues can be mentioned as the reason for this decline. This decline mostly took place in sectors like the industrial, petroleum refining, residential and electricity generating sectors, which had the ability to restrain their oil usage because coal or natural gas could take the place of oil. The cost of making this substitution was relatively low as these fuels (coal and natural gas) were already available, there was a well-established technology for the use of them and many boilers could be simply converted in order that a switch between fuels could be possible. Weaker economic growth and also greater efficiency in oil usage were also associated with part of the decline (Kaufmann et al., 2008). A further reason could have been the nature of the supply management of OPEC. The swing producer country, Saudi Arabia, would decrease the production of its crude oil, conditional on the production levels agreed by the other members of the OPEC, as much as needed to decelerate the reduction in the prices of crude oil. In fact, although the OPEC spent much effort on consent to this arrangement to reduce production sufficiently low to stabilize prices of crude oil, most of these efforts did not have the effects as the OPEC anticipated. In 1985, Saudi Arabia one-sidedly withdrew from the cartel due to cheating cartel members and compensation for crude oil production increases in other countries (Kilian, 2009). The OPEC countries tried to increase natural gas liquids production, which was not part of the quota, in order to compensate for reductions in the amounts of crude oil which they were allowed to produce since natural gas liquids do not come from oil fields.

The uncertainty associated with Iraq's invasion of Kuwait in 1990 and the subsequent Gulf War raised prices from $32.05 to $39.58. Due to the Persian Gulf crises, the early 1990s were a time characterized by both large oil price increases and large oil price decreases but it can be said that the oil price traded within a very narrow range from the beginning of the 1990s through to 2003. The reversion to the mean becomes again observably obvious in this period. Although the lowest price in real terms occurred in 1998 at $17.01 in this period, the period from 1991 to the end of 2003 was one of remarkable stability (Sadorsky, 1999; Verleger, 2009).

Oil prices have risen steadily since the end of the 1990s. However, the development in recent years might differ from previous developments. The trend after 1999 can be explained by a wide list of drivers including strong and rising demand particularly from developing nations from outside OECD, the consuming governments' strong demand for light sweet crude, lack of spare capacity in upstream oil, distributional bottlenecks, the OPEC supply response, geopolitical and weather shocks and the increasing role of speculators and traders in price formation (Fattouh, 2007). Several analysts have argued that a new period has emerged with the arrival of large developing economies, in particular, China and India, and the recent increase in the oil price is being driven by increasing demand, mostly related to the increase in productivity in such countries. By contrast, the oil price increases of the 1970s and early 1980s are consistent with the hypothesis most commonly used in the literature of an exogenous reduction in oil supply. For example, a demand shock due to the recovery of the Asian economies, extremely low interest rates worldwide stimulating aggregate demand as well as world oil demand, and the weakening of the dollar, combined with short-term fixed supply capacity has driven oil prices sharply upward (Krichene, 2005).

Meanwhile, efforts to curb carbon dioxide emissions produced by the combustions of fossil fuels and are at the basis of climate change could importantly reduce oil demand. In the past, fearing that they could trigger a decline in oil demand, oil producers like OPEC have been opposed to these kinds of agreements. In fact, whilst global efforts to decrease carbon emissions are stimulated by concerns about climate change, no one expects that these efforts will decrease demand for oil. Lastly, although many discussions are made on alternative fuels, only a few of these fuels are economically feasible at the prices currently envisioned. When the structural barriers are given, it is less likely for the market to generate important amounts of these alternatives over the forecast horizon (Kaufmann, et al., 2008).The main argument for the researcher to forecast is whether prices revert to the mean or prices shift to a new path. There

is no single explanation for the rise and fall in oil prices from 1999 through 2010 rather the causes are various.

Regarding the supply side, it appears that the international oil order in which most of the incremental global the non-OPEC countries meet oil demand and the OPEC supplies the capacity cushion has been shaken recently. In order to satisfy the previous gains in demand, the OPEC has provided most of the oil needed, as the non-OPEC countries have not increased their crude oil production since 2004. Thereafter, the OPEC countries produced crude oil and the OPEC and the non-OPEC countries provided natural gas liquids to meet the whole increase in world oil demand. With these developments, the OPEC has re-gained power of control over the marginal barrel (Fattouh, 2007; Kaufmann et al., 2008). In this sense, it should be noted that another change is the gradual decline of spare capacity in upstream oil which provides a large cushion against oil market shocks to very low levels, particularly compared to the mid-1980s and the beginning of the 1990s. This suggests that prices will carry the burden of adjustment when shocks occur. Here, the main point is whether spare capacity in upstream oil will be restored to its recent high levels and which one, international or national oil companies, will cover the cost of investment in spare capacity. In fact, specific market developments in the mid 1980s and early 1990s created a large spare capacity of the OPEC member countries and these market conditions may not occur again. A declaration was made by Saudi Arabia that includes maintaining a spare capacity of 2–3 mbd. This only represents about 2 percent of global production that is quite low. Therefore, the investment needed does not appear to materialize (Fattouh, 2007). To put it in different way, existing OPEC capacity provides this marginal barrel, which has driven up utilisation rates. In the last three-four decades, the OPEC has not importantly altered its short-run capacity to produce oil. As a consequence, the OPEC is now supplying oil at rates very close to its short-run capacity. For any other commodity, high rates of capacity utilisation drive prices up (Kaufmann et al., 2008).

There is another important change determining global crude prices, which occurred especially after 2006. As known, crude oil varies in quality, which is measured by density (light vs heavy) and sulphur content – sour (high sulphur content) and sweet (low sulphur content). The market has basically been divided since the middle of the 2000s. In today's world we can talk about two types of crude oil such as light sweet crude and heavy sour crude. Light sweet crude is dissimilar to heavy sour crude, just like coal is to natural gas (Verleger, 2009). Light sweet crude oils are more valuable than heavy sour crude oils. The reason

for this is that they not only produce a larger fraction of valuable products such as motor gasoline and jet fuel but also are less damaging to refineries. Because the production of the non-OPEC countries has declined and the OPEC has not increased capacity, however the OPEC has been forced to open fields that produce heavy and sour crude oils as a result of the latest growth in oil demand (Kaufmann et al., 2008). The application of regulations which are needed to remove sulphur from most petroleum products caused this division of the oil market and then, the OPEC was displaced, in one sense, by environmental authorities in consuming countries. After regulations mandating sulphur removal from principal petroleum products came into force, the authorities dealing with environmental issues started to control the market effectively. In 2003, similar standards were adopted to be effective in the European Union (EU) by January 1, 2009. The US started adjusting to the new rules in 2005, whilst European countries began in 2008. The name of the new cleaner fuel is ultra-low sulphur diesel (ULSD). Mostly, light sweet crude is needed to produce ULSD by refiners. However, only limited volumes of high-sulphur distillate are produced only in refineries that have massive desulfurization capacity by heavier crude oils with higher sulphur content, such as Arab Light and Arab Heavy. Therefore, the need for reduction of sulphur in diesel increased light sweet crude demand. This increase in ULSD demand put high pressure on light sweet crude markets leading the price of sweet crude oil to rise to extremely high levels (Verleger, 2009). Price cycles appear to have been aggravated by these types of environmental regulators and regulations.

Another transformation in the oil market has already been cited, that is, the shift from the spot to the futures market for determining the price. This has increased the role of non-commercial players in oil price movements and then, the OPEC was somewhat displaced by investors purchasing crude oil or financial claims on crude oil to diversify portfolios (Fattouh 2007; Verleger, 2009). These non-commercial players can be divided in two categories: index funds (long-term oriented, passive investors) which have emerged only more recently and reflect the desire to add commodities to one's portfolio in view of their risk/return profile, and speculators (active investors) who trade in the oil market on the basis of their supposedly better information in the hope of making profits by anticipating market movements in commodity prices. As index funds are not dealing with delivering oil, they do not provide any extra physical demand (Kaufmann et al., 2008). Since about the mid-decade, in order to diversify portfolios, pension fund managers and other investors started to purchase commodities. Inventory

behaviour was changed by the entry of investors and sometimes oil price attitude appear to have changed for the same reason (Verleger, 2009). According to some observers oil prices reached extremely high levels because of investors' behaviours in 2008 as the oil cash from investors has altered market's behaviour. However, Verleger (2009) claimed that investors appear to have a countercyclical role that softens the rises and decreases in price. Thus, this development may affect short-term movements in oil prices and volatility, but its long run effect could be small (Fattouh, 2007). As the date for the delivery of the future contracts approaches, spot and future prices have to converge and the supply and demand curves of producers and consumers would determine the spot price. So, according to several papers such as Fattouh (2007) and Fattouh et al. (2012), existence evidence is not supportive of an important role of speculation in driving the spot price of oil after 2003. Yet, evidence on this issue implies that it is not the sentiment of investors but the common economic fundamentals that determine both oil future prices and spot prices. Regarding the role of speculators, it can be mentioned that a great deal of the increase in the oil prices between 2005 and 2007 was associated with a change in the futures markets from backwardation to contango. As indicated before, futures markets were in backwardation during most of the 1990s and the early 2000s. In this sense, changes on the supply side seem to have had a key role. Countries exporting oil implemented output quotas in order to equalize global supply and demand during much of the 1990s. The OPEC's strategy to satisfy global demand to keep up prices partly supported the backwardation and it was felt by the speculators that the strategy would not work. Complying with the quotas was perceived that only a little additional oil was available to build inventories. Low inventories supported prices in the near term by keeping the market dependent on current production. The OPEC strategy, especially the strategy of Saudi Arabia affected the first years of the price increase after 1999. The leaders of the Kingdom paid particular attention to inventories in this period. However, as conditions in the global economy got worse, stocks started to cumulate quickly. Particularly in the Asian financial crisis, most of the increase took place and contango rose as stocks built. They started to pay attention to the issue after the member countries of OPEC, especially the Saudis, recognized that crude oil markets had been switched into contango by a sharp rise in stocks in 1998 with a resulting drop in spot crude prices (Verleger, 2009). This situation generated not only market conditions that have a tendency to boost prices but also an opportunity for speculators. When the physical cost of storage is exceeded by the price difference between a near-month contract and a far-month contract, more expensive future month prices induce firms and speculators to

build stocks. This means that it becomes cheaper for firms to buy oil now and pay the storage costs than to contract for more expensive oil deliveries in the future. The crude oil market switched from contango to backwardation, as inventories reduced. The member countries of OPEC were forced to reduce their production and bring down stock levels in March 1999 by Saudi Arabia who threatened to increase oil production. After that, in general, oil stocks have reduced. Between 1999 and 2006, Saudi Arabia demonstrated its market power in regulating the price of oil. The oil minister of Saudi Arabia suggested that the other producers join the Kingdom in cutting output. Saudi Arabia successfully kept markets in backward during the subsequent six years. In order to implement its strategy, the Kingdom used market mechanisms. Since then, Saudi Arabia sells its oil by setting prices relative to well-known and accepted benchmarks. In spite of these problems, it is proposed by a number of studies that higher oil prices have not systematically been determined by speculation (see IMF (2006)) because these studies indicate that causality runs from prices to changes in speculative positions (Kaufmann et al., 2008; Verleger, 2009). Afterwards, the OPEC comes up against a complex decision making process and there is a requirement to think about making its output decisions, such as inventories' level, the shape of the forward curve, the bearish or bullish sentiments of traders and the speculative positions' size in the futures market. In fact, this situation has caused undesirable results on oil price fluctuations, leading to volatility and sometimes generating sharp increases or declines in oil prices (Fattouh, 2007).

In this period, the beginning of the USA military action in Iraq in March 2003 was of particular political significance. A price increase occurred in 2004 due to the growing demand for oil products linked to economic development and the expectation of a future lack of petroleum products. Between late 2004 and mid-2007,prices of near and far-month contracts changed such that the market was in contango. Together with the increased diesel demand described briefly above, supply shocks occurred in petroleum markets in both 2007 and 2008. The disruption involved Nigeria who provides nearly 40 percent of total world supply of light sweet crude. In fact, after the member countries of the OPEC sharply restricted inventories in consumer countries, an increase in the price of oil was observed. After that, prices increased to high levels as a result of new environmental regulations associated with inappropriate energy policy(Chardon, 2007; Verleger, 2009).

7. Findings

Although it is possible to reach some conclusion by visual interpretation of the graphs, it is necessary to test to see the statistical behaviour of the series by running unit root tests, as is often done. I start by testing for the presence of a unit root in crude oil prices using the ADF, DF-GLS (Elliott et al., 1996), P–P, KPSS, ERS point optimal and N-P(2001) unit root tests. I not only utilize the modified Akaike information criterion (MAIC) of N-P (2001), which produces the best combination of size and power, in the ADF, DF-GLS, ERS point optimal and the N-P tests for the selection of the optimal lag length, but also the kernel-based criteria, put forth by Newey and West (1994), in the P–P and the KPSS tests for the selection of the bandwidth. Table 2 reports the results of these univariate unit root tests.

According to the results, the log of crude oil prices in 2010 dollars is non-stationary under the ADF, P-P and the KPSS tests. Because conventional ADF and P-P unit root tests cannot distinguish highly persistent stationary processes from non-stationary processes very well and also the power of unit root tests diminish due to adding deterministic terms to the test regressions, I also test for a unit root in the crude oil prices using the recent tests, such as DF-GLS, ERS point optimal and N-P (2001) for comparison purposes. While the DF-GLS and N-P MZ_t provide consistent results, indicating that crude oil prices are non-stationary, according to the ERS point optimal tests and N-P MP_T the null of unit root is rejected in favour of the TS alternative. It is worth mentioning that the KPSS test results are shown differently as seen in the footnote of the Table 2.

Table 2: The Results of Linear Parametric Unit Root Test without Structural Breaks

			Crude Oil Prices		
			Intercept	Trend&Intercept	None
ADF	Level		-1.92 (3)	-2.00 (3)	-0.25 (5)
DF-GLS	Level		-1.39 (3)	-2.67 (3)	-
P-P	Level		-2.82 (3) *	-2.79 (4)	0.24 (13)
KPSS	Level		0.27 (9)	0.25 (9) ***	-
ERS Point	Level		9.49 (3) ***	15.38 (3) ***	-
N-P	MZ_t	Level	-0.75 (3)	-1.70 (3)	-
	MP_T	Level	8.68 (3) ***	14.43 (3) ***	-

*Notes: *, **, *** denotes significance levels of 10 percent, 5 percent and 1 percent, respectively at which the null hypothesis of unit root is rejected for all tests except the KPSS. For the KPSS test, *, **, *** denotes significance levels of 10 percent, 5 percent and 1 percent, respectively at which the null hypothesis of stationarity is not rejected. The numbers in the parenthesis are lag length and bandwidth to be selected.*

Regarding the specific tests, as seen from Table 2, results from the three more powerful tests of DF-GLS, ERS Point, N-P MZ_t and N-P MP_T are less in agreement. Actually these unit root tests provide mixed results. But as seen from survey of the literature and the results in this study, it is hard to conclude which test is the best. The DF-GLS test is particularly appropriate for highly trending data. ERS propose a simple modification of the ADF tests in which the data are de-trended. Either an intercept, or an intercept and a linear time trend, is included to take account of the deterministic components of data. By DF-GLS-de-trending the data series prior to running the test regression, the tests yield substantial power gains. When the integration order of the series under consideration is calculated from de-trending procedure developed, one can see that the DF-GLS test does not reject the unit root null hypothesis for crude oil price series. According to the ERS point optimal test, which has been found to dominate other commonly used unit root tests when a time series has an unknown mean or a linear trend and N-PMP_T test, the null of unit root is rejected in favour of the TS alternative. Although crude oil prices seem non-stationary in most of the cases, the unit root analysis made by new tests yields less evidence for non-stationary crude oil prices. These results could have been biased towards the non-rejection of the null of unit root because of the failure to account for structural change in the data. I investigate this issue next.

I consider the case in which the crude oil prices are assumed to contain a structural break. This break is searched endogenously from the data and Z-A does not rely on pre-test information to determine it, thereby avoiding the possible problem of "data mining". So, I run Z-A (1992) unit root tests on the full sample of data for the crude oil price. For this series, I estimate all three models (A, B and C). There are various ways to select the number of lags (k): Schwartz Information Criterion, AIC or t-test. I use minimizing the AIC criteria. The following table reports the Z-A unit root test results for the random walk hypothesis with structural breaks for crude oil prices.

Table 3: The Results of Linear Parametric Unit Root Test with Endogenous One Structural Break (Zivot and Andrews test)

		Crude Oil Prices
Model A	α	-4.34
	TB	1973 ***
	k	3
Model B	α	-3.04
	TB	1953 **
	k	3
Model C	α	-4.23
	TB	1973 ***
	k	3

*For each choice of breaking point, the optimum lag length, k, is selected by minimizing AIC. The 10 percent, 5 percent and 1 percent asymptotic critical values, obtained from Z-A (1992), are respectively, as follows. Model A: - 4.58,-4.80 and - 5.34; Model B: - 4.11, - 4.42, and - 4.93; Model C: - 4.82, - 5.08 and - 5.57. *, ** and *** denote statistical significance at the 10 percent, 5 percent and 1 percent levels, respectively, based on the asymptotic critical values.*

As known, Z-A endogenous structural break test is a sequential test that utilizes the full sample and uses a different dummy variable for each possible break date. In this test, the break date is selected where the t-statistic from the ADF test of unit root is at a minimum (most negative). Consequently a break date is chosen where the evidence is least favourable for the unit root null. The critical values in Z-A (1992) are different from the critical values in Perron (1989). The difference is due to the fact that the selecting of the time of the break is treated as the outcome of an estimation procedure, rather than predetermined exogenously. The asymptotic critical values are taken from Z-A (1992), who obtain them through 5,000 Monte-Carlo replications as reported in the Table 3's footnote.

Several observations can be drawn from Table 3. At first, the coefficients on the break dummies are significantly different from zero at 5 percent level but t values are not given for parsimony. Moreover, by incorporating the structural break, I find that the null hypothesis (H_0 : α=0 (series (y_t) contains a unit root with a drift that excludes any structural break) cannot be rejected for each of

two series. Therefore, it can be said that structural breaks does not affect the integration crude oil price series. This price series is still DS according to the Z-A test results. It is important to find 1973 and 1974 as break dates that are very important years for crude oil market, consistent with the earlier literature. According to these findings and the literature, oil prices appear to be determined under a different institutional regime since 1973 and 1974 respectively than before. But apart from these years, there could be other significant shocks in the crude oil time series data due to structural or policy changes in the market aforesaid. While our main focus in this paper is on studying mean reversion of crude oil prices, it is still interesting to investigate whether there are some other structural breaks accounted for by major policy changes or economic events in this market. For this purpose, I employ the B-P (1998, 2003) methodology to test for structural breaks and estimate the corresponding break dates in the series.

As written before, the B-P methodology estimates unknown break points with ordinary least squares under fairly weak conditions. The maximum permitted number of breaks is set at m=5 in this test. To ensure an adequate number of observations for each regression, it is standard to use "trimming" such that breaks do not occur at the very beginning or end of the sample. Since the limiting distribution of these tests depends upon the proportion of the minimal subinterval, measured by ε, I calculate the test statistics based upon two different constraints on this parameter. For example, when I use 0.10 trim factor these breaks can occur no earlier than 1874 and no later than 1996 for crude oil. ε=0.15 and ε=0.10 are used as a trimming to construct the minimal length of a segment: h = ε T. In Monte Carlo simulations, B-P find that the maximal value of m for ε=0.15 is 5. I allow for heterogeneity and autocorrelation in the residuals, and also heterogeneity in the regressors across segments. I complement the B-P sequential procedure to select structural break dates with the Bayesian Information Criterion (BIC) and a modified Schwarz criterion (LWZ).

The estimation results for the breaks for crude oil prices are given in Table 4. The first issue to consider is testing for structural changes. Here, the sup $F_T(k)$ tests, testing no breaks hypothesis versus the alternative hypothesis that there is a known from one to five number of breaks, (sup $F_T(1)$, sup $F_T(2)$, sup $F_T(3)$, sup $F_T(4)$, and sup $F_T(5)$ respectively), are all rejected at the 1 percent level. While B-P advocate using the sup F_T test with given numbers of breaks, they acknowledge that there are circumstances in which they might be deceptive. For example, for a regime-switching model in which the parameters switch back to an initial regime, the test will underestimate the number of breaks. For this reason, they also suggest testing

the hypothesis of no breaks against an unknown number of breaks (Lewis, 2006). The double maximum tests, UDmax and WDmax, testing the null hypothesis of no structural break versus an unknown number of changes given the upper bound of five breaks, are all significant at the 1 percent level. But the significance of these tests does not provide enough information about the exact number of breaks. But they mean that one break is at least present in crude oil prices.

Table 4: The Results of Bai and Perron Test with Endogenous Multiple Structural Breaks

Specifications : z_t={1} q=1 p=0 m=5 Crude Oil Prices (2010 dollars)						
	ε=0.15 h=22			ε=0.10 h=15		
$SupF_T$ (1)	13.0317***			13.0317***		
$SupF_T$ (2)	19.4184***			27.0547***		
$SupF_T$ (3)	25.6974***			34.4686***		
$SupF_T$ (4)	25.6974***			47.9207***		
$SupF_T$ (5)	17.9348***			50.3813***		
UDmax	25.6974***			50.3813***		
WDmax	44.8918***			101.0735***		
sup F(ℓ+1|ℓ)						
supF(2/1)	13.2350**			33.3320***		
supF(3/2)	21.8409***			25.4934***		
supF(4/3)	3.5433			11.8368		
supF(5/4)	0.9126			11.8368		
Number of Breaks	Sequential (3)	BIC (3)	LWZ (3)	Sequential (3)	BIC (4)	LWZ (3)
Break Dates and Confidence Intervals for the break dates (%95)	1882 (1878-1913) 1926 (1919-1942) 1973 (1964-1974)			1877 (1874-1885) 1926 (1919-1940) 1973 (1964-1974)		

, ** and * denote statistical significance at the 10 percent, 5 percent and 1 percent levels, respectively, based on the asymptotic critical values. In crude oil price case, when a minimal break fraction of 0.15 (ε=0.15) is used, corresponding to a minimal regime length is 22 periods (h=22) and when ε=0.10 is used, minimal regime length is 15. The 95 percent confidence intervals are reported for the break dates.*

Table 4 also reports summary evidence for the sequential sup F_T test. In this test, a sequential procedure estimates each break one at a time, and estimation stops when the sup $F_T(\ell+1|\ell)$ test is no longer significant at the given marginal significance level. To identify when the structural breaks are, I begin the analysis by conducting sequential Sup F_T tests for crude oil price series, allowing up to maximum five breaks. Sup $F_T(3|2)$ test generally is rejected at the 1 percent level, showing three structural break dates.

For crude oil prices, sequential procedure selects 3 breaks as BIC and LWZ does. When I use ε=0.15, the break dates are estimated at 1882, 1926 and 1973. But if I choose trimming ε=0.10, only the first break dates change and the test shows 1877 as a structural break as Dvir and Rogoff (2010) found. The estimation also provides confidence intervals for breaks dates. Thus for each of the estimates of break points, I estimate 90 percent and 95 percent confidence intervals around the break points but report only the intervals found according to 95percent. This provides upper and lower bounds for which the break points occur with 90 percent or 95 percent probability. So I can say that 1882 is found because of percentage "trimming" constraint, ε, to be used to construct a minimal length of a segment.

Figure 1 in the previous section shows the price of crude on an annual basis in 2010 dollars from 1861 through 2010. For the whole historical period, prices averaged $29.44 per barrel over the 150 observations, while the standard deviation is $21.5 per barrel. Actually instead of examining the period as a whole, I divide it into four regimes due to structural breaks according to B-P test results. The first regime is found between 1861-1876 and 1861-1881 similar to Dvir and Rogoff (2010) who found as 1861-1878. Table 5 presents some sample statistics regarding each of the four periods as well as the entire series[11].

Table 5: Sample Statistics of Crude Oil Price Series

	Sub-Samples						Entire Sample
	1st Regime		2nd Regime		3rd Regime	4th Regime	
	ε=0.10	ε=0.15	ε=0.10	ε=0.15			
	1861-1876	1861-1881	1877-1925	1882-1925	1926-1972	1973-2010	1861-2010
Mean	53.3	47.1	21.7	21.1	14.7	47.7	29.44
Standard Deviation	27.2	26.7	6.7	5.5	2.5	23.5	21.5

11 Although I use logarithm of the crude oil prices series in the univariate analysis, I use their actual prices in figures and tables showing sample statistics.

The differences between the sub-samples are as follows. The mean price (measured in 2010 dollars) between the years 1861-1876 ($53.3) was almost two and half times more the mean prices between 1877-1925 ($21.7) and almost quadruple that of the period between 1926-1972 ($14.7). In contrast, there is only 11.7 percent difference between the mean price between the period 1861-1876, and the last period, 1973-2010 ($47.7). In terms of the standard deviation of annual prices across these periods, a similar pattern can be observed. The standard deviation of price in the period 1861-1876, at $27.2, is quadruple that of the period 1877-1925, at $6.7, but strikingly eleven times higher than the standard deviation of prices in the years 1926-1972, at $2.5. But the first period's standard deviation was only 15.8 percent higher than the standard deviation of price in the years 1973-2010, at $23.5. We can draw the conclusion from the table that there seems to be much in common in terms of the behaviour of oil prices between the periods 1861-1876 and 1973-2010. But these periods look markedly different in most respects from 1877-1925 and especially from the period 1926-1972.

Dvir and Rogoff (2010) make mention of historical similarities between the two periods similar to my findings, 1861-1876 and 1973-2010, with regard to supply and demand factors affecting the market for oil. They pinned down that the monopoly of railroads on transportation in the former period and the OPEC's ability to restrict access to easily exploitable reserves in the latter period, created uncertainty regarding the continued access of consumer markets to oil in terms of the supply side. For example, in the current regime of oil beginning in 1973, some members of the OPEC initiated an oil embargo more than doubling oil prices. The demand side of these periods was characterized by persistent growth shocks. Both periods were years of intense industrialization. The industrializing countries that create uncertainty about future demand are the US in the first period and East Asia in the second. But, while in the first period, the increased volatility was due to greater amplitude of price movements, the frequency of price movements increased substantially after 1971 (or a decline occurred in the duration of large price cycles) (Cashin and McDermott, 2002).

It seems that the crude oil price series is generally found to have I(1) processes according to conventional unit root tests, meaning the impact of a shock does not die out even in the infinite horizon even being exposed big structural breaks. But it is usually difficult to justify this infinite memory on theoretical grounds for many economic time series, such as not only inflation, interest rates but also non-renewables (crude oil). Indeed, the series found as having unit root process

are likely to have a long memory process. Yet more, crude oil prices may still be characterized as mean reverting processes, although these shocks have a long-lasting effect. Long memory creates a deviation in favour of finding a unit root in the conventional unit root tests. For this reason, the implementation of fractional unit root tests seems to be inevitable. I test this strong persistence using the long-memory models without abandoning the mean reversion and equilibrium properties. From an economic perspective, the long-lived impact of shocks under a long memory model is quite distinct from economic models associated with rare structural breaks. Here, I show whether the series is non-stationary but mean-reverting, with an order of integration smaller than one. These models could be a convenient alternative to explain the strong persistence in crude oil prices. Several estimators have been proposed in the literature to estimate the fractional memory parameter d. Table 6 displays estimates for the order of fractional integration, d, by using the GPH and GSE methods[12].

Table 6: Fractional Unit Root Tests Results (Geweke and Porter-Hudak and Robinson Gaussian Semi-Parametric Estimator)

		$T^{0.4}$	$T^{0.45}$	$T^{0.50}$	$T^{0.55}$	$T^{0.6}$	$T^{0.65}$
GPH	d	**0.49**	**1.06**	**0.92**	**0.88**	**0.9**	**0.67**
	sd.reg	0.2669	0.4404**	0.3163***	0.2453***	0.210***	0.1879***
	sd.as	0.3829	0.3160***	0.2568***	0.2205***	0.1828***	0.1592***
GSE	d	**0.49**	**0.69**	**0.76**	**0.82**	**0.82**	**0.58**
	sd.as	0.1890***	0.1667***	0.1443***	0.1291***	0.1118***	0.1***

*GPH and GSE estimates are the Geweke and Porter-Hudak (1983) log periodogram and Robinson (1995) Gaussian semi-parametric estimates, respectively. *, ** and *** indicate that the unit root null hypothesis is rejected at 10 percent, 5 percent and 1 percent significance levels, respectively. s.d.reg is the ordinary least squares standard error of d and sd.as is the asymptotic standard error of d. Tα determines the number of periodogram ordinates (sample size) used in the estimation.*

For the semi-parametric GPH and GSE estimators, the choice of bandwidth parameter may be quite important in the application of tests to estimate the long memory parameter d. For the GPH estimator a choice has to be made with respect to the number of low order frequency ordinates (bandwidth). The ad hoc $T^{1/2}$ order bandwidth suggested by GPH (1993) for the stationary region of d is commonly used. Hurvich, Deo, and Brodsky (1998) prove that the mean squared

12 I am thankful to Mehmet Balcilar for supplying his Gauss "longmem" library to estimate these tests.

error minimizing bandwidth m is of order $T^{4/5}$. This is the upper rate for its class of estimators (Balcilar, 2002). However, the common implication is either to use only 0.5 or to use those between 0.40 and 0.60. In order to be robust against the choice of the bandwidth parameter, I report the GPH and the GSE estimates for various values, such as for 0.40; 0.45, 0.50, 0.55, 0.60 and 0.65. We must keep in mind that inclusion of high order periodogram ordinates will lead to bias in the estimates of d. If the time series is not ideal, e.g. if it is an ARFIMA (p,d,q) with not both p = 0 and q = 0 , then we should use small values of order periodogram ordinates, since at higher frequencies the short run behaviour of the series will affect the form of the spectral density. Hence, determining the d parameter can test the unit root hypothesis. The d estimates are reported along with asymptotic and ordinary least squares standard errors for testing the null hypothesis. The estimated d values can be seen in Table 6. Non rejection of the null hypothesis of both tests imply that series under examination does not have long memory feature meaning that they may have unit root process. In other words, the series are not fractional stationary rather they could be DS. For the log of crude oil prices (in 2010 dollars), the GPH and GSE test results indicate that the crude oil prices is characterized by I(d) behaviour with $0.5<d<1$. Hence, it can be said that the crude oil price series is non-stationary but it contains not exactly a unit root but a fractional one. The evidence supports the finding that the crude oil price series in 2010 dollars exhibits mean reversion, though its dynamics can be rather persistent and the shocks have a long-lasting effect since an innovation will have no permanent effect on its value. This is a very interesting result for applications in energy economics since Pindyck (1999) claim that the rate of mean reversion is slow. According to fractional unit root tests results, crude oil prices will eventually return to their mean in the face of a shock, although this may take a long time due to the presence of long-memory.

At 0.50 (a commonly used choice) value crude oil price series integration levels are below 1.0, revealing evidence of long memory in the prices. The structural breaks are also still such an important issue that macroeconomic series may show apparent long memory due to neglected structural breaks, similar to the arguments in the literature on unit roots versus structural breaks.

I have conducted several unit root tests so far. Generally they indicate that crude oil price series are non-stationary in line with the literature. Again, according to test results taking structural breaks into account, it can be seen that there are big changes in the crude oil market. This causes one to think that model parameters change from one sub-sample to another beyond a certain threshold.

Due to these kinds of structural changes, the series under consideration has undergone a shift in the parameters before and after the event and could very well be stationary if we run the tests in the pre and post event data separately. But when the model changes during the sample period, the data are non-linear (Ghosh and Dutt, 2008). Actually, fractional integration test results above present interesting results supporting the idea that the crude oil price series exhibits mean reversion, though its dynamics can be rather persistent and the shocks have a long-lasting effect since an innovation will have no permanent effect on its value. Moreover, the fact that crude oil prices respond differently in relation to positive and negative shocks contributes to non-linear behaviour observed in the crude oil prices over time. Therefore, in order to determine whether we have a linear model (no change in model parameters) with a unit root, or a non-linear model with no unit root, or a non-linear model with a unit root, I employ two econometric tests that can distinguish between non-stationarity and non-linearity. The C-H procedure is one such test and the other is KSS test.

When applying the C-H test[13], the first issue that must be addressed is if there are threshold effects and hence nonlinearity. I use the Wald test, W_T, to examine whether we can reject the linear autoregressive model in favour of a threshold model. The results of the Wald test are reported in Table 7 below for crude oil prices by assuming trimming range as 0.15-0.85 and 0.10-0.90. Apart from Wald tests W_T, I also report the bootstrap p values for threshold variables of the form $z_{t-1}=y_{t-m} - y_{t-m-1}$ of C-H test with intercept and trend for delay parameters from 1 to 8. All bootstrap tests in this section are obtained via a parametric bootstrap with 10,000 replicates. Many of the statistics are significant, which supports the presence of threshold effects. However, when applying the C-H test with intercept for crude oil prices, I do not find significant threshold effect. Therefore, we may argue under this assumption that the crude oil price series follow a linear process implying that the results of the standard unit root tests are still valid for this variable. But I also employ the C-H test with trend and obtain different results for crude oil prices.

13 I am grateful to Mehmet Balcilar for providing his own R codes to estimate these tests.

Table 7: Caner Hansen Threshold Test

Exogenous term=Intercept	**Crude Oil Prices**	
$Z_{(t-1)}=y_{(t-m)}-y_{(t-(m-1))}$	.15-.85	.10-.90
Wald Statistics	14.46	14.46
Bootstrap p-value	0.32	0.38
Optimal delay parameter m	3	3
Threshold parameter λ	-0.01	-0.01
Number of observations in Regime 1-its percentage	74-0.53%	74-0.53
Exogenous term=Trend	**Crude Oil Prices**	
$Z_{(t-1)}=y_{(t-m)}-y_{(t-(m-1))}$	.15-.85	.10-.90
Wald Statistics	24.32***	24.32**
Bootstrap p-value	0.04	0.06
Optimal delay parameter m	3	3
Threshold parameter λ	0.01	-0.01
Number of observations in Regime 1 and its percentage	71-0.50%	71-0.50%

Bootstrap p-values for the threshold is calculated from 10,000 replications.

The results are sensitive to the choice of delay parameter, m, making it necessary to select endogenously. This is made endogenously by selecting the least squares estimate of m that minimizes the residual variance as mentioned by Caner and Hansen (2001). Instead of assuming its certain value, one must first estimate m and use this value in the rest of the procedure. I find that W_T is maximized for crude oil prices when m=3. Taken together, the bootstrap p-values indicate that we can reject the null hypothesis of linearity in favour of the alternative, that there is a threshold effect at least at the 5 percent significance level in crude oil price series barring crude oil price case with intercept, indicating that simple linear models are inappropriate.

Table 8: Caner and Hansen 1-sided and 2-sided Wald test

			Crude Oil Prices (estimated delay=3)			
			Intercept		Trend	
			R_{1T}	R_{2T}	R_{1T}	R_{2T}
.15-.85	Statistics		---	---	27.0***	27.0***
	p values	Asymp.	---	---	0.0007	0.0009
		Bootstrap	---	---	0.0045	0.0047
.10-.90	Statistics		---	---	27.0***	27.0***
	p values	Asymp.	---	---	0.0008	0.001
		Bootstrap	---	---	0.005	0.0056

*Bootstrap p-values for the unit root tests are calculated from 10,000 replications. I use the trimming bound of 0.15-0 .85 and 0.10-0.90. *, **, *** denotes significance levels of 10 percent, 5 percent and 1 percent respectively at which the null hypothesis of unit root is rejected.*

In the preceding measurement, I find evidence that crude oil, in one case, are nonlinear processes. Here, I explore the unit root properties of the crude oil prices. I calculate the threshold unit root test statistics R_{1T}, R_{2T}, t_1 and $t_2$for estimated delay parameter m=3 for crude oil prices. All my results in this test are based both on 0.15-0.85 and 0.10-0.90, which can provide an optimal trade-off between various relevant factors. These include the power of the test and the ability of the test to detect the presence of a threshold effect. Each regime must also have enough observations to identify the parameters.

I examine the threshold unit root properties of crude oil prices based on the R_{1T} and R_{2T} statistics for estimated delay parameter. Both one sided and two sided Wald tests are used to test the null hypothesis H_0 against the two alternatives H_1 and H_2. The R_{1T} and R_{2T} statistics results, together with their asymptotic and bootstrap p value are reported in the above Table 8. We are able to reject the unit root null hypothesis for crude oil prices almost at the 1 percent significance level. The results of both the one-sided R_{1T} and two-sided R_{2T}Wald tests show that crude oil prices are a threshold stationary process. It is true that a significant test statistic can justify the rejection of the unit root hypothesis, but it cannot discriminate between the stationary case H_1 and the partial unit root case H_2.

Table 9: Caner and Hansen t tests

			Crude Oil Prices (estimated delay=3)			
			Intercept		Trend	
			t_1	t_2	t_1	t_2
.15-.85	Statistics		---	---	2.39	4.63***
	p values	Asymptotic	---	---	0.51	0.0026
		Bootstrap	---	---	0.253	0.0057
.10-.90	Statistics		---	---	2.39	4.63***
	p values	Asymptotic	---	---	0.545	0.0028
		Bootstrap	---	---	0.265	0.0066

*Bootstrap p-values for the unit root tests are calculated from 10,000 replications. I use the trimming bound of 0.15-0 .85 and 0.10-0.90. *, **, *** denotes significance levels of 10 percent, 5 percent and 1 percent respectively at which the null hypothesis of unit root is rejected.*

After the Wald tests is rejected, I examine further evidence on the unit root hypothesis by measuring the individual t statistics, t_1 and t_2, to investigate which regime has a unit root and which one is stationary individually. If t_1 is rejected, the first regime is stationary and analogously the rejection of t_2 implies that the second regime is stationary. For crude oil prices with trend at m=3, the bootstrap p-value of t_1=0.253 (insignificant) show that we cannot reject the null hypothesis and the bootstrap p-value of t_2=0.0057 (significant at the 1 percent level), however, is evidence of partial unit roots(see Table 9). As mentioned above, examination of the actual estimates of one-sided and two-sided Wald test indicates stationarity in the data.

In order to take nonlinearities into account due to multiple regimes, I also perform the KSS unit root test to the raw, de-meaned and de-trended data. Table 10 reports the test statistics of the log of crude oil prices for the periods of 1861-2010.

Table 10: Kapetanios, Shin and Snell (2003) Test Results

	Crude Oil Prices
Raw Data (t_{NL1})	-0.766773 (3)
De-meaned (t_{NL2})	-3.180209 (8)**
De-trended (t_{NL3})	-3.387773 (8)*

The number of augmented terms for KSS shown in the parentheses is selected by the sequential testing procedure. The 10 percent, 5 percent and 1 percent asymptotic critical values for raw data are 1.92, -2.22, and -2.82 respectively, those for de-meaned data are -2.66, -2.93 and -3.48 respectively, and those for de-trended data, 3.13, -3.40 and -3.93 respectively, taken from Kapetanios et al. (2003, p. 364)., **, *** denotes significance levels of 10 percent, 5 percent and 1 percent at which the null hypothesis of unit root is rejected with critical values mentioned just before.*

For non-linear ADF test, KSS, I report three statistics. First, I use the raw data of the crude oil prices and apply the KSS test to the raw data and report the t ratio as t_{NL1}. Next, I subtract the mean of the crude oil prices from the raw data and apply the KSS test to de-meaned data and report the t ratio as t_{NL2}. Finally, I de-trend the raw data following both the procedure of Hodrick and Presscott (1997) filter and the procedure explained in KSS[14] and apply the KSS test to de-trended data. I report the t ratio as t_{NL3} only for the de-trended data obtained by the procedure in the KSS due to similar results. The number of augmented terms for crude oil prices is found 3 for raw data and 8 for de-meaned and de-trended data. As explained in the methodology, in this test the null hypothesis which is a unit root process is tested against the alternative of a globally ESTAR process. KSS tests for crude oil price series indicate mixed results. But generally we reject the null of non-stationarity against the alternative of nonlinear but globally stationary since the test statistics are greater than critical values. To explain in a specific manner, according to the KSS test result; the null hypothesis of unit root appears to be rejected in de-meaned and de-trended cases for crude oil prices against the ESTAR alternative.

14 See Kapetanios et al., 2003, p.364.

8. Conclusion and Further Research

The question of how to use the simple non-structural Hotelling model that examines the stochastic behaviour of exhaustible resource in an attempt to construct forecasting models of energy prices using models prices has moved to centre of debate after Pindyck (1999) showed how simple competitive Hotelling model of extraction of exhaustible resources could produce great variability in the trend and in the level of an unobservable long-term marginal cost which resource prices revert to, and suggested that rather than use of structural models which take into account a wide array of factors including supply and demand factors. Without taking any theoretical side, I have just examined the stochastic properties of crude oil prices using not only conventional unit root test but also new different techniques and taken part in the discussion by showing whether oil prices are mean reverting or not, the rate of mean reversion is slow, and the trends to which prices revert also fluctuate over time. I have re-examined these data and advanced the literature by considering unit root tests with multiple structural breaks that are endogenously determined by the data and fractional and nonlinear unit root tests.

According to the results of this paper, linear unit root tests with and without structural break have generally found that crude oil can be characterized as a random walk process and that the endogenous structural breaks are significant but they have not affected the random walk process. From an economic perspective, the long-lived impact of shocks under a long memory model is quite distinct from economic models associated with rare structural breaks. According to the fractional unit root test result crude oil price series have been found non-stationary. Crude oil prices contain not exactly a unit root but a fractional one. This means that the crude oil price series does not follow strictly a random walk. The shocks have a long-lasting effect since an innovation has no permanent effect on its value. Even if sharp rises are observed during short periods for specific shocks, crude oil prices tend to generally to revert to normal level over a long period, since the resource is produced and sold in a competitive market, so that price should converge to its unobservable trending long-run marginal cost, which is likely to change only slowly, as the effects of shocks disappear.

Instead of considering the entire period, the regimes should be examined separately. While one regime shows DS process the other is TS. A cursory glance at the world oil market reveals similarities and differences of the market, specific to regimes. The geological, economic, institutional and technological conditions

that allowed oil prices to behave were unique to that regime. It is worth emphasizing that I have not focused on the source of shocks to the crude oil market, nor have I attempted to identify these shocks. The main objective here is to account for the different behaviour of crude oil prices possibly across different regimes, rather than determining the genesis of shocks to crude oil prices within a given regime.

There are still a number of issues that warrant further examination. As discussed to some extent in Section 5, Perron (1989) contributed to this literature by showing that standard unit root tests could lead to erroneous conclusions if the true DGP was a short memory (I(0)) process containing breaks in the deterministic components. The distinction between a random walk and a trend break largely concerns the frequency of permanent shocks to the trend. As known, in a random walk process, such shocks occur frequently, while in a trend-break process, they occur infrequently. Future studies may attempt to find alternative ways to narrow the difference between these models. One may also implement, in future studies, a variant of the smooth shifting-mean autoregressive process of González and Teräsvirta (2008) to estimate changing fundamentals with the aim of strengthening fractional unit root results. This would be of interest because it does not necessarily force structural change to be sharp but rather allows that it could be a gradual process over time. In this sense the smooth shifting-mean autoregressive process approach represents a reasonable alternative to that of Bai and Perron (1998), which forces structural change to be immediate and discrete.

Although detecting the nature of long-range dependence and, in particular, differentiating between true and spurious generation of this dependence is a rather difficult task, recently there has been a considerable interest in dealing with the possibility of confusing long memory and structural change in the literature. When the effects of structural breaks are taken into account, the fractional order of integration may significantly decrease. The opposite effect is also well documented, that is, usual methods for detecting and dating structural changes tend to find spurious break detection, usually at the middle of the sample, when in fact there is only fractional integration in the data. In the future studies one should use these kinds of techniques taking into account long memory and structural breaks together to determine whether a process of the crude oil price series is best represented as fractionally integrated or as I(0) plus some deterministic components, possibly perturbed by sudden changes.

Only univariate techniques have been used in this paper. The next step might be to make a model for each regime separately after understanding of

the series' stochastic behaviour. In the subsequent studies, structural breaks in the cointegrated relations can be detected by multivariate techniques, such as Gregory and Hansen (1996) and Arai and Kurozumi (2007). By these kinds of techniques, in further research, structural models can be formed to explain and predict the behaviour of the real price of crude oil in terms of the underlying supply and demand structures by considering structural breaks, long memory and nonlinearity. Such models should incorporate the findings from this analysis. I hope that this paper will further the development of this literature.

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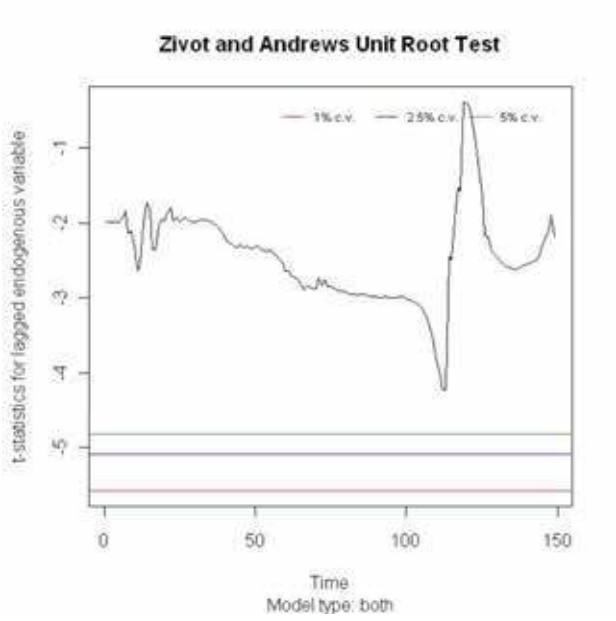
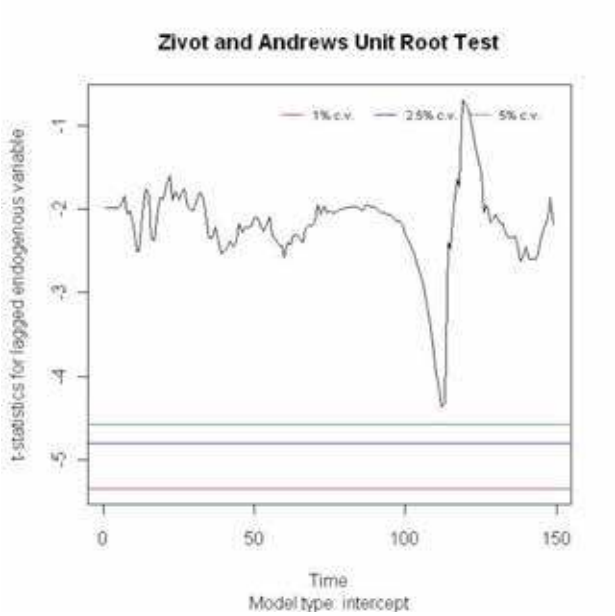
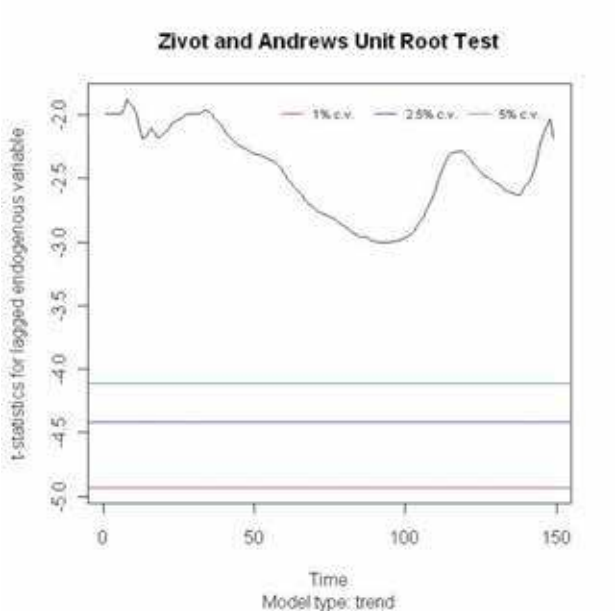
Appendix Figure 1: Zivot and Andrews Unit Root Test

Appendix: Zivot and Andrews Unit Root Test




Zivot and Andrews Unit Root Test
1% c.v.
2.5% c.v.
5% c.v.
t-statistics for lagged endogenous variable
-1
-2
-3
-4
-5
0
50
100
150
Time
Model type: intercept


Zivot and Andrews Unit Root Test
1% c.v.
2.5% c.v.
5% c.v.
t-statistics for lagged endogenous variable
-2.0
-2.5
-3.0
-3.5
-4.0
-4.5
-5.0
0
50
100
150
Time
Model type: trend

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