The impact of supply changes on the relationships between global oil benchmarks

PhD. Thesis

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To Emma and James

“John, you’re immortal now”

I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. The thesis has not been previously submitted to this or any other university for a degree and does not incorporate any material already submitted for a degree.

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Abstract

The global oil market witnessed considerable supply changes between 2010-2015, most notably from the USA where vast discoveries in rock formations have catapulted the USA to be among the top three oil producers globally. This has altered the global oil supply map and has had major implications for the market. An examination of the existing literature shows that many of the assumptions made regarding the global oil market do not factor in the new oil supply map. Another notable omission in the literature is the consideration given to the Russian oil blends. The new dynamics require a re-examination of the interconnected nature of the global oil market. This study addresses this by looking at the relationship between globally traded blends of oil; is there a long-run equilibrium relationship between, for example, oil sold in the USA and oil sold in the UK and has it changed in light of changing oil supply dynamics?

Oil market transactions price against one or more benchmark blends, notably West Texas Intermediate, from the USA and Brent, drilled in European waters. Other, less publicly recognised benchmarks exist based on the quality of oil, where it is drilled and where it is sold to. These benchmarks also provide important pricing data to the market. Movements in the price of one benchmark can result in changes in the price of other benchmarks. This is based upon a long-run equilibrium relationship where the movements in the price of one oil blend are cointegrated with the movements in the price of one or more benchmark blends.

In the extant literature the cointegration debate posits alternative views of the global oil market either being a homogenous pool of resources versus a segmented market based upon inherent qualities and markets served. This study examines the data for evidence of these long-run relationships and asks to what extent they have changed over time? Do cointegrating relationships exist in the global market for crude oil between blends of crude with different properties and how have the changes from 2010-2015 in US oil production affected these cointegrating relationships? Furthermore, are the relationships static through time or are there structural breaks that prices adapt to? Do all markets adjust at the same pace to these structural breaks?

The study was designed around the use of an ARDL bounds test for cointegration using monthly data for six global benchmarks in the period 1996 to 2018. The results show a cointegrated market that prices predominantly from the European based blend, Brent. It finds evidence of the importance of Russian oil to the market. It confirms that US oil decouples from the cointegrated price relationships at the same time as new discoveries from Texas and the Dakotas come on stream, around 2011. The growing role of Dubai based oil due to its role in pricing exports to Asia is supported. There is also evidence of a strategic shift in OPEC and Saudi Arabian policy in 2014. Moreover, the presence of structural breaks in the relationships between blends is confirmed with increasing speeds of adjustment to price innovations over time perhaps due to increased financialisation of the market. Overall, the study finds support for a global cointegrated oil market but with some relationships stronger than others based on quality but more importantly on the markets served.

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Chapter: 1 Introduction

1.1 Introduction

The global oil market is a vast network of producers, consumers, refiners, distributors and traders. There are few markets that exhibit the same level of complexity. This industry and its markets are fascinating for academics, political scientists, journalists, politicians and conspiracy theorists. The backdrop to this study is one of considerable change in the global oil market which principally occurs from 2010-2015. The changes are substantial and will reverberate in the market for decades. Technological progress creates beneficiaries, in this instance the USA has reaped the most, and it creates losers. The supply revolution has catapulted US oil production to the top three globally within the last decade. The full impact of this innovation should be assessed over the longer term as the complexity of the oil market and its feedback mechanisms suggest anything but a linear cause and effect response. In the short term, observing the market adapt to this new paradigm has been interesting, especially the collapse of conventional wisdom that governed so much of the thinking prior to the global financial collapse. In 2008 Goldman Sachs oil and gas analysts predicted an oil price of $200 per barrel by the end of that year (Blas and Flood, 2008). This was peak oil, the idea that conventional oil supply could not keep pace with exponential demand growth and would thus result in strategic resource competition between global powers, at its persuasive best. Events have run contrary to this competitive vision, oil prices did not reach $200 per barrel and there is now an abundance of crude oil, not all of it conventional oil, although the strategic resource competition has not gone away as old habits die hard. The dominant discourse may perhaps be shifting from peak demand to focus on peak supply.

Wisdom, conventional or otherwise, is always hostage to events or in this case shocks. A demand side shock, the global financial crisis, saw the price of oil crash to $43 per barrel by October of 2008. Then a supply side shock, the mass use of fracturing technologies unleashing the US's vast reserves of oil tightly packed into rock formations in the Dakotas and Texas, created the conditions where oil prices struggled to sustain levels in excess of $70 a barrel from 2013 onwards. There is a salutary lesson here in relation to forecasts and the faith invested in them but that aside these changes are worthy of investigation across a number of areas.

This thesis does not examine all of the manifold changes in the global oil market. Instead it explores one particular aspect of the global oil market- the cointegration between benchmark blends. That is the relationship between globally traded blends of oil; is there a long-run equilibrium relationship between, for example, oil sold in the US and oil sold in the UK and has it changed in light of shifting market dynamics? If the global market is cointegrated, how has it changed in light of the US Light Tight Oil (LTO) supply shock? It is through this prism that we will examine the changes that have taken place.

This enables both the researcher and the reader to understand and quantify these important phenomena, outlined in chapter two, in a specific context. There are a number of necessary phases of this thesis that allow the reader to take stock of the change, to examine the suitability of the methods employed – specifically how they lead us to a greater understanding of the market, and a contextual evaluation of the results in terms of the academic cannon and the wider knowledge. This takes the form of an examination of the oil market, the existing literature, followed by a detailed analysis of the methodological approach and finally the results.

1.2 Research idea – oil blends and their price relationship

Oil is sold in 42-gallon barrels and is named, usually, according to where it is drilled and some indication of the quality of the oil, heavy, sour, light. The financial media and occasionally the mainstream media refer to oil prices in their reports, these are benchmark prices of certain blends, usually West Texas Intermediate or Brent. The reported oil prices are series of data recorded on a timely basis, minute by minute, hourly, daily, weekly or monthly. The market does not sleep and at any point in the day, oil is transacted. As time series data it has certain behavioural characteristics. It may not be stationary in that the mean and the variance move from period to period, this is referred to as non-stationary and these statistics cannot talk for the sample as a whole, only for one period. In a market prone to shocks to demand and supply this is perhaps apposite.

The oil market may be a set of variables that are all on their own paths being pulled up and down by the vagaries of supply and demand. There may be no coherence or pattern between the prices of these variables, except for the fact that many of these blends of oil can ultimately be substituted for each other. Practical considerations, time and money, aside it is important to note that it is technically possible to swap one blend of crude oil for another at the refinery stage but as we will observe throughout this is neither costless or geographically straightforward to transport oil vast distances to leverage cost differentials. The end user is none the wiser whether this is US or North Sea crude and has no real preference, they simply seek the product's utility. The ultimate substitutability between blends of crude oil should not be forgotten when examining the interplay between the prices of blends of crude oil on their individual markets.

As will become apparent in chapter two, the global oil market is not one or even a few places where the commodity is transacted, indeed most of the transactions take place off exchange and are reported to make the price. The market for crude oil can be characterised as a system of markets, they are not independent of each other for the sole reason that the blends of crude traded can ultimately be substituted for each other and therefore there is a degree of interdependence.

As there is no single place where these transactions happen, what unifies these geographically disparate markets into a system? Is there a heuristic in play that allows buyers, sellers and traders to weigh up the movements in the price of one blend and adjust accordingly factoring in differences in quality and geography? Prices may vary but do the differences remain static as market participants revert back to these notional differentials? Is this a long-run homeostasis?

This is cointegration; the idea that two different variables can appear to randomly vary, but when visually examined side by side it is noticeable that they follow the same path while the difference between the two, no matter which period examined, remains the same. The stability of the difference between the price of the two variables is the cointegrating relationship and is the primary focus of this work, which attempts to answer the following questions:

- Do cointegrating relationships exist in the global market for crude oil between blends of crude with different properties and how have the changes from 2010-2019 in the global oil market affected these cointegrating relationships?

From the central question stems a number of subsequent questions:

  - Do changes in price of one blend of oil reverberate throughout all oil markets or are certain markets insulated?
  - Do all markets adjust at the same pace?
  - Are the relationships static through time or do they break?

This thesis provides answers to the central and ancillary questions, importantly it is against a backdrop of profound change in the crude oil market. This change is fundamentally a supply side issue but there are also changing patterns of demand that provide some of the rationale/impetus for this study. In basic economic theory we understand the impact of change to supply and demand for crude oil on a market, does the oil market actually reflect these changes?

1.2.1 Why Cointegration Matters

An examination of figure 2.0 may tell us much about the nature of the variables in this study. It appears that all of the variables in this study are following in the same path, despite its ups and downs they are, largely, following in the same direction. This will be mainly around Brent as it is the global benchmark as it is the benchmark that informs all. The spot market captures around 40% of global trade in oil and Brent features as a guide 40% of all spot market trades (ICE Research Insights, 2020). What we have witnessed in recent years is the displacement of exports from the US market leaving oil looking for a market. This ultimately leads to discounts which then present opportunities for refiners and arbitrageurs. Essentially, a cointegrated relationship between two or more benchmarks blends is a long run equilibrium, any deviation from that equilibrium presents an opportunity to make money on the correction of those blends of oil back to this equilibrium relationship. Displacement from a market as profound as the US import market could present challenges to many of these long run relationship as could events in Libya in 2013 or sanctions against Iran or Venezuela.

Theoretically cheaper blends of oil such as Bonny light challenge its long-term relationship with a blend such as Brent, in this case there is an incentive to go long, buy, the cheaper Nigerian blend in the expectation that its price will increase back to its equilibrium relationship with Brent. If the oil benchmarks are not cointegrated then such a trading strategy will not work, equally if the break in the pricing relationship between Brent and Bonny light is more longer lasting then those undertaking this trade in the expectation that the Nigerian crude will rise in value back to its level will be out of the money. This is a structural break which could lose many market participants money should they have backed the wrong price movement.

The importance to traders aside, the cointegration of oil benchmarks is an important part of the price discovery process. With crude oil production estimated at around $1.6trn in 2019 (ICE Research Insight, 2020) understanding the dynamic relationships between blends of crude oil is worth substantial amounts of money. A vast financial architecture hangs on what happens in the spot market, termed contracts are written based on spot prices, hedging and contracts for differences all require spot market rates to work from. Therefore, it is incumbent on all market participants to not only understand how those spot prices are discovered but also to understand the nature of the relationship that blends they may be trading have in, the long-run, to a key benchmark such as Brent. Finally, to understand and react to how exogenous events can cause shifts in that relationship. This is why an appreciation of the cointegration of global oil benchmarks matters to all who work in and study the market.

1.3 Research Contribution

The results of this research can hopefully contribute to in the following ways.

Firstly, many of the existing studies are out of date, there is little in the way of new research that either accounts for the innovations in the market or examines them within the cointegration framework.

Secondly, much of the previous work tends to revolve around US blends and eschews Russia. This is not nationalism but more to do with reliability and availability of data but nevertheless a gap in the literature exists.

There is also the idea of a global blend, that is one blend that all others relate to. The academic research is very light in this respect but trade and financial writers speculate heavily on the shifting dynamics and the idea that there are blends that market participants reference.

Lastly, there is little in the literature that examines the structural breaks in these cointegrating relationships in terms of their timing, the regimes therein and the speed of adjustment to disequilibria.

There is a wider contribution of this study beyond plugging gaps or updating one’s understanding. In economic writing and research there is a reductivist tendency to tame the complex. In a market such as the oil market the researcher has their work cut out in this respect.

The questions in this thesis may seek to reduce the issue to its essence however the answers and consequences may be far from prosaic. The change affects not only those involved in the global crude oil market but also the economies of the nations that find themselves newly minerally enriched and those economies that now face stiffer competition than they have had for a considerable period. Oil is a strategic commodity and whilst we may, arguably, be in the final throes of the age of oil, control of this asset still conveys geopolitical advantage. Are these changes reflected in the cointegrated systems of oil benchmarks? Is the US benchmark, West Texas Intermediate, now a powerful presence in terms of its relationships with other blends? Are traders more likely to reflect this importance by using this blend as a yardstick more often than other blends? This study seeks to offer empirical evidence that goes some way to answering these questions.

The road map for this thesis allows us to answer these questions as fully as possible by understanding the extent of current academic thinking on the issue of cointegration of blends of crude oil and establishing areas where the knowledge is in need of updating. The reader must also be able to set this body of academic knowledge in context of the machinations of the global crude oil market.

1.4 Background to the study – the oil market

The oil market has many layers and in much of the research, that complexity seems to be overlooked unless it directly leads into a specific area of research. Chapter two of this study aims to unpack some of that complexity whilst adhering to the supply and demand prism. Interwoven with this narrative are the strategic aims of resource abundant participants. It is difficult to divorce these aims from the methodological study at the core of the study and as we hold the change up to the light of examination we should be mindful that the oil market may be a game within a game. The reader should gain a comprehensive understanding of the global oil market, and detailed context of events of the last decade and in so doing be able to understand the significance of the results of this study.

1.5 Review of Literature

From the existing literature we introduce the idea of Maurice Adelman (1984) that the global oil market is “one great pool”. If this is the case then there will be connections, and various feedback loops, between all blends of crude oil and a stable long-term relationship that pulls the components of the system back into place, like a magnet, will exist. The advance of the literature has moved from a purely econometric debate to one that factors in geology and chemistry. With each advance more nuance is added to the debate and it appears that there is a basis to the "one great pool" notion that is grounded in the idea of substitutability but in extremis. Crude oil has to go through several processes before it turns into a useable product. Swapping one crude for another, in reality can be a costly business if there is more process to be undertaken, thereby leading to refiners to (mostly) swap within narrowly similar blends if the price is right. They are unlikely to buy a crude from the other side of the world, no matter how much a discount it offers, as it may incur extra transportation costs and reconfiguring the refining process to accommodate a different type of crude. These impediments act as thresholds to cointegration and lead many academics to refute Adelman and see the global oil market as "regionalised", which we should take more as a qualitative than a geographical barrier, although that cost is also a factor.

Much of the existing literature that relates to the theme of cointegration and oil tends to skip past the interplay between blends and examines the relationship that oil prices have with either other commodities or financial/macroeconomic variables. In the haste to do so researchers have overlooked a market in a state of flux and a market that the research (arguably) no longer speaks to. It is changed, perhaps immeasurably, in a number of ways, the methods of extraction, the use technology in exploration, the patterns of demand, the nations that produce oil, the list of differences between the current period and that when Adelman conducted his work are endless.

This thesis aims to address the previously mentioned gaps in the existing literature, see section 1.3. The variables used in this study address the US bias in the existing research, the time frame for the study, which will be discussed in the next section, can address the timeliness aspect and the use of certain techniques can deliver a wealth of data that can be mined to extract meaning from.

1.6 Data and sample period

Chapter four is a justification of the variables in the study, the timeframes in the sample and a route map/explanation of the methodological approach used in the study.

As noted earlier this is a study that examines cointegration of global oil benchmarks over a certain period of time. That period of time is 1996 to 2018, the frequency of the data is monthly and the spot price of six benchmarks are over that period provide the inputs. By spot price we mean the over the counter for delivery prices that are quoted which is different from the forward contracts that many studies use. The reasons for this are fully explained in the chapter, however the “wet” section of the market is not for speculative purposes, it is for market participants intent on taking delivery of the product. These benchmark blends vary in terms of where the oil is extracted, the inherent quality of the oil and the markets that they are sold into or act as a reference for West Texas Intermediate, Brent, Dubai, the OPEC basket, Urals Mediterranean and Bonny Light from Nigeria. The logged values of the closing price on the last trading day of each month over the 22-year period have been used.

It is worth noting at this point what is not included in the sample time frame. Since the end of this study there have been a number of factors that have affected crude oil prices. The US under the Trump administration has been active in sanctions against Venezuela and Iran which have some effect on the availability of certain types of crude and pushed refiners optimised to process these blends to other suppliers, and ultimately blends, which impacts prices. There is also the Covid-19 pandemic and the headlines of negative oil prices where storage facilities ran out and producers were effectively paying refiners to take the oil off their hands. These events have had an impact on oil prices but if one were to reset the sample period and begin again the study would never be completed as the oil market is very rarely without events. Indeed, the change that occurred in the first half of the decade 2010-2019 is arguably of greater importance. The oil market has absorbed war, attacks, sanctions and sharp falls in demand before but the discovery of vast resources of crude in the USA alters the market and the assumptions made, therefore this period that is of prime interest.

The study relates to the cointegration of benchmark blends of crude oil and the relationship between them, there are many other factors that could be examined through the prism of oil and cointegration, interest rates, the stock market, sales of electric vehicles. All of these are worthy topics but they are not the focus of this study.

1.7 Methodology

The study examines the cointegrated relationships of these blends over a 22-year period. As has been noted cointegration is testing for a long-run equilibrium relationship between two or more variables. With time series data there is a strong likelihood that the data is non-stationary and therefore it requires a set of techniques to produce results that are meaningful. A full discussion of these techniques is available in chapter four complete with mathematical notation. By way of introduction here the nature of the data requires testing and methods that are not in themselves complicated.

The price of a barrel of crude oil is obviously related to the supply and demand for the commodity but where do the pricing cues come from? What are the yardsticks that those who discover these prices use? We may find that the price of this notional barrel of oil is influenced by changes in the current price of other closely related types of oil but also by past values of itself and past values of the closely related blends. The relationship between the blends in this equation may be long-run, they may not move very much over time, these may be some differential or indeed a coefficient. This is the cointegration that the study seeks to identify. The research is designed to test the idea that the variables are cointegrated but there is a strong case to say from the outset that cointegration is present, an examination of the graphed raw data or the logs of the variables points strongly towards this. The exact nature of the system and the variables that belong in each system is something that the test results will uncover. The context of this study requires an examination of how the change in the market affects the cointegration of the variables?

The conventional way to examine a data set for cointegration is to use the Johansen's technique or the Engle-Granger 2-step model. The nature of the data, however, may render these methods inadequate as there is more than one variable and there is visual evidence of structural breaks in the data. A structural break means that a divergence from the long-run relationship becomes permanent and the static relationship between the variables moves onto a new trajectory. This can make otherwise stationary data seem as if it is non-stationary and thus produce test results that are misleading. In turn, interpreting the data to be non-stationary when it is not can lead to the use of incorrect techniques. The Autoregressive-distributed lag (ARDL) bounds test is a way of circumventing this problem as it can accommodate data that is stationary I(0) and non-stationary I(1). It can be used to establish the presence of a cointegrating relationship and in addition create a single equation model that specifies those variables that are statistically significant to the dependent variable. This test provides the backbone to the study and the foundation to progress into further tests/analysis.

The variables, benchmark blends, that are proven to be significant in the cointegrated systems are tested for the presence of structural breaks in the system, using the Bai-Perron break test within the confines of an ordinary least squares regression. This shows the break dates within the cointegrated system, the strength of each coefficient from period to period, or regime to regime, and quantifies the speed at which disturbances from the long run cointegrating relationship are corrected. The break point dates may correspond to significant events either in the industry or geopolitically/economically, so where possible the breaks are mapped to events in order to provide some, anecdotal, causality.

Finally, the predictive power of the model, including the regimes, is tested with the predicted values of the variable mapped against the actual values of the variable over time. This neatly rounds out the study. Firstly, the interplay between the variables is a test for evidence of a longer-term relationship to which the system equilibrates, the statistically significant variables are tested to establish breaks/changes in that long run system and then how well the model created can predict what happens to the dependent variable. In some instances, those fitted values have been swapped out for other variables in order to examine to what extent the performance of a given independent variable can predict the value of the dependent variable. This analysis is done across not only the entire sample period but also in the regimes suggested by the structural breaks.

1.8 Findings and Analysis

The findings of this research are significant and provide a more up to date picture of the interrelationships between the global benchmarks. The extent to which they reflect the changes in the market is a point that will be debated in the final analysis of this work. Chapter five is the full examination of the results, which are also analysed in context of both the related cannon of literature and the understanding of the market laid out in chapter two.

What we can see from the results is that there is strong evidence of cointegration across all blends in the study. However, not every variable in the model is an explanatory variable in each system. There are benchmark blends that incorporate information from all blends, while there exist some blends that feature in all systems. There are no surprises that blends such as Brent feature across all models in the study, blends such as Dubai and West Texas Intermediate are worthy of our investigation as they can tell much about the changing nature of the market.

There is also strong evidence of structural breaks across all benchmarks and their equation systems. This is not surprising given the nature of the data, financial time series. However, the changing composition of these systems from regime to regime is worthy of further study. This provides us with an interesting set of data against which we can project what we understand about the changing nature of the market.

Across the entire sample period there is strong evidence of cointegration, however when we examine the concomitant regimes established by the break point analysis, there are periods in some regimes where we can question the extent to which the market, for those blends, is cointegrated. Essentially, we have some systems that are partially cointegrated, although these are partially cointegrated for any great period of time. The examination of the error correction process allows us to arrive at this conclusion.

The error correction process is another point that the study will dwell upon. The residuals should have a negative coefficient, which suggests that there is a correction to disequilibria in the system, and the greater the size of the coefficient informs us of the speed of adjustment. An -0.8 coefficient indicates that 80% of the error has been corrected within one period. The salient point from this is that with regimes closer to the end of the study sample, the adjustment to disequilibria is faster. This may indicate the impact of financialisation of the market and the greater availability of real time data.

The values predicted by the model are fitted against the actual value of each variable. This test of predictive power conclusively demonstrates the strength of each model. There are very few deviations, with the exception of West Texas Intermediate when the period 2010-14 shows a clear divergence between the predictions of the model and the actual values. This may seem to undermine the model, however this is a period that many commentators suggest that US oil decoupled from the global pricing system due to supply and refining bottlenecks and lends greater weight to the model suggested by the study.

Finally, there is some examination of certain variables one on one, with the values being graphed together which may render some of the findings slightly irrelevant. Simply swapping the fitted values of some benchmarks with blends such as Brent or West Texas may indeed provide as good a predictor of the value of a another (dependent) benchmark. Indeed, an examination of these two variables with the OPEC basket provided statistically significant evidence of a break point occurring in the relationship with the US blend, West Texas Intermediate, and a change in the relationship with the European blend, Brent. That this occurs at the same point as a major strategic shift in policy by OPEC underpins the suitability of the model/methods to highlight this date as significant is in itself significant. Some existing research tries to de-emphasise this date and lead the reader to conclude that the market was increasingly pricing this eventuality into the model. The results here would suggest otherwise.

As with every research project there has to be a retrospective step in order to examine the nature and the scale of the project, its aims and objectives, the methods employed and to what extent it has delivered upon the time and effort invested. The concluding section, chapter six, uses a longer lens to consider the work in respect of these factors. By fusing together all of the threads of the work it brings this research process to a satisfactory conclusion and scopes out potential areas where the research could develop in the future.

Chapter 2: The Global Oil Market

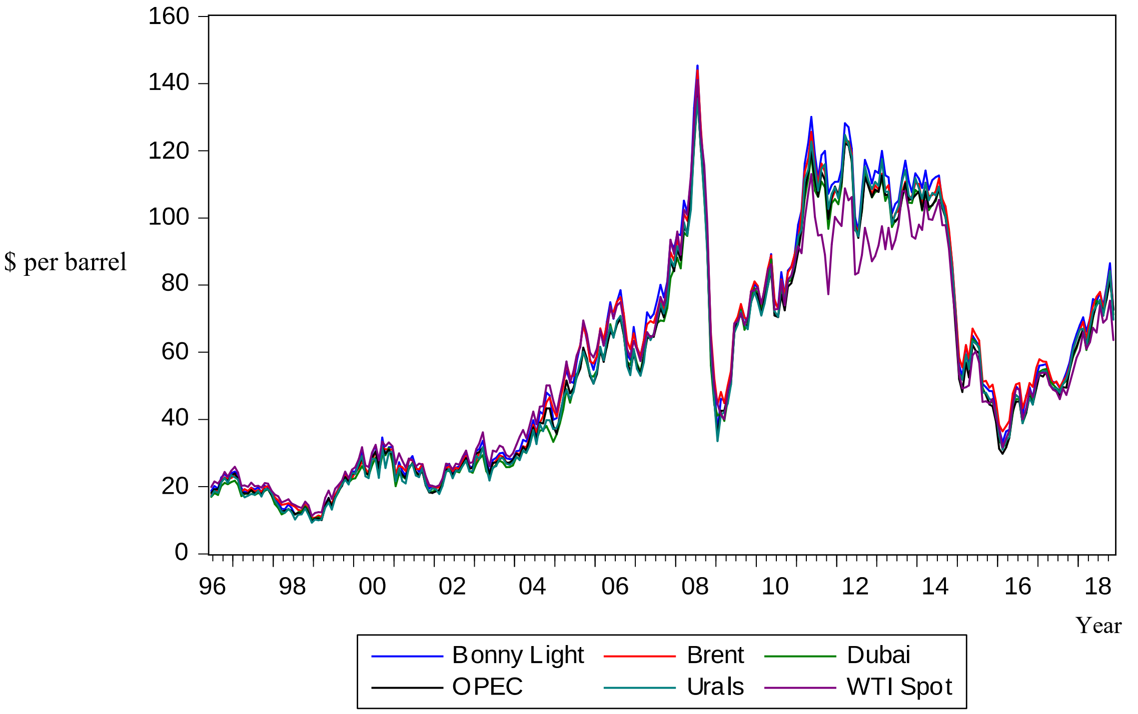
2.1 Introduction

This chapter provides a background to this study of the global oil market which will provide the reader the context to fully assess and evaluate the central research questions. Specifically, it introduces the dynamics of the global oil market: the supply and demand for oil, the significant role of technology in changing the supply picture and the financialisation of the market. The chapter concludes on a chronological examination of the responses of the significant participants in the market to the challenges of rising and declining prices from 2014 through to October of 2018.

The time period is significant in that it affords the researcher the ability to examine all aspects of the oil market, supply and demand shocks, strategic change and geopolitical events. In the main, oil prices trade on supply and demand fundamentals and the strategy of market participants, this period is no different other than it compacts a number of events, some of them seismic economically, politically and technically, into one study.

As a means of introduction, a common search on Google in terms of “what influences the price of oil?” will lead to websites such as Investopedia where the reader will be informed that the global price of oil is determined by 1) supply and demand and 2) market sentiment. Whilst not technically incorrect it presents an extreme oversimplification of what moves and shapes the market. In order to do this, one has to understand factors such as emerging market economies, the price of the dollar, the spot and forward price, the availability of refining and storage facilities and to be able to divine the opaque strategies of the world’s dominant producers in order to get to the basic story of supply/demand and sentiment. The analysis of the changing face of the market in this chapter should leave no doubt as to the complexity of the supply/demand and sentiment hypothesis.

Figure 2.0: Oil Price Benchmarks 1996-2008



Source: Datastream, 2019

2.2 Oil in the global economy

The global oil market is important in economic terms due to the ubiquity of the commodity in the modern economy. From transportation fuel through to the plastics derived from crude oil, its price is integral to the global economy and can often drive the news agenda as a result. Oil price movements garner a lot of attention due to the price inelasticity of demand and the way in which prices can rapidly surge which is quite unlike many other products that people use on a daily basis (Killian, 2007). The monetary value of oil exports in itself is indicative of the size and importance of this market to the global economy. The level of oil exports from the Kingdom of Saudi Arabia (KSA) in 2016 totalled $136bn with the value of exports from the top 15 exporters reaching $552bn (cia.gov, 2018).

Oil price increases have an impact on the global economy and on financial markets (Hamilton, 2009). There have been three major supply side shocks in since the 1970s; firstly, the Yom Kippur war and the subsequent OPEC oil embargo in 1973. Secondly, the Islamic revolution in Iran in 1978 followed by the Iran/Iraq war two years later and finally the Iraqi invasion of Kuwait in 1990 (Hamilton, 2009) that have led to precipitous increases in the oil price and ultimately to global economic recessions. The impact of oil price shocks on the economy has been widely covered (OBR, 2017) with much in the way of supporting empirical evidence (Blanchard and Gali, 2007; Millard and Shakir, 2013).

Hamilton (2009) contends that there are two main ways in which oil price shocks transmit to the real economy, firstly by raising production costs which can lead to higher prices and either lower sales or smaller margins depending on whether the firms in question pass these costs on to the end consumer. Oil price shocks also transmit through to the real economy by decreasing household demand, for other products, when oil prices increase. The impact on the economy varies depending upon whether the oil price rises or falls. There is an asymmetry of response (Mork, 1989) to oil price changes with price decreases having a smaller, in some instances near negligible, effect on macroeconomic variables compared to the larger effects of price increases. The impact of oil shocks on stock prices is equally widely covered in the literature. Studies posit a negative relationship between oil prices and stock prices (Hammoudeh and Choi, 2007; Miller and Ratti, 2009; Sadorsky 1999). In short, economic and financial fortunes are affected by changes in oil prices and as such the study of the oil market always has significant implications. This sentiment is captured in a 2015 World Bank briefing paper, which laid out the impact of the 2014 price collapse in global economic terms:

"A supply-driven decline of 45 percent in oil prices could be associated with a 0.7-0.8 percent increase in global GDP over the medium term and a temporary decline in global inflation of around 1 percentage point in the short term." (Baffes et al, 2015)

Given this importance, the increasingly dynamic nature of the oil market makes reading the movement of oil prices and prediction more of a challenge. Reducing the oil market to just an analysis of the supply and demand lends itself to a superficiality that lacks a depth of understanding. The market price of crude oil responds to factors that could be described as supply and demand factors but within these broad categories are layers, each of which in its own way contribute to explaining how prices are made and strategies evolved, even for dominant players.

The following sections shed light on the layers within the global oil demand and supply to provide the context within which the central research questions are going to be examined.

2.3 Global oil demand

The demand for crude oil and its associated products has increased over the last 25 years. In 2016 a total of 96,558,000 barrels of oil were consumed on a daily basis (bpd), compared to 1970 when 45,253,000 bpd (BP.com, 2017) were consumed it illustrates a doubling in consumption over the 46- year period. If one examines the largest consumers globally, the USA is the largest single nation consumer but the interesting, and perhaps unsurprising, increase over this period comes from the rapidly developing nations of China and India. Looking at Table 2.0, below, the daily consumption rates in barrels per day are recorded across the world's largest consumers of oil from 1970 to 2016, with figures shown at the beginning of each decade. As can be seen from the table, consumption has increased in each country over the period, with the exception of the EU where consumption has decreased due to a combination of taxation, urban living and mandated mileage performance in automobiles.

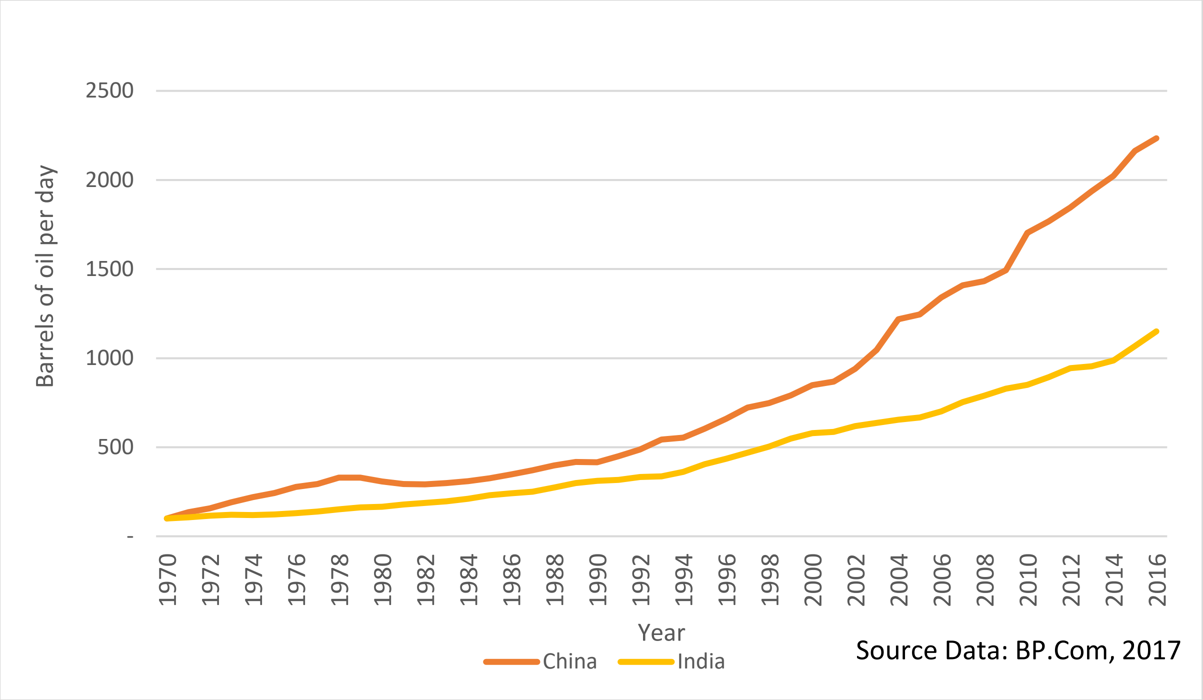
Table 2.0: Consumption: Thousand Barrels of oil per day

	1970	**1980**	**1990**	**2000**	**2010**	**2016**
China	554	1707	2297	4697	9436	12381
India	390	643	1211	2259	3319	4489
USA	14710	17062	16988	19701	19180	19631
EU	12605	14535	13879	14661	13942	12942

Source: BP.Com, 2017

If we examine China and India more closely, we can see (Figure 2.1), that over the given time frame, the extent of the consumption increase in these key emerging markets. In 1970 terms, oil consumption in China is over twenty times greater in 2016 than it was in 1970. Given the pace of development in the Chinese economy and the associated demand for energy to power that economic growth an increase in oil demand is expected. India, contrastingly, presents a more conservative picture with oil consumption/demand just over 10 times over the highlighted period, this correlates strongly with the slower economic growth that India has experienced relative to China.

Figure 2.1: Chinese and Indian Oil Demand



Source Data: BP.Com, 2017

The shift in demand from the developed to the developing world has impacted on the global oil market and led to changes in trading patterns, which will be examined in full later. The increase in oil prices up until 2008, see Figure 2.0, were in no small part, encouraged by the rapid development in emerging economies; a phenomenon commonly referred to as the commodities super cycle, where prices of metals, food stuffs and oil/gas rapidly increased, due to the rapid industrial development, urban renewal and migration in China and India (Erten and Ocampo, 2013).

Asia is now the largest export market for global crude oil exports and China is the largest market within Asia (BP.Com, 2017). KSA's most important oil trading relationship is no longer with the USA but with China. This appears to increase over time as Chinese demand (IEA, 2016) is forecasted to increase to 13.6mb/d by 2021. Not only has demand increased for normal crude oil use (transportation, plastics and fertilisers) but the Chinese government, mindful of the US Strategic Petroleum Reserve, has been stockpiling oil as it seeks to insulate itself from global supply shocks. Forecasts suggest that the Chinese strategic reserve could be as much as 500mb by the end of 2020 (IEA, 2016). This move should reinforce China's position as a significant player on the demand side of the oil equation.

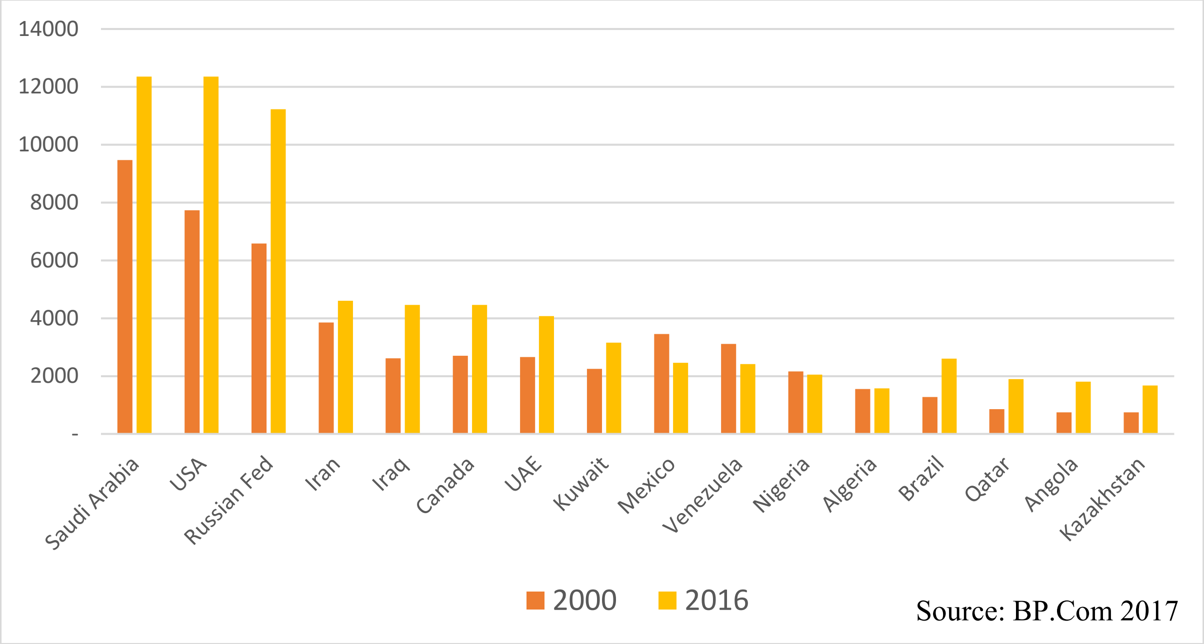
2.3.1 The impact of the dollar on prices

The global oil market is quoted in dollars, the contracts are settled in dollars, therefore anyone trading in oil needs dollars in order to finance the transaction (Gahlayini, 2011). The relationship between the dollar value and oil prices has been covered by many researchers. The relationship between the currency and the commodity is recognised to be an inverse one with rises in the dollar leading to falls in the price of oil, this is due to non-US market participants having to find more of their own currency to finance an oil transaction. This cost is then passed onto the end customer, thereby leading to higher prices at the pumps which then lead to a decrease in demand. The directional causality investigated by the literature focusses on the impact that rising oil prices have on the dollar or other currencies but in these studies, cited by Gahlayini (2011), the relationship between the level of the dollar and the price of oil is clear. While the inverse relationship between dollar price and oil price is fairly well recognised, the complex way it affects the demand, renders it as an important factor to include in the examination of the influencers of oil prices

2.4 Global Oil Supply

The supply of oil has undergone significant changes since 2000. The amount of oil that can be extracted from an oil field is surprisingly low; in a conventional oil field (see 2.4.1 for a discussion of Conventional v Non-conventional) it can range widely but the rule of thumb is approximately 30-35% of the oil in place at the discovery phase will be extracted over its lifetime, for a non-conventional field such as shale this can be as little as 10% (Fragoso et al., 2018). Technological improvements mean that more supply can be squeezed from fields that were deemed to be in terminal decline, the rise in non-conventional oils has also been a significant factor in boosting global oil supply.

Figure 2.2: Global Crude Oil Production 2016 v 2000, thousand barrels per day



Source: BP.Com 2017

As evidenced by the chart above, Figure 2.2, based on data from the 2017 BP statistical review, the increase in production is quite pronounced in some nations. Global production has increased by 22% over the period 2000 to 2016 but for some producers the increase in production has far outstripped this. The US is the most notable with an increase of approximately 60% and a production level that rivals KSA, however smaller producers such as Brazil, Angola and Kazakhstan have posted increases of 102%, 142% and 125% respectively over this period. The other notable increase is that of Iraq which has re-entered the global oil market following the end of the second Gulf war and is now producing approximately 4.5mbpd, an increase of 70%.

The points to take from this data is that whilst the increase in US production will gain the most attention as it directly threatens KSA dominance, there have also been significant changes in other, relatively smaller scale, producers which contribute to a changing supply map. This presents a picture of increasing complexity. If we compare the two periods the change in the global supply market from the beginning of the century (and certainly since the 1970’s, not shown on the graph, when arguably, KSA’s power over the market was at its strongest) the contrast is marked. A point that will be detailed later but worth noting is that wielding control or influence over a market with 50 producers of whom 15, shown above, are significant producers, is a difficult proposition.

2.4.1 Conventional v unconventional oil

A significant classification in the oil market is that between conventional and non-conventional oil. Canadian and US oil production has increased by 65% and 60% respectively since 2000 (BP.Com, 2017), this is due to improvements in technology and the growing significance of a part of the market termed "Unconventional Oil" which contrasts with conventional oil. The term conventional oil relates to the standard image of thick black crude oil gushing out to the wellhead. The distinction between the two categories is due to the method of extraction, with conventional oil being that which is extracted using the drilling and oil wellhead method, the "nodding donkeys" of the popular firmament. Unconventional oil, on the other hand, is oil derived by any other means. There are three main methods of extracting oil in an unconventional manner. Hydraulic fracturing, or "fracking", shale oil both known as Light Tight Oil (LTO) and tar sands. This type of oil is the main component of US production. Maugeri (2012, p41) states,

"shale and tight oil are conventional oils (light oils with low sulfur content) trapped in unconventional formations, which make it extremely difficult to extract hydrocarbons."

Whilst the oil may be broadly similar to that which is pumped out in the Persian Gulf or in the North Sea it is the manner of extraction that makes this unconventional. Tar sands is another oil deposit that is exploited principally in Canada and Venezuela, with high pressure jets of water being pushed through the bitumen to separate the oil and the grains of sand. What each of these, main types of unconventional oil have in common, is the cost of extraction. Relative to oil being produced in the Persian Gulf these are expensive forms of crude oil to extract for use. On one hand LTO requires little in the way of refining, it is the extraction that is expensive, whereas refining tar sands into useable oil is where costs increase dramatically. In terms of cost differentials this puts oil drilled conventionally at a distinct advantage. LTO currently accounts for 4% of global oil production.

Examining the cost differentials between conventional oil and non-conventional oil illustrates the issue that has surrounded the oil price declines since 2014. KSA produced crude oil breaks even at \$6-8 per barrel, whereas US tight oil has a substantially higher break-even cost, \$40-60 per barrel depending on which technology is used (Maugeri, 2012). Anecdotally, the break-even costs of producing US LTO seem to have fallen but not by an amount to make any significant incursions on the advantage enjoyed by many conventional producers. The cost differential from fracked LTO stems from the rapid decline rates from wells and the measures taken to extract as much oil as possible. At the end of the first year of production a typical well in the Bakken region of North Dakota, a major area for LTO "fracking" in the US, can be producing less than 65% of its initial production flows. Within four years production can be as little as 20% of the initial output which does not compare favourably with conventional wells where over the same period the decline is less severe with a loss of 30-40% from initial production rates. Moreover, to achieve decent recovery rates, producers have to drill then frack continuously which adds substantially to the capital cost (McNally, 2017). Thus, there is a clear advantage that conventional producers enjoy relative to unconventional producers.

2.4.2 Technological Change

Since 2010 the oil industry has changed considerably due to advances in technology. 3D imaging, horizontal drilling mechanisms and a resurgence of hydraulic fracturing for oil and gas have altered the operating landscape and influenced supply positively. Prior to the advent of new technology, the debate regarding peak oil centred round supply now this is a demand side question as technology has led to more efficient means of exploration and of production (Stanislaw, 2013).

New shale deposits are being discovered on a regular basis across the globe as the premia on prices from the commodity super cycle has been invested in exploration. The technology to find and extract the oil deposits has increased continuously since 2014. As Spencer Dale (BP.Com, 2017), British Petroleum's (BP) Chief Economist notes in relation to the increased productivity *"a rig operating in the Permian (a shale producing area in the US) today is equivalent to more than three rigs at the end of 2014"*. US LTO producers have harnessed technology to improve recovery rates and remain in business despite the low benchmark prices, as will be explored in section 2.10.

The IEA believes that the use of data analysis and artificial intelligence could produce meaningful cuts in production costs. The use of computing technology has moved beyond the early use of 3D imaging and now seismic analysis could result in an increase in recovery rates from the 8-10% that LTO producers currently experience. In addition to this, (Crooks, 2018) the use of predictive maintenance and automation are currently enabling oil companies, and LTO producers to significantly cut costs which is important given the relative differences in break-even costs between LTO and conventional oil, outlined in section 2.4.1. In essence, the US LTO producers are examining every means of cutting cost and remaining competitive.

2.4.3 Oil Storage and Stockpiles

A significant aspect of oil supply is the availability of storage. The WTI hub at Cushing, Oklahoma, with its ability to store 13% of US production, 73 million barrels, is speculated to be an increasingly important factor in the global oil market (Berman, 2016). Given the increasing importance of US LTO production and WTI, its benchmark price, the ability to store oil has an impact on the decision to produce. This in turn affects factors such as rigs in production that the market pays attention to when pricing the commodity. Oil companies have to take two things into consideration when deciding whether to produce or leave the oil in the ground, firstly the spot price and secondly the cost of storing oil (Pindyck, 2001). The relationship between inventory and price is therefore an inverse one. As the price and availability of storage facilities became increasingly important in the 2014-2016 period market information firms took to flying drones over the Cushing facility in order to gauge the level of spare capacity, this information was sold at premium prices to market participants seeking to arbitrage the spot and futures price (Economist.Com, 2017).

Stepping back from the example above to examine the role of stocks in the price discovery process oil like many other commodities is a “hybrid” product, (Frankel and Rose, 2010). It is a product that can be consumed and it is also an asset which can be stored either in facilities, refineries, offshore on tankers or ultimately in the ground.

Killian and Murphy (2014) see the role of inventory as an important aspect in determining the future price of oil. Inventory can help the market smoothly adjust to shocks with inventory levels falling as a result. Therefore, the level of oil stocks can have an impact as the market assimilates and prices in deviations from what was expected. The higher the stock level the more the market can smoothly respond to the shock.

2.5 The Oil Market

As Wallin and Joseph (1997) note in the introduction to the 1997 Crude Oil Market Handbook,

"The price of crude oil emerges from a complex interaction between the signals provided by product markets through the purchasing decisions of refiners, and the varying revenue objectives of producers. This process has rarely been purely economic, and it has had political overtones for most of this century because of oil's strategic importance".

Whilst this is over 20 years old, this definition still has resonance today.

The global oil market is as complex as it is vast. It is not a market as such and more of a highly interconnected network. On April 13th 2010 Reuters reported that the trading volume between London, The ICE exchange, and New York, the NYMEX, the two main futures trading hubs, that 2.5 billion barrels of oil were traded (Reuters.Com, 2010). A significant proportion of this oil is not for physical delivery but the prices that are being discovered have important implications for the global oil market. Chapter 3 will expand upon this point as the idea of benchmarks is introduced but it is a point worth making that much of the oil sold in the world is sold off exchange, the contracts are usually long-term but in the pricing these off exchange contracts the benchmark prices are used as references and as such highly important.

A vast cannon of literature exists discussing the impact that oil price shocks have on other variables, from different benchmarks of oil, to the stock market and the economy. Essentially an oil price shock is when the actual price deviates from expectation, this could be on the part of producers, consumers or the financial markets (Baumeister and Killian, 2016).

2.5.1 The Spot market

Oil for over the counter delivery is known as the Spot price, and as in any other commodity market, oil can be bought for future delivery. The "spot" price does not actually mean that it can be taken away, it is more like a "near-term" futures contract that can be delivered in 10-60 days (Dunn and Holloway, 2012). Futures contracts can be for delivery in a period of three, six, nine, twelve and eighteen months or whenever those purchasing can take delivery.

Until the 1980's most oil was sold on the basis of long-term contracts and as such the spot market was not considered to be of great importance. Non-OPEC producers then undercut long-term contracts and gained market share in the process by selling on the spot market. Consequently, oil sold on spot markets increased from around 10% of the market to over 50% by the mid-1980s (Haubrich et al, 2004). The increase in spot market activity allowed oil companies to benefit from the spikes in prices that long-term price fixing contracts prevented. The increase in spot trading and the volatility meant that a futures market evolved to enable market participants to balance risks that may affect them in an adverse financial way (Haubrich et al, 2004). Kaminska (2013) believes that the spot market has been undermined by the need for long-term financing and consequently the volumes transacted on the spot market have declined. The level of capital required to develop an oil field is considerable and with companies operating on a global scale will resort to external financing via securitised bond and loan markets. That is, the borrowing costs are lower if the end product can be sold on a contracted long-term basis to an offtaker, refiner or distribution company. This means that the time horizon of sales has moved from on the spot, being around 40-50% of physical sales.

KSA (Hume, 2014) via its state-owned company, Saudi Aramco, sells oil on long term contracts to refiners all over the globe. In order to reflect the latest prices, it informs its clients of loading prices based on three key benchmarks, and then a differential is applied to this which can be above or below the reference rate. The price paid by the importer is then adjusted for this differential. The reference rate for exports to Europe is based on Brent Weighted Average in Europe, sales to the Americas based on the Argus Sour Crude Index and sales to Asia based on the aforementioned Dubai/Oman average price. The monthly differentials are keenly watched by the market as they indicate Saudi pricing policy, although whilst these differentials are noted they are not pivotal. There is no explicit Saudi benchmark sold on an exchange, which perhaps reflects KSA's desire to trade on a longer-term basis and also to keeps its affairs/pricing somewhat opaque.

The derivative market has now grown into a Frankenstein's monster relative to its initial purpose. The growth of the importance of the futures prices in the global oil market cannot be underestimated but perhaps is overestimated. Many of those participating in the buying and selling of contracts have no desire/capacity to deal with the physical product. Their sole aim is not to manage risk but to make profit on arbitrage, prior to a futures contract delivering these participants will sell the contract to those who are able to take physical delivery.

It is here where we must make the distinction between “wet” and “paper” markets. The paper market is for speculators who trade contracts based upon the future price of oil that will never be delivered, whereas the “wet” market is for physical delivery. The purpose of the “paper” market is to provide a means of risk management for the oil market. It allows participants to mitigate their risks or simply speculate on the movement of prices.

This begs the question; do spot prices, the ‘wet market”, offer a more accurate barometer of true market sentiment?

How prices are formed is a key part of the oil market and the differing strategies of each of the market participants only adds to opaque manner in which prices are arrived at.

2.5.2 The Futures market

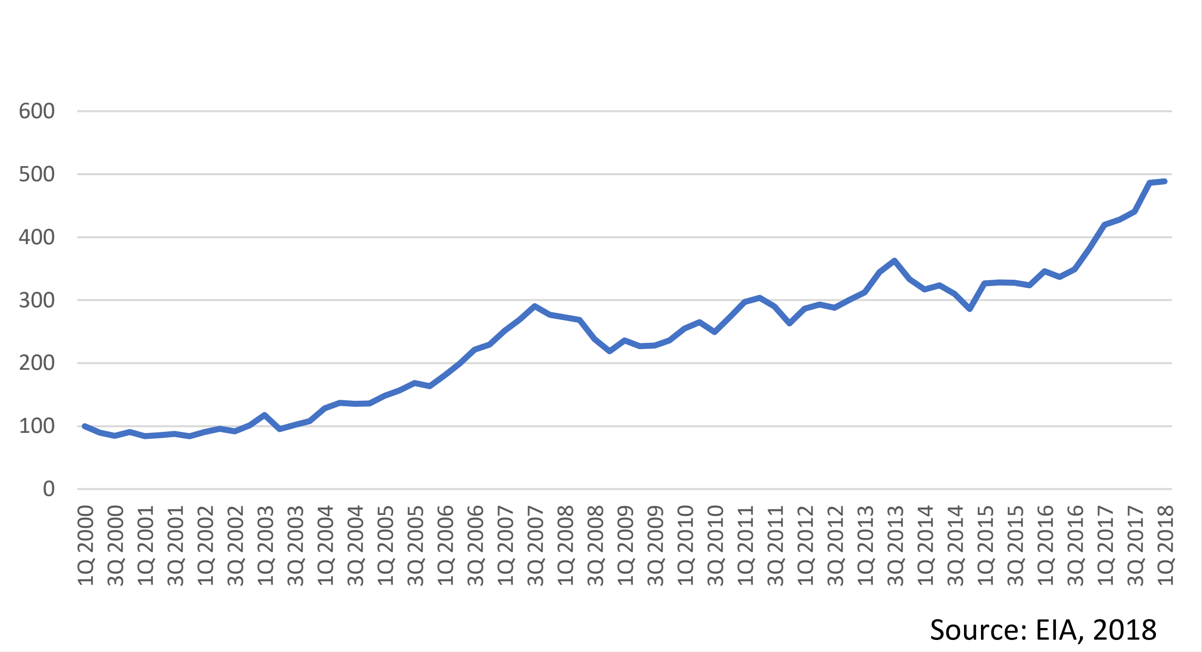
The futures market fulfils two functions, in that it allows participants to hedge and mitigate risk, and forms part of the price discovery mechanism (Figuerola- Feretti & Gonzalo, 2010). The oil market has many participants but perhaps there are two broad categories; financial traders who will arbitrage the market with no intention of taking physical delivery and market participants representing large buyers or sellers of oil looking to either cover shortfalls or hedge risky positions (Wang and Wu, 2013).

With futures contracts available over varying levels, three months, six months etc., short-term contracts are generally regarded where the speculative activity, the arbitragers and noise traders, takes place in the market with longer dated contracts linked more strongly to governments and oil company participation in the management of risk (Wang and Wu, 2013: Chang and lee, 2015).

The role and involvement of non-trade participants has grown in the oil market and coupled with this increased interest has been the number of derivative products that are offered (Fattouh & Mahadeva, 2012). Options, futures contracts are standard for most commodity markets but the exchange traded fund (ETF) has seen a growing number of those with no connection to the oil industry, become part of the architecture. ETFs are funds that invest in a basket of oil related assets ranging from the stock prices of oil companies to derivatives and futures contracts, these are then sold on in individual units and traded on markets such as the NASDAQ.

The links between oil prices and stock markets is a very well researched topic but many of these studies examine this impact from a macroeconomic point of view, with directional causality from oil price to the equity markets. There is another link that is worth noting, Fattouh and Mahadeva (2012) contend that financialisation makes oil prices more sensitive to changes in stock markets and hence more volatile.

Figure 2.3: Index of Average Daily Open Interest Contracts on US exchanges



Source: EIA, 2018

A measure of the activity in the futures market is the number of Open Interest contracts that are traded on exchanges where oils futures contracts are sold. Open interest are contracts or commitments that are entered into by buyers and sellers to buy or sell oil at a future date. Over a shorter period of time movements in this can be taken as an expression of where the market is heading with more contracts showing bullish sentiment and fewer new contracts on a daily basis indicating bearish sentiment. As we can see from figure 2.3, is the level of participation in the oil futures market, based on quarterly data, is increasing at pace.

Speculation plays an important role in the price discovery process in oil markets, especially if we consider that longer dated contracts are principally the domain of oil companies. This provides the market with a long-range forecast by participants in possession of asymmetric information, production data etc.

The growth of the futures market is not without challenges. Evidence suggests that the role of financial speculators, in addition to commercial traders, playing the futures market has increased volatility in global oil markets. The fundamentals of supply and demand, Cifarelli and Paladino (2010) find that adverse movements on a daily basis in many instances bear no relation to a market driven by fundamentals and one driven more by speculative models. Indeed, as they note *"speculatively driven high prices can persist for a considerable time before fundamentals bring them back into line"*. Furthermore, it has been shown (Qadan & Nama, 2018) that investor sentiment in this era of financialisation and non-trade participants via vehicles such as ETFs, has an impact on the price of oil and increases volatility. The increase in prices from 2000-08 was largely blamed on the increased financialisation of the market and yet there is little in the way of empirical evidence to suggest that this was anything other than emerging market demand boosting prices (Fattouh et al 2013, Baumeister and Killian, 2016). However, in the wider commodity markets literature, some researchers feel speculation can also reduce volatility (stabilising) and also play an important role in improving liquidity thus allowing easy entrance and exit from the market.

The increased financialisation of the oil market poses questions for those who seek to study and predict its behaviour. A substantial segment of the market has no interest in physical delivery of the underlying asset, the growth in derivative products and speculation adds another dynamic into what is already a crowded explanatory market place.

Contango and Backwardation are situations where the spot and forward prices are out of line with each other. The former, contango, is when the spot price of oil is lower than the forward price, or one month's delivery contract is lower than the next months. This can happen for a number of reasons but using the period of 2014-16 helps illustrate the phenomena. Due to lower prices of oil many market participants bought oil and stored it in facilities across the globe. As this availability of storage space dwindled, producers in the market were forced to cut prices as demand was low and those looking to buy oil to benefit from future increases in price had nowhere to store the physical product. Hence the spot price traded at a discount to the forward price as in the future expectations were that demand would recover and storage concerns would ease as stocks were run down. In principle this is the same phenomena that attracted considerable attention in the initial phase of the Covid-19 lockdown when the market price became negative, not because of the lack of demand (which did factor) but primarily due to the lack of available storage space. The price of storing oil in the sample period has played a significant factor in the relationship between spot and forward prices and was especially acute in the market for WTI oil, when a 20% premium on holding oil in storage forced oil majors such as Shell to lease tankers on one-year contracts as floating storage facilities (Cornell, 2015). Backwardation is the opposite scenario. Essentially, spot oil prices trade at a premium to forward prices. The recovery in prices in 2017 resulted in spot and futures prices deviating as markets predicted that prices would ultimately fall with increasing spot prices leading to increased production and supply at some point in the future. This would then lead those who had bought oil when the spot price was lower than the futures price to sell as there is no longer profitable to stockpile (Raval, 2017).

2.6 Global oil market – key players

This section examines the dynamics of KSA supply and the role of OPEC particularly after 2014. It also examines the US production phenomenon and how producers have remained producing despite sharp declines in the globally traded price of oil in the period 2014-2018.

2.6.1 Saudi Arabia and OPEC

OPEC is the Organisation of the Petroleum Exporting Countries. It now has 13 members, with Qatar announcing its departure in December 2018 (Economist, 2018), and controls 79.4% of global proven reserves (OPEC, 2018). KSA is the largest producer within the group and possesses the largest proven reserves (12.3mbpd). Within the group, this has given KSA greater leverage and gives it de facto leadership, thereby strengthening its' influence on the global market.

The reason to band together, into what many detractors would term a "cartel", is to stabilise the market whilst providing a suitable return for its members (OPEC,2018). It does this through the manipulation of supply to achieve a desired price, rather than through overt price setting. That said, there is a measure of debate over the role that KSA plays within OPEC. The extent that collusion and the strategy behind these moves is adhered to and other members taking advantage of KSA's willingness to stay on message by flouting supply agreements.

2.6.1.1 Is OPEC a cartel?

KSA's and OPEC's ability to manipulate the global oil market has been the subject of scrutiny since the 1973 oil embargo. Many studies have examined the market structure and the extent to which OPEC and its most powerful member, KSA, have used oil production to their own strategic ends. According to Cairns and Calfucura (2012) KSA does exhibit some price making behaviour which could be strengthened through its membership of OPEC membership; however, OPEC's actions do not show it operating as a cartel in the truest sense.

OPEC's historic manipulation of supply, inventory, has allowed it to exert a significant influence on real oil prices but this power may vest with the discipline of its de facto leader. KSA, as has been noted throughout, yields considerable market power, around 12% of global oil production (IEA, 2016), how it responds to changes in supply and demand has traditionally been significant in determining global oil prices. As Behar and Ritz (2016) have noted, OPEC behaviour "is a mix of near collusive episodes and subsequent non-cooperative breakdowns". There are limits in terms of what OPEC can and cannot do to enforce production quotas (Mann, 2012). There is no means of enforcement or supervision to ensure compliance and therefore the organisation has relied upon KSA to be the balancing factor or 'swing producer". Studies by Huppman and Holz (2012, 2015) contend that had OPEC operated in the truest sense of a cartel then oil prices during the commodity super cycle would have been greater than the spikes of $143 a barrel. Golombek et al. (2018) present evidence that over the period 1986-2016 OPEC operated in a dominant firm role; whilst interesting, the study does not break the period down into phases that where the impact that OPEC and Non-OPEC production has had, with the question of how this dominance changes from the beginning of the sample period to the end. This is a crucial oversight for determining the power of OPEC and KSA in the modern era.

Colgan, (2014) notes that KSA's membership lends weight to OPEC rather than KSA gaining extra leverage from OPEC membership. This back up previous research into the competitive structure of the oil market.

Alhajji and Huettner (2000) contend that we should see the global oil market as a dominant firm model, it is not a cartel, it is a market that responds to production and supply decisions of one entity, which is not OPEC but KSA. It has the largest reserves and is among the largest producers globally. Almoguera et al, (2011) find evidence that the oil market is characterised as a Cournot model of competition whereby each producer arrives at their production decision independent of each other, but simultaneously. In essence decisions are made based upon what the producer thinks its competitors will do. A key element in the theory is the inability to collude. Whilst this seems somewhat contradictory given the nature of OPEC, the empirical evidence from this seminal study indicates few periods of collusion over a 30 year period, 1974-2004, and a greater level of competition than could be expected in part due to a small, but growing, "competitive fringe" of non-OPEC producers.

2.6.1.2 Is KSA a swing producer?

Given its spare capacity, KSA, is able to respond quickly to prices to either dampen increases by flooding the market with excess supply or cutting production to boost prices in a falling market (Fattouh and Sen, 2015); this entails effectively increasing or decreasing production in order to stabilise global oil prices (Westelius, 2013). It can quickly swing its increased production in behind the strategic direction of price, hence the term "swing producer". KSA's dominant position within OPEC ensures that it adheres to the plan. With leadership comes responsibility, that is has had to act to stabilise prices whilst others within OPEC.

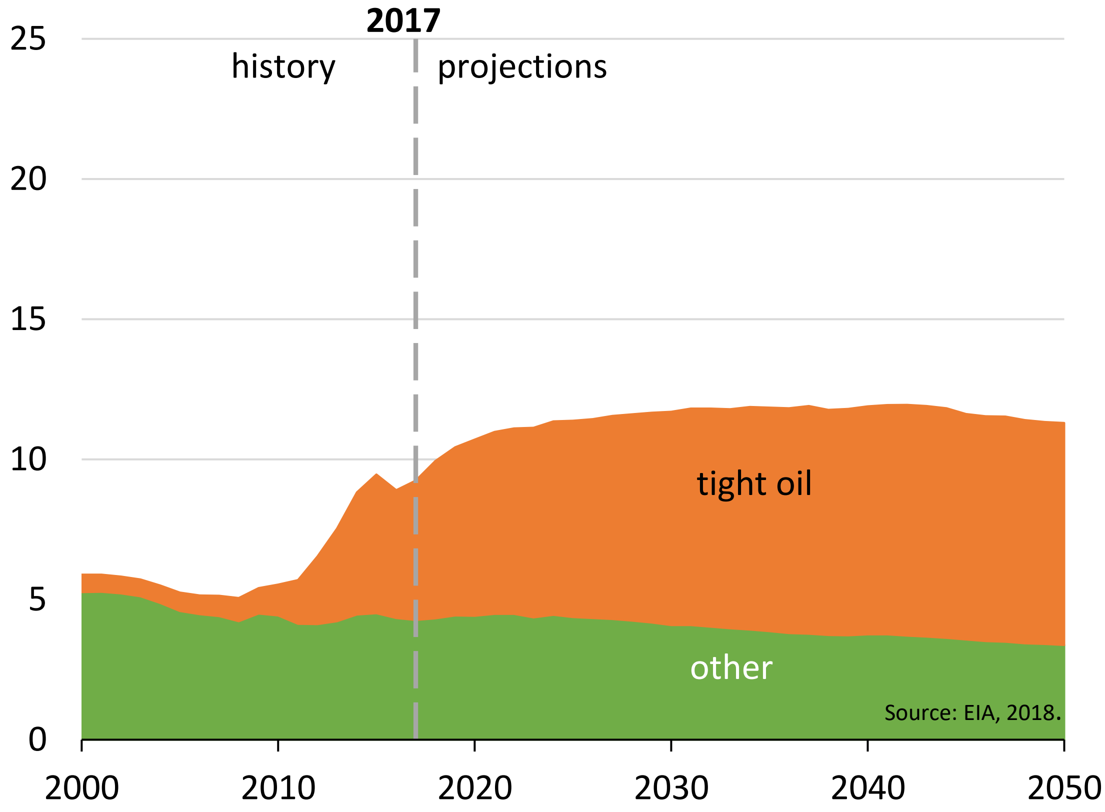
This role is the subject of debate (Smith, 2005; Mabro, 1998; Griffin and Nelson, 1994) with studies ranging from little in the way of evidence of KSA as dominant or swing producer or caveats to the idea acknowledging KSA practice in certain periods. Fattouh and Sen (2015) point out that KSA output is negatively correlated with other OPEC production which would indicate that KSA has provided some form of balance, brake or support, to oil prices whilst the other members do what they want.

Mu (2020) suggests that KSA could use its dominant position to exact a toll on those members of OPEC, or indeed wider agreements, who break or flout production cuts in support of price. Simply KSA could produce more and force prices downwards, but wouldn't this also hurt KSA? As Mu (2020) also notes this would also inflict pain on KSA and recent evidence, the 2014, price fall, suggests that this policy of swinging production levels behind a policy direction has had limited impact. McNally (2014) suggests that KSA has powerfully signalled to the market since 1985 its reluctance to act as swing producer and as such the 2014 '"no cuts" policy to bolster prices should not have been a surprise. Indeed, US LTO producers may now fulfil part of this role due to its break-even dynamics (McNally, 2014).

2.6.2 US oil production and changing role in world oil market

As previously noted, the USA is now a major producer on the global oil market having been a significant consumer in the popular firmament for many years. Its, relatively smaller scale, exploration and production companies have tapped into the changes in technology and buoyed by high oil prices in the first decade of the century, raised capital to use this technology to great advantage in the energy rich rock formations of North Dakota and Texas. Modern 3-D imaging technology has revealed the previously unknown scale of the deposits to be of a magnitude far greater than previously thought.

Figure 2.4 Projections of US oil production

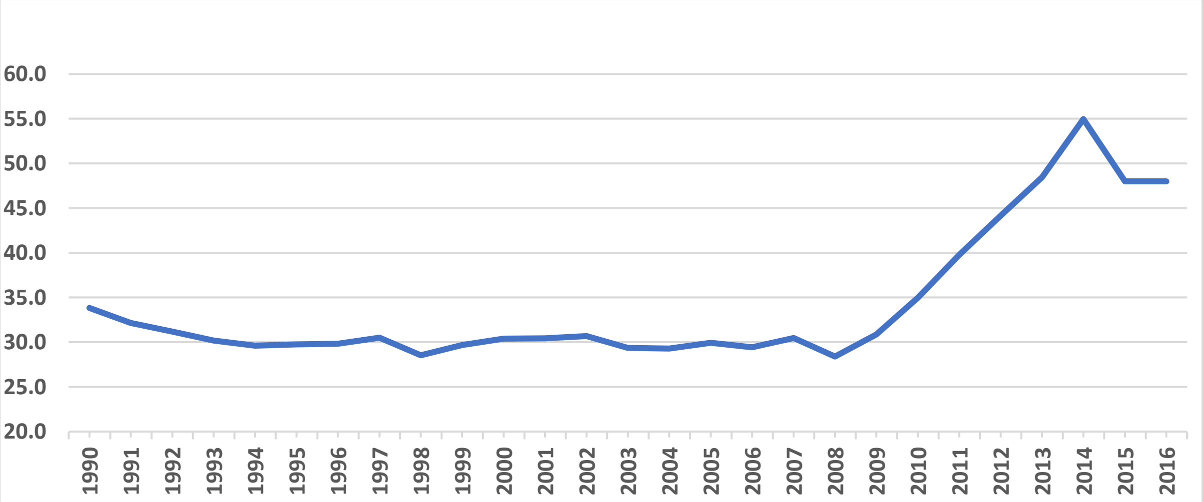


Source: EIA, 2018.

As evidenced by Figure 2.4, the impact of new technology that enabled increased LTO exploration and production has resulted in a paradigm shift. At the millennium US production was concentrated in mainly conventional sources of oil but increases from 2010 onwards have come from the growing LTO sector. The EIA (2018) forecasts no change in this respect between now and the middle of the century with LTO increases more than compensating for declines in conventional production.

Global oil markets have had to factor in a shift in oil market fundamentals and dynamics. Not only is it the increase in production of US LTO production that has led to change in market dynamics but the temporal focus of vast proven and unproven reserves in US rock formations may be the longer-term harbinger of change. The IEA has forecast that between 2018-23 that US LTO will account for greater than 50% of supply increases, a 3.7mbpd increase (IEA, 2018). US production has already pushed through projections made at the beginning of the LTO boom. There are differences in forecast from BP, which includes gas to liquids as part of its projections through to the very conservative projections of the EIA relate but leaving the semantics aside the trend is clear, US production is greater than even the most aggressive projections of 2014 when LTO became a significant factor in the global oil supply story. By 2050 the US EIA (2018) has forecast that LTO production will be in the region of 8 million barrels of oil per day, accounting for 70% of US production.

Figure 2.5: US proven reserves, billion barrels



Source: BP.Com, 2017

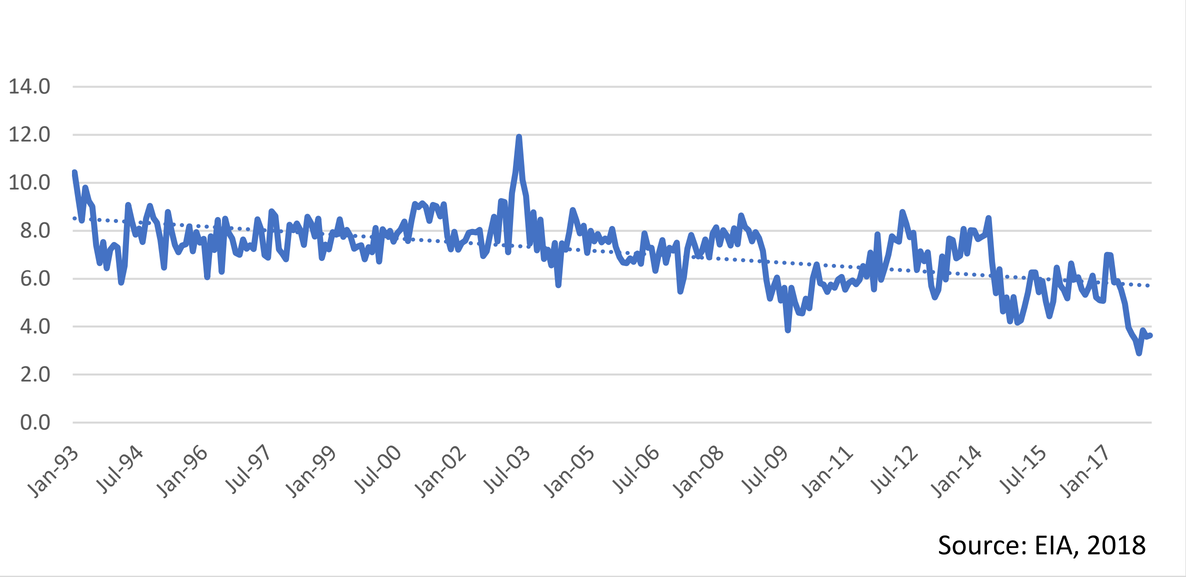
From this we can confidently predict that US LTO will play a major role in the global oil market in the short, medium and long term. Revisions to the future and the potential scale of US resources has a limited impact on current oil prices but in the period relating to this study it is the displacement of imports to the US that has had the greatest impact on the market globally. However, the removal of the export ban on US crude in 2015 the discussion is already growing in relation the disruption caused by US exports.

The strategic restrictions (ban) on the exports of raw crude were out of place given the scale of LTO production, therefore the ban on the export of crude oil, imposed by Richard Nixon following the OPEC oil embargo in 1973, was lifted by the Obama administration in 2015. US producers were finally able to export raw crude, having previously been limited to selling refined products on the global market. This changes the dynamics of the global oil market over the longer term with US producers now able to access and impact foreign markets and consequently influence prices. Exports have increased since the ban has been lifted, prior to this the US was only able to export crude to Canada which was not covered by the ban. Now the US exports its crude to staging posts in the global oil supply market, Curacao, the Marshall Islands and the Netherlands awaiting transfer or blending with other blends of crude with the final destination hard to account for (EIA, 2016).

The removal of the crude oil ban allows US crude to compete on international markets against other blends of crude of similar quality.

Initially the surge in US production displaced the imports of oil, mainly from West Africa, despite that US refining capacity was not optimised to refine US LTO. The majority of the refineries in the US, predominantly in the Gulf of Mexico, were unable to process this lighter crude as they were calibrated to refine heavier crude imports, mainly from KSA. This led to the US producers (Killian, 2017) circumventing the exportation ban by refining then exporting the final product, gasoline or diesel. This in itself may be indicative of the leverage/impact that KSA/OPEC supply decisions had on the US oil market. To some extent this issue of refining capacity optimised for the light sweet crude that US LTO has not completely abated with storage and refining capacity important dynamics in price discovery.

Figure 2.6: Saudi Arabian Imports as percentage of US Consumption



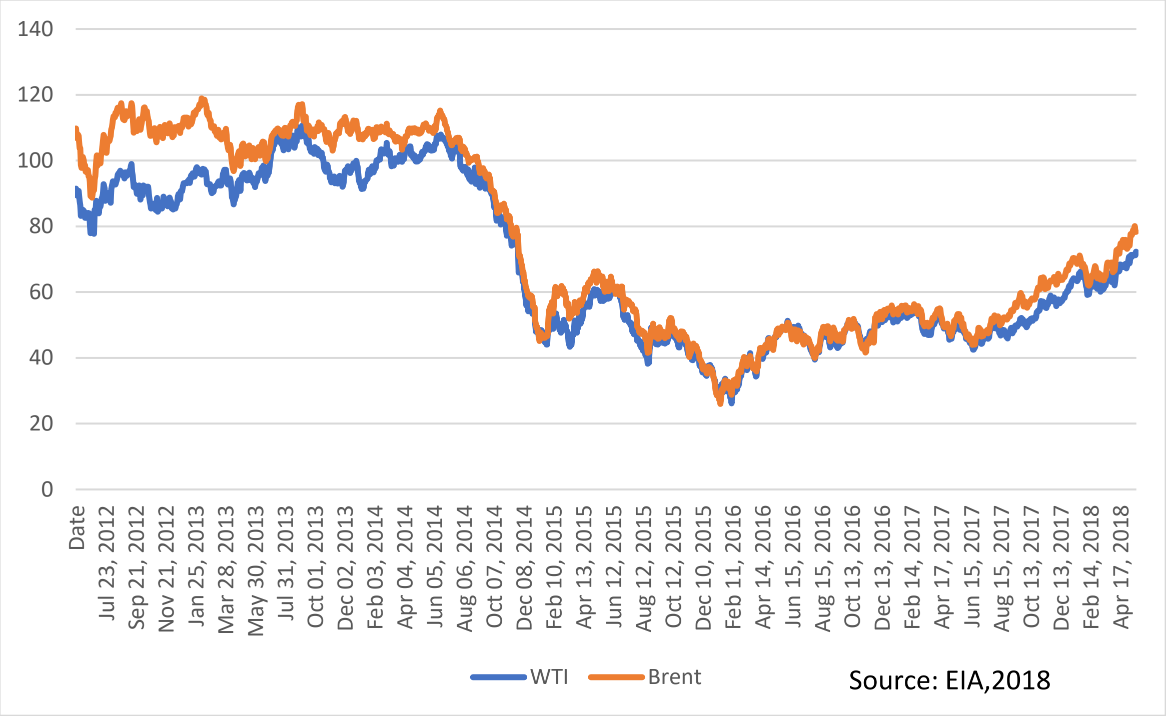
Source: EIA, 2018

Bottlenecks aside, the displacement of imports in the US market is clear to see. In Figure 2.6 the level of exports from KSA to the US is clearly shown to have been in decline for some time. KSA imports now account for less than 4% of US consumption. Using the US Energy Information Administration (EIA) data the level of exports as a proportion of US consumption is broadly in line with 1990s levels of around 50% but significantly down on early 2007 levels when imported oil accounted for almost 70% of US consumption. US production has eased this and now has the potential to impact global supply patterns.

The recent performance of the US supply market has been witnessed a complete turn-around in a relatively short period of time. The trajectory of US LTO production has seen the US go from being a large net importer, to the displacement of foreign imports and now onto the export market.

2.6 Oil Price Volatility

Figure 2.7: Brent/WTI Spot prices



Source: EIA,2018

As can be seen in Fig 2.7, over the six-year period of this study the spikes and slumps of the global oil market are evident. The period from 2012-2014 is evident for Brent trading at a premium to WTI followed thereafter with the two global benchmarks following each other as prices slump then regain some, but certainly not all, of the territory that had been lost with the market reaction.

Volatility in the global oil market is not a new phenomenon, spikes and crashes are evident in price charts over the last 50 years. The last ten of those fifty years have been momentous, increases well beyond $100 a barrel followed months later with precipitous falls that have market participants scrambling to update their post-event narratives, future forecasts and trading positions.

There have been two substantial falls in the price of internationally traded crude oil since 2008. The first sharp fall in oil prices occurred in 2008 followed the near collapse of the global financial system and the spectre of global recession. The second steep fall occurred in 2014/15 when the price of benchmark US crude, West Texas Intermediate (WTI), fell from $105.25 per barrel in July 2014 to $42.03 in March 2015. The 2008/9 price collapse was demand driven due to the global financial crisis but the drivers behind the 2014/15 decrease in prices are the subject of debate. What we do know is that the response of KSA to the market dynamics is something that market participants and observers have debated vigorously.

McNally (2016) contends that prices being stabilised through various swing producers with the dynamics of the market aligning to some geopolitical economic goals. He continues that since 2008 the global oil market has entered a period of marketisation and with that comes increased volatility. Importantly he notes, "*when oil supply and demand are unbalanced and no supply regulator is present, oil prices should range between a floor defined by the cost of production and a ceiling defined by economic pain".*

The shifts in the price of oil have been debated throughout the literature, with analysis focussing in on different periods to examine the causal relationships between the some of the factors outlined here and the eventual price of oil. The period prior to the financial crash in 2008 is of particular interest in the literature. Studies (Killian and Murphy, 2011) have downplayed the role of speculation and financialisation in that period with increasing demand and stagnating supply being cited. Juvenal and Patrella (2011) highlight the importance of demand, with 45% of the oil price fluctuations in the period from 2003-2008 caused by demand shocks. This chimes with Golombek et al (2018) and the 30-year study of the oil market which finds that GDP is the main driver of global oil prices. The period from 2014 is relatively simple to characterise, with supply being the prime driver behind the fall in oil prices. The price of oil is volatile but whether this is the result of the increased activity of non-trade speculators is not conclusively answered.

2.9 KSA/OPEC Strategy 2014

How KSA and consequently OPEC, responds to changes in the oil market is amply covered in the academic literature through to the popular press. The nature of OPEC and the KSA's role within it, leads to a number of accusations with regard to a cartel and price fixing, albeit through supply. Studies by Smith (2005) suggest that strategic concerns play a role in determining OPEC members' production levels, whereas non-OPEC producers are more responsive to economic variables when setting production (Kaufmann et al., 2004). Kaufmann et al. (2007) suggest that oil prices should not be thought of as a consequence of OPEC behaving like and oligopoly or a dominant firm within an oligopoly but as a consequence of political and strategic decisions within OPEC member states.

Perhaps the shock of 2014 was that a decline in price of the magnitude in 2014 would inevitably provoke KSA and OPEC into a response, but not the one the market expected. The received wisdom was that the KSA/OPEC response, to falling oil prices has been to cut supply to boost prices (Hochman and Zilberman, 2015) so why would the strategic response be any different in 2014? As Maugeri, (2016) noted in regard to the fall in oil prices from 2014 onwards, *"Finally, in November 2014, they (oil prices) collapsed when Saudi Arabia essentially imposed a policy of no production cutbacks on the Organization of Petroleum Exporting Countries (OPEC)".*

What is undisputed, is that KSA confounded the market in 2014 by announcing production increases rather than cuts to production in support of global prices. This response was counterintuitive, production was ramped up rather than scaled back. Production exceeded OPEC's 30mbpd target as KSA, UAE and Iraqi production increased (EIA, 2015). Rather than act as the swing producer, as in the past, and curb its own supply to boost price per barrel, KSA increased production slightly to approximately 9.71mbpd in 2014 from 9.63mbpd in 2013 (OPEC, 2015). It led most observers to question exactly what KSA and OPEC's strategic objectives were.

KSA's policy is deliberately opaque and there will always be conjecture regarding its motives and desired outcomes. The schools of thought range from the geopolitical with not defending prices to impact pain on its long-time rival Iran, to cost-centred arguments with KSA using its superior cost structure to predatory price US LTO producers from the market and impact its financing as it is a highly leveraged sector.

The November 2014 decision did mean shrinking profits for KSA and other OPEC members but in the US it led to the mothballing of LTO production and debt defaults as prices fell below where the market considers the LTO break-even to be, but the impact was ultimately limited. This would seem an obvious target for KSA strategic policy to eliminate at source the threat posed by the US LTO "frackers". Using superior cost advantage, if this indeed was the strategy, could result in some pain for the US LTO market with lenders being hit.

KSA strategic thinking (Maugeri, 2016) viewed the impact of no supply cuts and no cessation to planned investments in the medium term as a pain game that it could endure, whereas supply cuts to increase prices would hand important strategic advantage to its competitors inside and outside OPEC. There is a recognition that KSA would endure pain but not to the same extent as its competitors and that eventually the competitors would submit and the market rebalance in line with KSA's strategic aims of defending its dominant position. The work of Cairns and Calfura, (2017) gives the sense of KSA pursuing a calm rather than being a knee-jerk strategy. Their view is that the market demand and supply conditions dictated the decision not to cut and defend market share policy. In the face of declining global oil demand and slow global economic recovery the decision to increase supply was less limiting competition from US shale producers than KSA's own short-term needs. Doubts persist with the structure of this argument. The strategic options open to KSA/OPEC with the advent of US LTO as a market contender was "accommodate" or "squeeze" (Behar and Ritz, 2016), essentially share more of the market with the new unconventional producers or use the cost advantage to remove them from the market. The latter of the two inevitably means that the price of the underlying commodity has to fall in order to achieve this which if we accept this provides a more than plausible motive for KSA's action.

This however is a debate that will not recede. Recent studies, (Baumeister and Killian, 2017) cast doubt on the retaliatory nature of KSA's actions. There are irrefutable elements demonstrating KSA's market power, the vast quantity of its proven reserves, its cost structure with beneficial break-even differentials relative to US production. That said, Baumeister and Killian (2017) contend that the dynamics of the oil market were shifting prior to 2014, that a series of supply and demand shocks were being priced into the market hence the fall in price. The cause and effect sense of US producers being priced out by KSA is compelling but, in their view, needs to be downplayed in order to examine more prosaic facts.

Baumeister and Kilian (2017) using empirical data propose that oil prices would have declined without the increases of US production, that the 2014 price decline was due to a slowdown in the global economy which global oil markets incorrectly forecast and that the OPEC announcement of November 2014 had not as much bearing on the global price as one would think. That said, chapter 5 of this study presents evidence that suggests we should not downplay the impact of the KSA/OPEC announcement.

McNally (2015) contends that KSA's behaviour is entirely predictable as it had warned OPEC members it would not support prices and it saw US LTO as a brake on prices. US LTO producers may lack the resources of KSA producers or the ability to bring spare capacity to market when prices rise but the dynamics of this market "puts a floor on prices" by virtue of its inability to break even below the $50b. Falls below this level would be uneconomic and force many US LTO producers from the market thus reducing supply.

The fixation with KSA and OPEC strategic moves stems from the chaos of the OPEC oil embargo in the 1970s, but much has changed on both the supply and demand sides in the intervening years. The scale of change is such that it should lead to a critical revaluation the idea of a dominant KSA exercising market power in the wake of the post 2014 price collapse. Subsequent market movements have proven that if KSA's strategy has been to price either the US producers from the market and/or protect market share then it has not entirely succeeded. Inevitably with a shock experienced in 2014 a degree of post-hoc rationalisation is entered into, with writers claiming that the writing was on the wall or the moves by KSA were entirely predictable. This does not ring true with the sentiment at the time, this was shock that few in the market foresaw.

2.10 US Resilience

Increased efficiency and consolidation within the US sector meant that the collapse in price did not impact the US LTO sector in the manner anticipated. US LTO producers did leave the market but perhaps not in the numbers anticipated suggesting a greater degree of resilience. Despite the differentials in cost structure between conventional oil and US produced LTO with benchmark prices at $40b US LTO producers managed to remain in business. By early 2016 US LTO (IEA, 2016) production held firm at 9.0mb/d, whilst a decrease, it was clearly not the predicted reset and overall US production continued to increase year on year. As time elapsed it became clear that US LTO producers had become comfortable with the new price dynamics putting further pressure on KSA and OPEC. In September 2017, US crude oil exports, (Raval, 2017) despite the impact of lower benchmark prices hit a record 1.5mbpd and since the relaxation of export restrictions in 2015 the US had become a significant presence in the export market, overtaking some OPEC producing nations. US LTO oil competing on international markets against product from KSA, OPEC and non-OPEC producers such as Russia.

The US LTO sector is highly leveraged requiring capital to explore and produce but the price collapse of 2014 did not result in long-term loss of appetite for investments in the sector.

Financing of the sector appeared almost immune to market oil prices. Lending covenants on loans to the sector were relaxed to such an extent that in 2015 the US banking authorities were so worried that banks were told, in secret, to apply the conditions of loan agreements to the sector and call in the non-performing loans (Tett, 2015). Cumulatively, the 60 largest E&P companies in the US burned through $9bn per quarter and a racked up a debt of around $200bn, on average during 2012-17.

This is not to say that problems did not persist or that the price collapse did not negatively impact the sector but there was a willingness by investors to continue to lend to the sector. As we can see from the charts below, figures 2.8 and 2.9, the scale of the debt problem increased throughout 2010-2015. Investors were not immune to this deteriorating financial position priced the risk accordingly, especially throughout 2014 when the price declines hit hard (EIA, 2015). The need for cash to service debt was such that between 2015-2017 firms in the US LTO raised external finance in the form of equity, some $70bn, has been used to pay down debt and yet despite the deteriorating financial position investors continued to lend to this sector of the market (Economist, 2017).

Figure 2.8: Deteriorating financial position of US LTO producers

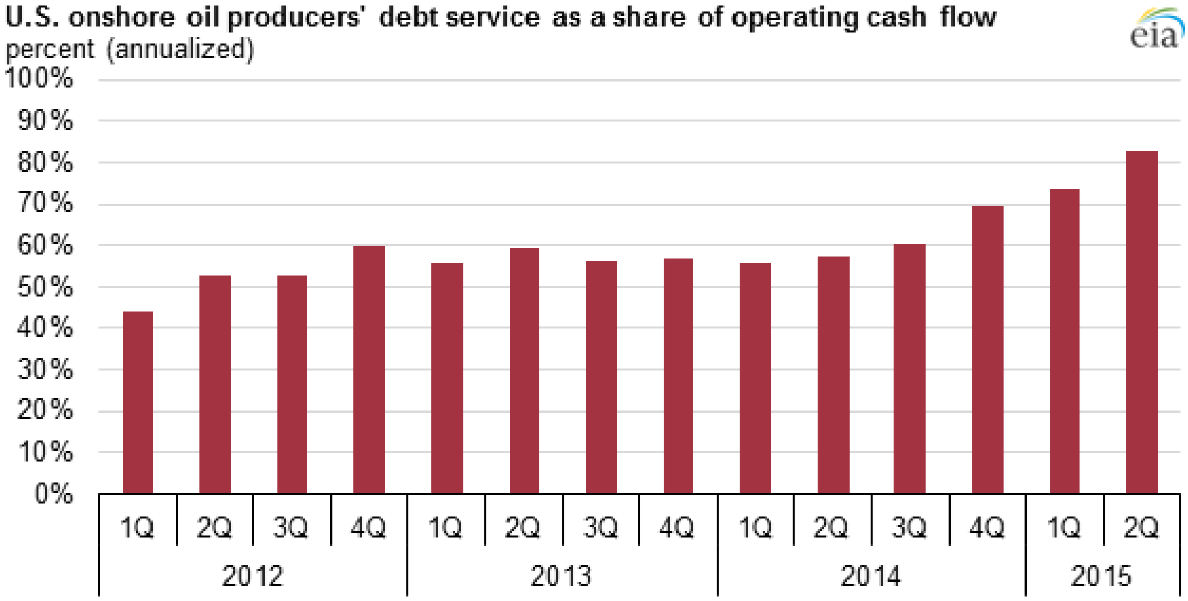


Figure 2.9: Increasing risk of US LTO debt

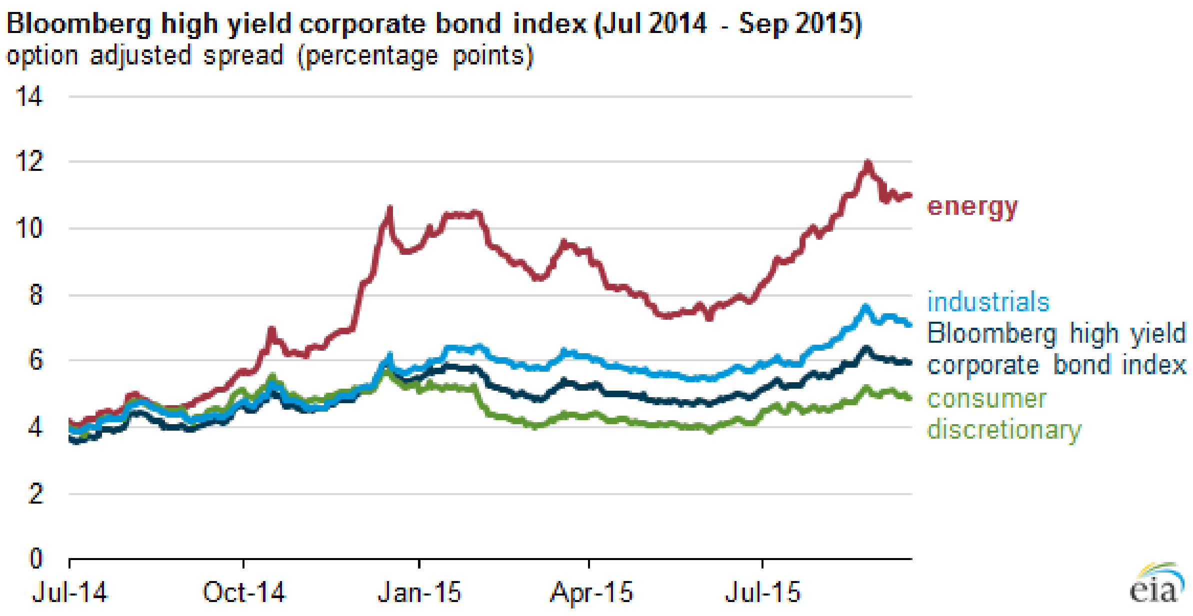
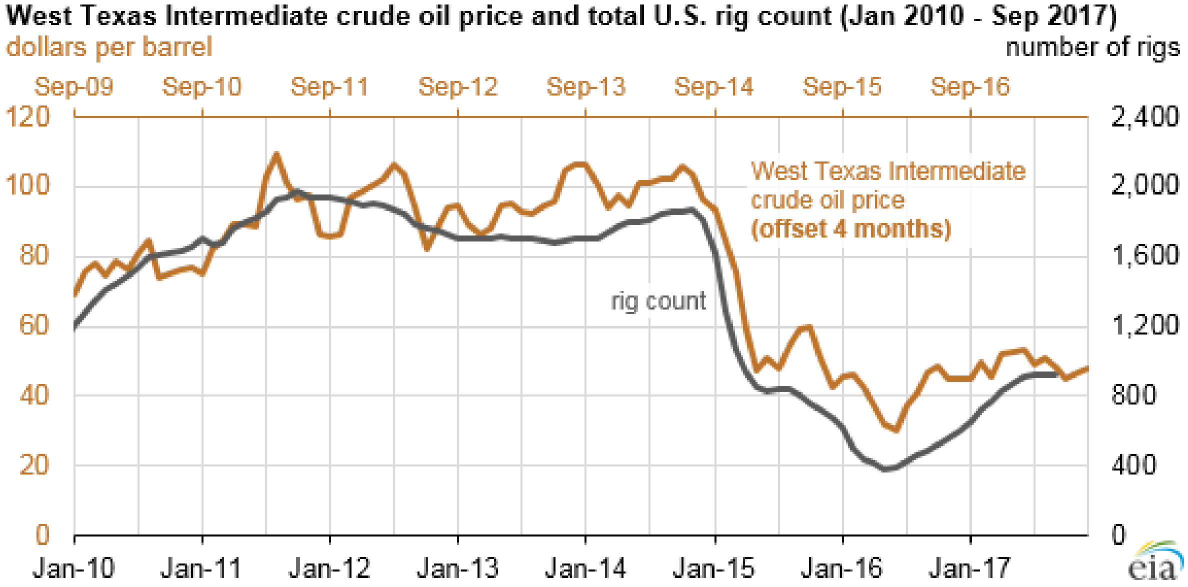


Figure 2.10: WTI and US operating rigs decline



The number of rigs in production in the US was adversely affected. The rig count is published each Friday by the US oil services group Baker Hughes (Terazono, 2015), recording the number of rigs actively in production. It is generally considered a barometer for the health of the US oil drilling industry. It is clear from the Figure 2.10, produced by the EIA, that the relationship between this count and the level of the benchmark WTI, is a positive one, and as prices fell from mid-2014 so too did the number of rigs in operation.

There is no doubt that this period was challenging for US LTO producers but by 2016 and a muted/stuttering recovery in prices underway the financial picture had improved. The financing gap between operating cash flow and capital expenditure had fallen to $10bn for the sector as a whole, down significantly from a the $25bn estimated in quarter one of the same year (EIA, 2016).

Whilst, many small-scale producers had gone out of business, their drilling rights however were sold to more solvent companies. The sector, overall, remained viable by adopting a number of strategies, (Killian, 2017, Curtis, 2017); cutting back on production, adding new wells at an accelerated rate and mothballing older wells as due to the high depletion rate in production in the first years of production the newly minted wells provided increased cash flow, concentrating drilling on areas considered to be prime (that is those with high levels of proven reserves and likely to provide a high return to the cost of drilling in terms of output) and by shaving efficiencies from the oil services contracts. The IEA (2017) estimated that cost savings were significant in the US LTO sector with an average fall of 30% in 2015 and further 22% in 2016. Fluctuations in oil prices above the $50 level allowed US LTO producers to sell their product on forward contracts ranging up to 18 months (Raval, 2017) thus guaranteeing future cash flow.

In all this, the resilience suggests that if the intention of KSA's strategic decision in 2014 was to eliminate competition by leveraging its superior (lower) break even cost then it did not have the desired effect. It may have created a more potent competitor able to survive at extremes. If allowing the market price to fall further was an actual strategy then it was abandoned when the OPEC meetings in 2016 led to a joint communique with Russia announcing the strategic shift from maintaining/increasing supply to curbs to support a higher oil price.

2.11 KSA Strategy post 2014

KSA's publicly stated policy of not defending oil prices in 2014 did not have the desired effect. Oil prices increased slightly, some US producers exited the market, but the strategic gambit of defending market share did not appear to pay off and may have rebounded. KSA (Raval, 2017) lost market share in 9 of its top 15 markets. If anything, it increased the competition from established exporters. Russian, Nigerian and Angolan oil sold at a discount, as those producers who like KSA overwhelmingly rely on oil revenues for their economies, entered some of KSA's traditional markets.

The announcement of production cuts that took effect at the beginning of 2017 were seen as acceptance that the 2014 strategy had failed (Economist, 2017). The deal involved KSA and most other OPEC producers to cut production by 4.6%. Notably this agreement included a commitment by the Russian government to cut production.

The IEA (2017) placed an interesting spin on event by claiming that the period 2014-17 was a "great experiment" and that the moderate increase in prices coupled with KSA and Russian announcements on oil production cuts to support global prices illustrated that "market management is back". The "pain" that Maugeri (2014) referred to the point of the 2017 production cuts had been quite considerable. The IEA (2017) estimates that export revenues of OPEC producers were approximately $450bn in 2016 compared to $1.2trn in 2012 before US LTO came onstream in a substantial manner.

The bottlenecks that dogged US supply as it struggled with its production boom have become more manageable. There are, however, some signs of the longer-term implications. The idea that the importation of heavier and sour crudes from the Persian Gulf to Asia is insulated from what happens in the market for lighter crude is being challenged. US refiners have stretched capacity in terms of the amount of lighter crude that can be refined. That the excess is now being exported and Asia is one of its main destinations. The EIA (2019) estimates that US exports could increase to 6mbpd by 2024 from their 2018 level of 2mbpd. Markets for US oil are in Europe and Asia.

Politics is never far from the fore in the global oil market. The imposition of sanctions on Iran and Venezuela by the Trump administration have had a knock-on effect that turn the market convention on its head. The production of heavier crudes from these countries has left those refiners of heavier crudes buying up product across the globe which means that the heavier blends trade at a premium to lighter blends, a reversal of the position given the more expensive refining costs associated with heavier blends.

2.12 Conclusion

A review of the global oil market demonstrates that a complex mosaic of supply and demand factors influence the price of oil. The global oil market is very dynamic, there have been changes on the demand and supply side of the industry since the beginning of this century that lead us to question the notion that KSA or any other significant market participant is unilaterally able to shift course in the global oil market to establish or maintain price within certain bounds.

A key learning from this investigation is that the global oil market is not a single entity. There are several markets orbiting this one commodity, of which there are several variants with qualitative differences. The prices reported in the financial press are but one part of the mosaic as are the off-exchange transactions reported through the Price Reporting Agencies.

On the demand side, emerging economies such as China and India have increased oil consumption as their economies develop. Against this is the declining demand in Europe and Japan. On the supply side, the emergence of the US LTO has had a major impact upon the global supply of oil. There has also been increases in production in other countries such as Canada, Mexico and Brazil. A full understanding of the global oil market should not be restricted only to the US and KSA oil dynamics, instead, it needs to take into account global supply and demand, stock hangovers, the value of the dollar, the supply infrastructure in key producer markets, changes in technology (cost of production) and the increasing financialisation of the market.

Chapter 3: Review of literature

3.0 Introduction

This chapter examines the extant literature in relation to the degree to which the global oil market is unified or cointegrated. This has important implications in relation to the assessment of the strategic changes that have taken place since 2012 in the global oil market. This chapter principally examines the extent to which global oil benchmarks are cointegrated, that is each benchmark mirrors the price movements of other benchmarks as they respond to price changes. With oil traded in many markets with a variety of blends examining the dynamics of this market and assessing its unity is central to the study. If the market is unified with each benchmark blend following or leading price movements of others this would suggest that strategic production decisions by large producers could amplify outside their own markets and affect other benchmarks thus imbuing those large producers with significant market power.

If the market can be described as unified, then an examination of how those benchmarks and cointegrated relationships is necessary given the level of change in the market.

There are three points that should be borne in mind when considering the extant research. Firstly, the literature breaks down into two broad categories, technical and market oriented. In the former category there are a number of papers that concern themselves more with the application of a specific technique or specifically a modification to a technique. The oil and commodity markets offer a data rich environment in which to apply (modifications to) econometric techniques. There is a second type of academic paper which is less skewed towards the examination of technique and more to an examination of the oil market. In keeping with the central theme of this study, it is the latter that resonates more but where the technique is deemed to be significant in terms of the message of the oil market then then there will be some discussion.

Secondly, this examination demonstrates that much of the existing literature is mainly based upon studies conducted when oil prices were rising, although this is changing somewhat. This means that many of the ideas we form regarding the behaviour of the oil market in regard to its unification are from empirical studies examining price movements in one direction, the dynamics following downward shift in oil prices have not received as full an examination as price increase, that said prices have been on the rise since the beginning of this century with a huge fall in 2008 and recovery towards 2014.

Finally, the new dynamics of the oil industry are not adequately captured by the existing body of research. As explored in chapter 2, US LTO production has ushered in a new dynamic into the market. This means that many of the salient points from the areas of literature that this chapter will explore need to be considered against this backdrop. That said, many newer studies do include this period in their samples, but the emphasis would seem to be on the longer term and the analysis does not single out this particular period, 2014 onwards, for special investigation which is interesting given that the events of that year or indeed some of the variables examined in this study.

Thirdly, market behaviour must also be considered against the increasing financialisation and speculation and the realisation that many market participants neither seek physical delivery of the commodity nor use the futures markets to cover short positions but simply look to profit from arbitrage opportunities prior to delivery dates.

3.1 Benchmarks

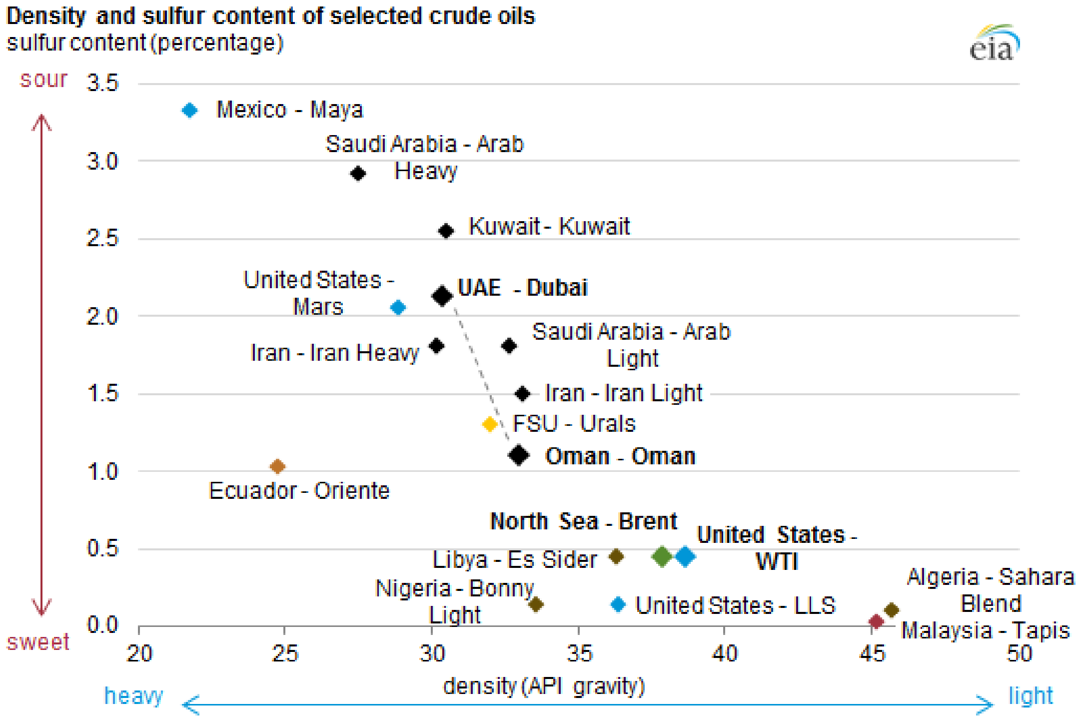
The oil prices that make news headlines are in fact a relatively small group of blends that act as reference or benchmark for buyers and sellers across the globe despite the fact that there are several hundreds of blends of oil and close to 160 traded crude oil streams of different varieties of oil pumped across the globe (Fattouh, 2010). Whilst a US importer could be buying oil from Nigeria, the transaction may be referenced against Brent which is a blend of oil from the North Sea in Europe. The many varieties of blends of oil are referenced to a handful of oil benchmarks which concentrates pricing power in a very small number of global blends (Bhar et al., 2008). There are no hard and fast rules for each transaction but it is more likely that the benchmark used in any given transaction would refer more to the inherent qualities of the oil (Hammoudeh et al, 2008) rather than its country of origin, although distance is a factor, with some blends, Urals Mediterranean, the transportation costs are included, see section 4.18.5. There are two important factors when it comes to pricing different grades of crude oil. Firstly, its quality, the principal measures of quality are gravity and sulphur content which can represent a significant premium or discount to producers. The second factor is the proximity to refining capacity. The further away the more it costs to transport which obviously adds to the cost (Bacon and Tordo, 2005).

The main global benchmarks are Brent oil, which is traded predominantly in Europe, West Texas Intermediate (WTI) traded on the US markets. The Dubai blend is the main middle-eastern benchmark for trade principally into Asia. To see this blend as a measure of KSA's influence on the global oil market would in many ways be wrong as KSA plays its cards very close to its chest. Saudi Aramco, the state oil company of KSA uses three reference prices depending upon where the oil is being sold to (Dunn and Holloway, 2012). Oil sold in one market, Europe, may use Brent as its reference price whereas that sold into the US may use WTI or the Argus Sour Crude Index (ASCI) as its benchmark. ASCI is a daily composite price of three imported blends into the US market and reported daily by price reporting agency, Argus Media. It does use a combination of the Dubai and Oman blends for transactions into Asia. Brent is still regarded as the global benchmark but with Asia becoming the world's largest import market, and China the largest importer of oil, then the Dubai crude contracts may have gained greater weight as a reference point for others with KSA and other gulf states using it to price Asian exports (EIA, 2014).

If we pick up on the qualitative aspect of crude oil, whilst it is drilled all over the world it varies in quality and the rule of thumb is that lower the quality then the more it needs to be refined before it can become an end product such as petroleum (Fattouh, 2008. Dunn and Holloway, 2012). The global oil benchmarks, previously discussed, differ in quality with sulphur and API gravity being the key differentials. The general yardstick being the higher the sulphur content and API gravity then the more involved the refining process before the raw crude can be sold for commercial use which adds to the production costs (EIA, 2014). WTI is a 'light, sweet crude" with a low sulphur content and a fairly high density and therefore requires less refining. With crude oil being sought after, in the main, for transportation fuel and heating then WTI due to its sweetness and gravity yields higher levels of transportation fuel and less heating oil relative to other blends, Brent in particular, and therefore should trade at a premium (Milonas and Henker, 2001). The differentials between blends are important yardsticks for the market. Pricing differences between blends represent arbitrage opportunities, once other costs have been overcome, the cost of transporting oil from one regional market has to be borne in mind as does the refining capacity and cost required to turn it into a useable product, commonly referred to as thresholds, and the price of the end product it can be refined into (Fattouh, 2011).

The majority of tight oil from rock formations that has signified the boom in US oil production is of the light sweet variety. The graph below, Fig. 3.0, illustrates the inherent qualities of the different grades of crude. As evidenced WTI is lighter and sweeter than Brent and many of the blends sourced in the Persian Gulf.

Figure 3.0: Oil benchmarks: Sulphur content and API gravity



(Source: EIA, 2014)

The evidence points to the popularity of Brent as a means of pricing and referencing. Indeed, major oil companies use the price of Brent as their reference point when project planning investments and calculating rates of return (Bossley, 2017).

This may in part due to its reliability in recent years. Whilst there are proven disparities in the different grades of crude that should see consistent differences in price, there are infrastructural issues relating to WTI (Wlazlowski et al, 2011) that can see its price trade at a discount or an increased surplus to Brent depending upon the market that it is traded on and consequently affect its role as a benchmark. These price imbalances relate to the fact that Brent is a seaborne crude, which can be easily shipped and it therefore not as prone to the same logistical bottlenecks as a land borne crude such as WTI (Dunn and Holloway, 2012). This makes Brent more reliable as a global benchmark to reference against hence its role in many trades. Given the changing dynamics of the market and the rise and rise of WTI as a benchmark and its, arguable, de facto "swing" status (McNally, 2016) the question is for how much longer Brent can be taken as *the* global benchmark? That said, as Fattouh (2010) points out the pricing of WTI at times dislocates from other markets in that its price does not reflect the global demand and supply balance but more the logistics of the US supply network. This is a point that is amply supported by the data in this research.

3.2 Cointegration of oil benchmarks

This section refers to the econometric technique/phenomenon cointegration, a full discussion of this can be had in section 4.9. In order to assess the extent to which these benchmarks blends have a long-term relationship, suitable methods must be selected in order to produce meaningful research insights. A significant proportion of the research that has been conducted into the influence of oil benchmarks on each other has looked at the extent to which the global oil benchmarks are cointegrated. Part of the challenge of examining the oil market and how the blends interact is that there has historically been no dominant price setter, that is a blend that can affect other blends but is not affected itself by movements of the other blends (Kuck and Schweikert, 2017).

Cointegration (Johansen, 1988) refers to a method of examining the manner in which two or more time series variables follow the same path. The use of cointegration techniques are common place and there is a wealth of empirical evidence to prove the suitability and efficacy of these models. It must also be noted that much of the literature that relates to oil, cointegration and ECM seeks to establish links between oil prices and other commodities. There is also a significant body of literature that relates to the cointegration of oil prices and stocks returns across many global markets. These relationships may be significant and important to study but by not focussing in on the interplay between blends of global oil the interplay between suppliers and demanders in a key element of the oil story is being overlooked.

The rationale for previous work in this area has been the potential arbitrage opportunities between different types of crude oil sold on the global markets. If there is a 'law of one price' (Samuelson, 1994) then then market price for one type of crude oil will adjust to movements in the price other benchmarks? (Bentzen, 2007). Otherwise this would present significant arbitrage opportunities for oil market participants. A cointegrated global oil market results in a differential between two or more benchmarks that holds over in the long term. That the long-term differential should reflect the differences in transportation costs and the costs of refining. Any significant deviation from this long-term pattern would present traders and market participants with an opportunity to make increased profit by buying the cheaper blend of oil. This is considered to be a short-term activity as ability to make this increased profit will attract others to the market thus increasing the price and competing the arbitrage opportunity away. Should the prices deviate from this long-term equilibrium relationship then this is known as a structural break which indicates the establishment of a new equilibrium between the benchmarks.

There is consequently an important debate regarding the extent to which global oil benchmarks move together. If there is a difference between the benchmarks and that price that is the oil market globalised or regionalised? Testing for a unifying relationship between these global crude oil benchmarks is important in assessing the impact that they have on each other and the power that dominant players in the market can exert.

The idea that the market moves as one or the “one great pool” notion of the global oil market was first put forward by Morris Adelman (1984, 1992). Weiner (1991) contributed to the debate by arguing to the contrary that the global oil market was in fact regionalised, evidence which was partly based on transportation costs and distance to market, thresholds in effect. Rodriguez and Williams (1993) rejected this using Johansen’s cointegration to show that between the period of 1982 and 1992 that there was evidence of global oil prices and a “homogenous world oil market”. Ji and Fan (2016) used correlations between the world’s oil markets. Their approach demonstrated that oil market shows increasing signs of globalisation with prices moving together due to the increase in flow and availability of market information. This, they contend, heightens the risk of global power and contagion from one market to the next. Gǜllen (1997, 1999) found evidence that global oil markets were cointegrated, but crucially, for the purposes of this research, that similar types of crude oil do move together with stronger evidence that this was the case when oil prices increased.

3.2.1 WTI/Brent

The relationship between WTI and Brent is a key one that is thoroughly explored in the literature "Historically, WTI traded above Brent by about $1.5–2 per barrel, roughly the cost of moving oil from the North Sea terminals to the refineries located along the US Gulf Coast". (Kaminski, 2014). Wilmot (2013) believes that the widening spread between global benchmarks, Brent and WTI, weakens the idea that the market for oil is globalised. Liao, Lin & Huang (2014) study the spread difference between WTI and Brent and present evidence in support of the globalisation hypothesis of the oil market. Reboredo (2011) found relationships between the major benchmarks was bi-directional, that they influence each other and by using OPEC reference rate as a benchmark in the study showed that OPEC was influential in setting global prices. Moreover, this study whilst raising the possibility of a diminishing role for Brent and WTI as a growing global benchmark, was conducted over the period 1998-2004 when the market was moved by fear of peak conventional oil and supply unable to keep up with burgeoning demand. As important as this study is there is a need to bring this up to date in order to reflect the new market dynamics which have radically altered the supply side of the industry and catapulted the US from chronic oil dependency to potential oil supremacy.

This should, ultimately, have an impact upon the price of the crude oil benchmark, West Texas Intermediate (WTI), this has traded at a discount to the international blend, Brent, but given its superior quality, it should trade at a premium. Market observers believe that this should lead to a change in the long run price differential between the two blends (Medlock, 2015). Arguably WTI's long term significance is being a global benchmark and not just an indicator of US supply and demand, especially as export restrictions have been lifted. There are, however, some significant aspects of supply that still affect the use of WTI as a reliable global benchmark.

The price spread between WTI and Brent is informative when considering the stability and ultimately stationary/nonstationary nature of the relationship. Since 2010 the WTI Brent spread, the pricing difference between the two benchmarks, is increasingly volatile (Chen et al., 2015). This in line with the bottlenecks around the Cushing supply hub in Oklahoma, USA, that have persisted at various times throughout this decade. This then provides further need to examine the level of cointegration between these two benchmarks and to examine breaks in the relationship in terms of duration and tie them, if possible, to pronouncements regarding to supply problems in the US system or if they signify a structural change. The volatility of the relationship between these two global benchmarks reinforces the requirement to reinvestigate the cointegrated relationship between the two blends, moreover Fig 2.7, Chapter 2, further illustrates the changing dynamic between the two with WTI initially trading at a discount to Brent then then from 2014 onwards the differential between the two tightening.

3.2.2 Cointegration with other blends

Since the work of Adelman (1984) many studies have been undertaken examining the relative price movements of global oil benchmarks, in order to test this idea out the idea of global integration under different market conditions and with different qualities of crude oil have been examined. In effect widening the empirical study beyond a simple examination of the WTI/Brent nexus to include other grades of crude oil. Bentzen (2007) uses cointegration and error correction modelling to assess pricing differences between different categories of crude oil based upon their inherent qualities. The study, in line with Gùllen (1997,1999), found evidence of a global oil market by comparing the movements of Brent, WTI, Dubai and OPEC reference prices between 1987 and 2004, moreover it highlighted a growing influence that OPEC had on setting prices. Again, the influence of OPEC should be re-examined given the shifting dynamics.

In contrast to the above findings Fattouh (2011) Kaufmann and Banerjee (2014) found that differences in the API gravity and sulphur content of oil produced differences in behaviour. The latter found that these differences decreased the likelihood of cointegration between certain blends. Their studies suggest that oil markets are regionalised, or segmented, based on the different qualities of the oil. The availability of new technology may lessen this differential as refineries are able to process different qualities into final products which again hastens the need to update the literature.

The established relationships in the market, WTI-Brent-Dubai provides valuable insights when studied but when the literature expands beyond the principal blends it offers the chance to examine the cointegration of other, more regional blends. Bhar et al (2008) found a high degree of correlation between blends such as Brent, WTI, Dubai/Oman and Maya, a heavy sour Mexican blend. Which whilst does not prove cointegration it does lend some empirical weight to the “one great pool” idea of the global oil market. Wilmot (2013) did find that regional blends of crude oil with similar qualities, those from Canada etc., were cointegrated and contended that for “globalisation” of the oil market to be true then there should not only be a long run relationship between the major blends but also among the regional blends such as those in his study.

An examination of the level of cointegration between five global benchmarks, WTI, Brent, Dubai/Oman, Tapis from Malaysia and Bonny Light from Nigeria, a major input into US and European refineries by Ji and Fan (2015) examined the level of cointegration across these blends over a fourteen-year period, 2000-2014. Their study indicated periods when, due to the supply constraints discussed in chapter 2, WTI was not cointegrated with the blends in the study. This is significant as it adds to the growing evidence that whilst WTI may create headlines that there may be a potential question mark regarding the extent to which it moves in lock step and responds to the same signals as other blends. That said, the causality looks to be predominantly one way with fluctuations in WTI prices a significant contributor to the volatility of the other blends. It also points to a market that contains a structural break. Over the period from 2000-10 the evidence presented by Ji and Fan (2015) suggests that there is cointegration between the blends but from 2010 the picture changes with WTI less in step with other blends, this coincides with the period WTI was widely considered to have decoupled from the global market is consistent with the findings of this research. In terms of causality the study finds that prior to 2010 WTI acted as a price setter but since then this role has vested more with Brent. In terms of the other blends in the study the Tapis has always reacted to other prices, that is in economic parlance, a price taker, but the Dubai/Oman and Bonny Light have switched back and forth from price take to price setter over the course of the study.

3.2.3 Thresholds and persistence of shocks

The speed of adjustment to shocks within the cointegrated relationship is an aspect of the literature that receives significant attention. In essence when modelling a long-term relationship between the blends the slightest deviation is rapidly corrected and the long-run equilibrium is restored. The evidence suggests that a quick re-establishment of the long-term relationship may not always be the case.

Fattouh (2011) examined the dynamic nature of price differentials and how markets corrected and whilst lending weight to the idea of “one great pool” some interesting differences were uncovered. Firstly, that the differentials between the different blends, including different categories, exhibited stationarity, which points to a long-run relationship between the blends used in his study. Using blends classified as heavy, medium and light in the model it was found that when the blends of oil possessed a similar sulphur content and viscosity then the dynamic relationship between the two blends was quite different to that between blends that were unrelated quality wise. The differences between different blends only reverted to the long run differential when certain thresholds had been crossed, namely the costs of transportation and refining. Where the blends of crude were broadly similar and there was an active futures market the differences exhibited error correction characteristics with no threshold effects. Borrowing from the VECM literature, the errors from any long-term equilibrium would correct as this would present arbitrage opportunities for traders which would move price back into line so that the opportunity no longer existed. If we regard the cost of carry and the differences between refining and transportation costs as threshold then there is cointegration when these thresholds have been crossed (Wang & Wu, 2013). Essentially, the markets are cointegrated once the difference in price is greater than the threshold cost and arbitrage is profitable.

The differential and threshold effects are taken up in the work of Mann and Sephton (2016) who find evidence of, threshold, cointegration between WTI and Brent and WTI and Dubai blend. The use of this technique allows them to build pricing thresholds into the model. These thresholds, that is, the differences between the transportation do exist in these global blends and when refining costs are outweighed by the divergence in price the arbitrage opportunities abound. Their research sought to answer the question of whether pairs of blends in spatial markets, i.e. those not in the same physical location, were cointegrated and which blend moved first in order to restore equilibrium. Their findings prove interesting in that all three of the time series moved to restore the long-run relationship a finding that they contend proves that there is no overall global blend. This is important as Brent has been widely regarded as being the global pricing blend. The gap in their research that is not addressed is why there was no investigation of a cointegrating relationship between Brent and the Dubai blend.

Certain issues affect the move back to a long-term equilibrium. Odemir et al. (2013) discovered there is an issue with persistence with non-stationary time series. By this we mean the extent to which shocks to the system last, or persist. By analysing Brent spot and futures periods over a twenty-year period, 1991-2011, they found that shocks were persistent, especially when structural breaks were not fully taken account of. However, even when these were accounted for shocks demonstrated persistence. What this may mean for the study of cointegration is that the restoration to the long-run equilibrium may not be as instantaneous, or linear, as theory would suggest. It may suggest regimes in which there is partial correlation.

The thresholds can be seen in the differentials between blends, if these blends were all identical the differentials would be minimal. Whilst the techniques and the relationships between the blends in the study by Plante and Strickler (2021) do differ from those employed in this study their findings are nevertheless important. The differentials between blends of stronger and weaker quality as they denote it, that is high yielding and low yielding crudes, has narrowed over time and that the arbitrage opportunities have decreased. Their study looked at the time period 1997 to 2018, again not dissimilar to this study and with the increased technology in refining, the differentials between blends has narrowed. The change in refining capacity means that refiners have more versatile/complex capacity that can deal with a variety of crudes and therefore leverage and cost differentials they see in the market. The lack of arbitrage may also be the results of no real incentive to do so as the glut of US produced shale may mean that refiners, accustomed to buying heavier crude because of the cost, can now purchase a superior crude at a significant discount to past prices. The error correction process and cointegration of benchmarks blends in this study supports their findings. The impact of breaks in relationships between blends has also been examined in the literature. Plante and Strickler (2021) examining how the differentials between key blends have changed over time, 1997-2018 find visually that there is clear structural break in the data around 2007-2008, on closer econometric investigation they find that their benchmarks are all subject to structural breaks. This is not only the case when comparing crudes of differing quality but also in crudes with inherent similarities. Indeed, Luong et al (2019) find evidence of a break between WTI and Brent over the period 2010-2015 when the blends despite strong similarities are not cointegrated.

3.2.4 OPEC

A study by Ghassan and Banerjee (2015) shed some light on the response of OPEC and non-OPEC blends to price shocks. They find that the price of a barrel of oil produced in both an OPEC and non-OPEC producing country exhibit a long-term relationship, that they both adjust to, over a period of fourteen years, 1997-2011. The study finds through the VECM structure that the causal direction is from OPEC to non-OPEC and that in the adjustment process is slower for OPEC produced oil than its non-OPEC counterpart. This may be in no small part related to the fact that the majority of the oil produced by OPEC producers is sold on long term contracts that are likely to reflect price movements in the global market at a more glacial pace than non-OPEC oil. For students of the oil market the classifications of OPEC and non-OPEC are not discussed in any depth which leaves questions regarding which benchmarks were used, were they of similar qualities and is there an active futures markets in these blends?

Reboredo (2011) contends that if oil markets are indeed truly global or regionalised then it has an important political and economic consequences. If it is the former, then this idea lends itself to the idea that a dominant producer, such as KSA, could exert its influence by manipulating supply to pursue its global strategic aims. This influence has been found in numerous studies, (Bockem, 2004; De Santis, 2003) with KSA and OPEC dominant. With the changing dynamic of the global oil market, Asian demand and US production there is room for further testing in terms of how the shifting dynamics have affected those blends associated with OPEC and the Persian Gulf.

3.3 Causal relationships in the spot market

In the academic literature this is known as the “lead-lag”, in short which blend leads and which blend lags. A causal relationship between variables is where changes in one variable has an impact upon others. From an econometric perspective we examine those variables that independent or causal and those benchmarks we could consider to be dependent.

The causal direction from WTI and Brent towards other blends was illustrated by Wlaslowski et al (2011). Importantly their study, where blends were marked upon their price setting and price taking qualities, found that the main two benchmarks, Brent/WTI, had an overwhelming price setting ability but did exhibit a small degree of price taking behaviour, which is no surprise but the role of Dubai/Oman and the Mediterranean Russian Urals blend were noteworthy. They found no real evidence that the Dubai/Oman blend displayed much in the way of price setting ability on the world market, Russian Urals Mediterranean, contrastingly, exhibited very strong price setting ability, on a par with WTI.

The reasoning for this is that WTI and Brent are high quality, low density crudes. In pricing medium to heavy crudes that lack the qualities of WTI/Brent then Mediterranean Russian Urals seems to provide the market with an adequate benchmark that is actively traded, unlike the Dubai/Oman blends which are not as active, that said the lack of an active futures market for

Mediterranean Russian Urals makes this result curious as an active futures market provides that an important price discovery function that tends to accompany a significant global benchmark. These findings are worth dwelling on for a number of reasons but some caveats have to be built in, firstly the test was carried out examining data, based on weekly spot prices between 1997 and 2006. Given the changing dynamics extensively dealt with in chapter two, how much can we rely upon the salient points from this research given those changes? Secondly, the development of the futures contract in the Dubai/Oman benchmark may enhance its price discovery properties and thus that of the blend overall thus changing its ability to set prices globally in this new era.

However, the importance of Russian Urals Mediterranean in this study is key. Many of the studies are narrow in the sense that they concentrate on a small cluster of variables. Many studies focus in on the US market and the different blends sold and their relationship to WTI. Russian oil fuels Europe and Asia yet its blends are infrequently used in studies relating to the oil market. This is a significant omission, especially given the results outlined above. It is therefore one of the contributions that this study aims to make with the inclusion of Russian Urals Mediterranean in the models.

The degree to which oil prices move, co-move and react to each other was tested by Kuck and Schweikert (2017) over a near 30-year period, 1987-2015. Examining WTI, Brent, Bonny Light, Dubai/Oman and Tapis – a Malaysian blend that is predominantly used as a benchmark in trades in the Singapore trading hub. The research found that in times of increased volatility or economic uncertainty that there was a stronger degree of cointegration, they also find that Dubai/Oman blend plays an important role as "price setter" over the period and that studies of global benchmarks should not be limited to the WTI/Brent axis.

The causal link between WTI, Brent and the ASCI, the reference price for exports from KSA, Kuwait and Iraq to the US market, was explored by Coronado et al. (2017). The important aspect of this study is the time frame covered, June 2013 – October 2015, as this includes the period when KSA confounded market expectations by increasing production in response to falling prices. The study, using modified Granger causality tests, found that changes in the price of WTI and Brent affected each other, bi-directionally, but the prices on the ASCI had no causal impact on the prices of Brent or WTI, but Brent and WTI did affect the ASCI. This is very important to note as the benchmark that KSA uses to price imports to the US and the conduit through which it could affect US prices demonstrates little or no impact of the price of the US benchmark, WTI.

Candelon et al, (2013) test for causality among regional oil blends during periods of extreme oil price movements. They found that during these periods that regional oil markets are less integrated. Their study splits pairs in terms of quality, gravity etc. of oils and finds that Non-OPEC blends dominate, more precisely WTI and Brent are prices setters when price movements are up and down, which is in line with expectations given the high level of speculation and the depth of these markets.

3.5 Price Discovery

The use of spot price data in this study is one area that may potentially go against the received wisdom of the market and the some of the academic literature. The process of price innovations or discovery is said to be more prevalent in the futures market where sentiment regarding the long-term future of the market is priced into contracts. According to Hasbrouck (1995) price discovery (PD) is the "the impounding of new information into the security price". In global commodity markets with contracts being traded on spot and futures markets the price discovery mechanism is complicated but it should not detract from the fundamental issue "How do innovations in world oil prices enter the market?" (Kaufmann and Ullman, 2009). Is this through all benchmarks, both spot and futures markets, or a more gradual process where one or two blends see price innovations "towards which the prices of other crude oils equilibrate" (Kaufmann and Ullman, 2009). The challenge of price discovery in the oil market is that many trades take place off exchange and are conducted on a long-term basis. The role of Price Reporting Agencies (PRAs) is significant in overcoming this information gap. There is no compulsion to provide transaction data and the judgement of the PRAs in reporting end of day closing prices contains an element of subjectivity (Kuck and Schweikert, 2017), this provides a degree of opacity in the oil market that is lacking in the stock market. The evidence from empirical studies points strongly towards the futures market as the traditional area of price discovery, drilling down further on this the evidence regarding whether longer dated or shorter dated contracts provide the market with the signals that it acts upon.

The futures market does not feature in this study, all of the variables are spot prices, see section 2.5.1, be it those from an exchange or reported amalgamations of several blends of oil such as the OPEC basket. The ideas are nevertheless worth explaining and a full justification of variable selection can be found in section 4.18. Suffice to say that it is worth noting that the literature may point to the futures market as a source of price innovations yet there are still many issues that relate to spot market relationships that merit further study.

3.8 Conclusion and contribution to the existing literature

This chapter has brought together the salient points from research involving a number of interrelated questions in so doing it seeks to establish an overwhelming case to update the empirical evidence that relates to the levels of cointegration in the oil market. Including the main points from Chapter 2 it is clear that global oil market has changed significantly since 2010. The increasing dynamism from new technology and the discovery of vast deposits in parts of the world have altered many of the assumptions that have been made about the global oil market. The market has changed considerably from the 1970s, which is perhaps when OPEC power was at its peak and the other players in the market were also rans. Roberts (1984) characterises this period for non-OPEC producers when they were *"regarded merely as a passive agents in a market in which the pricing decision is beyond their control"*

This is no longer the case. The global oil market has changed markedly since the high watermark of OPEC power, the situation has evolved into a more competitive and consequently volatile price environment. This review of literature repeatedly posits the question that whilst the market has changed has the literature caught up and made sense of it?

The fall in prices from 2014 and the partial recovery from 2016 onwards presents the researcher with all of the key elements of the oil market in a four-year period. The impact of technology on supply bringing new sources of oil to the market, the response of dominant players in the market which confounds the market, the (alleged) attempt to price US LTO from the market vis the cost structure, the resilience of US LTO production followed by production agreements between OPEC and Russia that are redolent of the 1970s. This period is one of intense interest to students of the oil market, each day there is another aspect which feeds into price and sentiment. The market simply does not stand still and it is inherent in this research project to take that backward step and make some sense of these machinations.

Examining the cointegration debate it is clear that these changes have implications for the level of cointegration in the market, the degree to which the oil market acts as one and the speed with which it impounds new knowledge and information in a uniform manner. The availability of data in this information age would tend to suggest that the oil market like many other spatial markets responds quickly and yet there is a lack of up to date empirical evidence and what exists does not conclusively prove that the correction process is clear and instantaneous.

There are significant gaps in the existing literature where the coverage is neither uniform nor timely. A critical aspect of the extant studies is the market dynamics at the time of their studies. There are critical points further to the results of the secondary research, presented in this chapter, that are worth considering given the march of time and the changing dynamics of the oil market.

The extent to which other blends respond to changes in Brent or WTI needs to be updated since the US production pushed through to unprecedented levels, thus displacing foreign imports and the resumption of US exports. These are changes that are worthy of investigation.

The logistical issues and historical bottlenecks have beset WTI trade resulting in trading at a discount and then at a premium to Brent. This series of events would indicate that there have been breaks in the long-term relationships. The dynamics of the US market, its infrastructure principally, add to the volatility of WTI's relationship with other benchmark blends and as such it calls into question the notion of a cointegrated market. Given the effects that this has had on the market, and the fall in prices post 2014, the literature needs to be updated so that this changing landscape can be more accurately mapped.

The influence of the OPEC blend, or blends related to OPEC producing countries and specifically KSA, is similarly worthy of reinvestigation. The importance of the Asian markets and the significant volume of oil trades that are priced against the Dubai/Oman blend require an examination of the extent to which this blend(s) is cointegrated with not only Brent and WTI but other blends that are sold globally. Moreover, the causal direction of this relationship is of the utmost interest. If the market is truly dynamic then KSA may enjoy less market power than has been the case since de facto control of the oil market passed from the Texas Railroad Committee to OPEC in the early 1970s (McNally, 2016). This is indeed worthy of examination and any light that can be shed on the influence of KSA has on the oil market in this turbulent era, even through the cointegration of Dubai benchmark or the OPEC basket, will be helpful as we consider the role that oil plays in a post-carbon world and more widely, the shape of politics and economic development in the Persian Gulf.

The role that Russian blends of oil play in the global system and the extent to which they are cointegrated with other benchmarks does not receive as much attention as perhaps it should in the literature. The reasons for this may be historical, it may be the lack of available reliable data, no matter it is a gap in the literature that is noticeable. The chart displaying the levels of production in 2016, figure 2.2, perhaps provides as much justification as is required. Russia is among the top three producers globally and therefore its sales of crude oil will have an impact on other blends of crude oil. A shift in strategy by Russian producers, potentially at the government's behest, is likely to have implications for others in the market? Does the market pricing calculus factor in price levels of Russian blends? If this is the case is this at a regional level, i.e. within qualitatively segmented market or is Russian oil treated in the same way as Brent, WTI or Dubai/Oman, as a global influence?

The impact of financialisation and the non-trade speculators on the oil futures market has been measured in many ways but this study will examine the speed of adjustment to disequilibria. The growth of the futures markets and the influx of non-trade speculators to the trading world and the contemporaneous increase in real time data has perhaps altered how the market behaves. When the regimes for each blend are examined in chapter 5, an analysis of the speed of correction to disturbances in the long-run equilibria provides key measures that we assess in the context of increased financialisation.

Drawing upon the salient points of chapters 2&3, one final question that can be posed. The literature thus far provides circumstantial evidence and generally accepted facts regarding the power of a dominant player such as KSA. The cointegration literature provides evidence of a conduit through which KSA could influence the global oil market. KSA's influence has been taken as a given and there may have been no compelling rationale to interrogate this idea. With the final analysis it will be important to consider if the research output from this study can be extrapolated to consider the influence that KSA has over the market. In some markets this would be straightforward but in the oil market this is about circumstantial evidence. KSA is clearly a significant influence on the global market due to its production and proven reserves, moreover it is able to strategically harness the output of a block that controls 80% of global reserves. However, most crude oil transactions do not happen on an exchange, KSA does not have a (traded) spot-price benchmark price that would allow a researcher to work from, preferring to price form a number of international crudes depending upon the market. As a market leader this makes it difficult to precisely analyse KSA and its de facto leadership therefore we have to piece together elements from our examination and consider this question in quite general terms.

Chapter 4: Methodology

4.1 Introduction

In any research project there has to be a breakdown of what the research hopes to achieve, a justification of the methods that will answer the central questions, the data used and the time frame and frequency of the data. This chapter aims to provide answers to the how and why of the research proposition. The broad approach employed moves the reader from considering the abstract to the practical. Initially we consider econometric methodology from an ontological perspective, the nature of time series data is then considered, from a theoretical point and the chapter concludes on the practicalities of setting out the methodological roadmap for Chapter 5. The appropriate choice of method(s) allows the researcher to not only examine the interconnected relationships but also explore some subsidiary but nevertheless important themes.

The chapter provides a detailed analysis of the research methods employed, their suitability and mathematically lays out the principles of the models employed. There is a brief examination of the methodology employed in the literature and the proposed methods of this study are considered within this context. Practical aspects such as the time periods, variable selection, and the sources of the data too are discussed. The format of this chapter is as follows:

1. Provide the reader with an overview of the study and methods used
2. Examine the choice of method within a wider ontological debate regarding econometric methods
3. Examine the nature of time series
4. Outline and explain the choice/suitability of the methods employed
5. Discuss the variables
6. Establish the time periods of the study

4.2 Purpose of study

The aim of this study is to examine the extent to which relationships between blends of oil can change over time which may in turn signify strategic shifts in the oil market itself. This is particularly apposite due to the discovery of significant reserves in the US, the consequent increase in US LTO production and the, much debated, impact on the global oil market from 2014 onwards.

This study examines the oil market over the period 1996-2018 through the prism of the cointegration of global benchmark prices. The idea that prices move as one reflects the ideas that have been widely discussed in chapter three, this chapter considers the way in which the appropriate methodology can bring further clarity to this debate.

Using the methodological framework of an Autoregressive distributed Lag (ARDL) bounds test we are able to examine the interplay between the blends over a key period in global oil market history. This choice of model allows not only to test for cointegration but also to examine the interplay between blends, through the error correction process. This provides the framework to examine structural breaks in the relationships, the speed of adjustment to shocks and look for signs of dominance of certain blends over others via the use of Bai Perron break tests.

4.3 Ontological Issues

Econometrically this study focuses on time-series techniques and cointegration in particular. In any empirical work there is the narrow question of validity that can be tested by looking at the stability and predictive power of the results. There is also a wider question regarding the validity of economic/econometric research and its ability to truly capture the phenomena that it sets out to. From an enquiry of this nature stems the question of how the results of research are produced and to what extent can they be determined as valid and reflective of the oil market? The debate is a reflection of an ongoing one within economics regarding complexity versus linearity.

The nature of economic research has its critics, much of this relates to the nature of the assumptions that precondition the models constructed to make sense of the economic realm. This can range from the critiques that doubt the status of economics as a "science" and the criticism of the methodology where Måki (p3, 2001) highlights the criticism that economics is *"driven by methodological values that have little or nothing to do with the goal of delivering truthful information"*.

The ability of economics to capture what happens in the real world is furthermore the subject of debate. Dopfer and Potts (2004) note that the world of economics is comprised of actors, be it firms or organisations that are subject to their own level of evolving behaviour, there are agents and there are resources, all of this comes together in a complex weave where behaviour is emergent and attenuates to the actions of other actors. Traditional economic research sits itself very much within the positivist framework (Collis and Hussey, 2009) the researcher is apart from the process of investigation and discovery. The approach is very much deductive where cause and effect are studied which fits neatly with much of the econometric line of enquiry. This study conforms to this pattern of approach. That is not however to say that the researcher is not unaware of the criticisms that come with such a stance.

The reliance on mathematics as a means of deduction is one that provokes debate within the field of economics. As Lawson (2005) notes *"The truth is that modern mainstream economics is just the reliance on certain forms of mathematical (deductivist) method"*

As Hey (1997, as cited by Blaug, 2002) wryly notes with respect to the usefulness of some economic research *"Simply producing a model that comes up with a desired result is a test of the cleverness of the author, not a test of the relevance of the theory"*.

4.3.1 Ontological debate

The use of time series analysis will be discussed in depth in later sections of this chapter, but there is an ontological debate that considers the efficacy of using time series data as a means of establishing relationships between variables. The question that stems from this is the degree of comfort or predictive certainty that can be taken from past movements of data and phenomenological patterns as some sort of indicator of the state of the market in the present and in the future. The financial crisis of 2008 is writ large with the problems of basing predictions on historical price movements and co-movements of variables, be it commodities, in this case, or statistical default rates in the case of the US housing market crash. There is also an emergent strain of popular literature that is critical of economics (Raworth, 2017; Earle et al, 2017, Beinhocker, 2007: Chang 2014), the over-reliance upon mathematical models, the failure to predict global events and the post-event critique that sought to blame the real world and not economic theory for being out of touch.

This study does not seek to make predictions with regard to what will happen in the future in the global oil market. This study is not a normative piece of work in stating what ought to be or where the market is failing vis a vis an idealistic model of the oil market. It makes use of historical data as a means of assessing what ***has*** happened and to use the existing data to analyse the extent of market power and control in a period of increasing dynamism in the oil market where best it can.

The overt aim of this research has been well stated throughout but with respect to the ontological considerations there is a subtext to this study. The attraction of the oil market for many observers is the mix of economics, politics and history which makes it both complex and highly unpredictable. Capturing this in equation form is a difficult and possibly a futile task. That said, by using established econometric techniques in the study the ability to make statistical sense of what is an increasingly complex market can offer some insight into the market, especially in the period of increasing financialisation and greater availability of data. Whilst this study makes a very small contribution to the knowledge, it adds, in its own small way, to the debate regarding the fitness of purpose of traditional econometric techniques to deliver results that contribute to the collective understanding rather than, as previous writers have suggested, delivering results that justify the selection of the methodological techniques. There has been a move in the literature to deploy a variety of methods that reflect the dynamic nature of the oil market (Xiaoloiang et al., 2017; Du et al., 2013; Qiang and Fan, 2016). The issue with this type of approach is that whilst they propose newer methods of addressing the complexity, do they tell us anything new about the oil market? Or is it the case that the availability of data and the importance of oil makes it attractive but has this new line of enquiry advanced the understanding of the oil market in the same way as notable researchers within the field, Lutz Killian, Robert Kaufmann or Bassam Fattouh? Their work has done much to further the understanding of the market and its dynamics through the use of straightforward and easily understood, but potentially limited, econometric techniques.

The results from this research are taken not as a vindication of the methods that have been employed rather than using the tools that are common to the theoretical approaches. This research is not about the econometric intricacies of using oil market data in one's model, it is attempting to say something about the global oil market using a limited but appropriate range of econometric methods. That there are clear results from this study is testament to how the question has been framed. The oil market can be as simple or as complex as one would like to make it, as said in chapter 2 it is simple story of supply and demand at one level but at another it is a complex weave. The question at the heart of this sought to examine the market from a relationship angle and how those relationships were affected over time, especially in a time of extreme innovation.

That said, there should always be humility on the part of the researcher to acknowledge that this has been conducted to the best of one's knowledge using the best available data and whilst it may speak for certain aspects of this market it cannot speak for all aspects. One also has to be careful in extracting too much meaning from these results. They speak for the blends included but there are a great many other blends that for reasons of practicality and the parsimony of the model were not included. The study addresses the interaction of these specific blends which do present a reasonable geographical and strategic spread. Readers should also not lose sight of the real action in the global oil market happening off-exchange, the prices in this study broadly reflect these interactions and those of participants trying to cover physical shortfalls or surpluses at the last moment in the spot market. This study is simply one facet of the market which both reflects and informs.

4.4 Methodological overview

The model central to this study is an equilibrium model. What many econometric models do is examine the robustness of the model to dynamic change (Banerjee et al, 1993), this change can be from within or externally generated, endogenous versus exogenous. Central to these techniques is the ability of the model to produce reliable results that say something meaningful, an important element of this is testing the stationarity of the data and the presence of structural breaks within the data. These two concepts will be explained further but testing for these phenomena and the combination of the two, present the researcher with issues that are surmountable but do require further analysis and techniques that are less straightforward and routine than the notion of cointegration may at first suggest.

The methods employed seek to examine the relationship between the variables, how this relationship changes over time and how it responds to shocks. Taking the nature of the data, the potential for breaks within the data generating process is methodologically sound and based upon rigorous testing.

4.5 Time Series analysis

The econometric analysis of time series involves a specific set of methods that can, if used correctly, provide interesting and rich results. Testing for relationships between time series does not follow the standard econometric procedure for relationship testing between variables. The dynamic nature of time series means that standard regression analysis may show relationships where in fact there are none (Koop, 2013). When examining time series data, the researcher may encounter a trend, some seasonality and perhaps cyclical patterns all of which may mean that the dataset is non-stationary (Banerjee et al, 1993). This calls for the researcher to apply other econometric techniques to take account of the dynamic nature of the data but caution should be exercised as the correct method can move the analysis beyond sketching out simple relationships between variables. Variables may move together through time and whilst these time series themselves may be dynamic the relationship between them may be constant thus allowing the researcher to say much more about the data and the inherent relationships. It can also offer a predictive component to the analysis of the interplay between benchmark prices.

The problem for the economic researcher is that using a standard ordinary least squares (OLS) regression is not straightforward when using time series. Techniques to render the data usable may actually remove much of the important information from the analysis. The standard response in dealing with non-stationary variables is to difference the data, that is use the change in closing price, in this example, over a given time period in the model. In many instances this is appropriate but with some time series variables this may obscure some valuable information with regard to the relationship between the variables and hence it is better to keep the variables in their original non-stationary state and use different, more appropriate techniques. In short, differencing may mean throwing the baby out with the bathwater, as we could be discarding the important information about long-run level relationship if the relationship between variables is the focus of the study.

4.6 Stationarity

The reductivist nature of econometric research and the requirement to take a complex global trading relationship and reduce it to a single, but significant, equation requires the sample selected to speak for the population as a whole. The relationship between the variables should remain constant throughout the period under examination. That is the mean and the variance should be constant over time and importantly the difference between observations should not be time dependent (Gujarati, 2015). The issue that researchers face when using time series data is that it is stochastic by its very nature, there may be cyclicality and or a trend which therefore results in a mean and standard deviation that can change from period to period thus negating the ability of an equation to characterise the population or relationship between variables in its entirety. This in econometric terms is known as being nonstationary, the data follows a random process from one period to the next and the data possesses a unit root. This makes the use of standard econometric techniques complicated and potentially confusing.

4.7 Spurious Regression

A basic or standard econometric technique is to use an OLS regression to establish the impact that changes in the independent variable have on the dependent variable. Applying this technique to data that is stationary can yield unbiased and consistent estimators but with undifferenced time series data containing unit roots this can present the problem of spurious regression, whereby the R^2, a measure of how much the movements in Y can be accounted for by movements in X, can suggest a strong relationship between two variables where in fact none exists (Granger and Newbold, 1974). This could, unchecked, lead to many false conclusions being drawn with regard to the nature and dynamics of a commodity market such as oil.

4.8 Testing for unit roots/stationarity

Prior to commencing test for cointegration it is important to test the data to establish the presence of unit roots so that spurious regression can be avoided, and if there is no unit root then we could proceed by estimating a linear model using an OLS regression. If there is a unit root then one method of examining the data is through a cointegration study which requires the researcher to then establish the order of integration of the data. The tests for a unit root performed on a single time series is then followed up, if necessary with a stationarity test to establish the order of integration (Gujarati, 2015). The stationary time series is written as I(0) whereas a time series that needs to be differenced once to render it stationary is written as I(1) and I(2) if it requires to be differenced again to render it stationary. A common method for determining the presence of a unit root test within time series data is the Dickey Fuller test (DF) or more commonly the Augmented Dickey Fuller test (ADF) which takes account of drift and a deterministic trend over time. There are a number of other stationarity/unit root tests, these break down into the first generation of tests that include the ADF, the Kwiatkowski–

Phillips–Schmidt–Shin (KPSS), both of which are used in this study, and the Philips Peron test (PP). A second generation of tests that account for the presence of structural breaks, which include the break point unit root test used in this study is the process outlined by Perron (1989) which is a unit root test that allows for a structural break in the trend process.

The whole purpose of a unit root is to test whether the time series has any memory, does it continue on its stochastic way or is there some memory of previous prices and some sort of reversion to a pre-determined path. The Dickey Fuller (Dickey and Fuller, 1979) and its augmented variant (Said and Dickey, 1984) test the null hypothesis of the time series does include a unit root.

When data is non-stationary it can show permanent effects from random shocks whereas the decay effect from these shocks on stationary data is quick as the data shows memory of its historical mean and variance, hence the use of the term, mean reverting. The basic premise behind a stationarity test is that if a time series was stationary there is a strong tendency for variations to return to a strong mean, in doing so large, positive, variations are tended to be followed by negative variations as the series adheres to the mean. This then makes a stationary time series predictable whereas a time series that is nonstationary lacks the predictive power as previous observations tell us little about the future and the series follows a random walk. The KPSS test approaches the central question from the perspective that the null hypothesis is the data is stationary around a deterministic trend. Therefore, for series to be stationary the test result, the LM values, should be below the critical values at the 1%, 5% and 10% levels.

4.8.1 Stationarity Tests in this study

In this study the ADF and KPSS procedures were used to test for unit roots/stationarity. Firstly, the data was converted into Logs so that the patterns are easier to detect and observe. By doing this, the variance of the time series can be stabilised, and changes are more readily observable (Lütkepohl and Xu, 2012). The testing of the data began with preliminary testing of each individual time series variable to assess the presence of unit roots and stationarity.

The choice of the appropriate test for unit roots and stationarity is an issue to be considered. The ADF test is in essence a unit root test, with the KPSS test a stationarity test. These methods are complimentary in that the KPSS test can used to confirm the stationarity of the data as such the two tests are used in tandem. As Dave Giles in his excellent Econometrics blog suggests “It’s good to have a cross check” (Giles, 2011).

The notation for the ADF test is as follows

$$\Delta y_t = \alpha + \delta y_{t-1} + \sum_{i=1}^{h} \beta_i \Delta y_{t-i} + \varepsilon_t$$

(1)

Where we assume that the times series y_t follows an autoregressive path, α is a constant and δy_{t-1} is the unit root process and lagged values is t lagged difference terms of the dependent variable.

$$H_0: \delta = 0$$
$$H_1: \delta < 0$$

(1.1)

The null hypothesis is that the series contains a unit root $\delta = 0$, whilst the alternative is that is does not contain a unit root thus $\delta < 0$.

The notation for the KPSS tests is as follows

$$y_t = x_t' \delta + u_t$$

(2)

Where the test is performed on the residuals from the of an OLS regression of y_t on the exogenous variable x_t, the term $x_t' \delta$ is the deterministic trend and u_t a stationary error term. The test output is assumed to be stationary under the null hypothesis, the KPSS statistic is based on the residuals from this regression an The LM statistic, is the Lagrange Multiplier upon which the stationarity is assessed is defined in the following way

$$LM = \sum_{t} S\,(t)^2/(T^2 f_0\,) \tag{2.1}$$

If the LM statistic is greater than the critical values, provided in the E-Views output at 1%, 5% and 10% then the null hypothesis, that the data is stationary is accepted, alternatively the null is rejected if the LM statistic is less than the critical values.

4.8.2 Low Power

There is, however, the issue of predictive power, especially in the ADF test when the data contains structural breaks. Test results and probability values can strongly suggest the presence of unit roots when the evidence is at best marginal. In this case the null of the no unit root is erroneously rejected. Structural breaks can introduce a unit root into an otherwise I(0) stationary cointegrating vector and present the researcher with difficulties as the structural break can make it very difficult to reject the null of a unit root even when the data may be stationary in the two periods around that break. Perron (1999) suggests that there is a bias towards a false unit root when the data is trend stationary but there is a structural break.

Pre-testing for unit roots is not powerful, lacking in diagnostic precision, when there are structural breaks (Gregory, Nason and Watt, 1996), "power" here refers to the statistical test that measures the probability of failing to reject the null. i.e. there is a large chance of a "false-negative".

Testing for unit roots is problematic regardless of the test used if structural breaks are present as it essentially tricks the unit process into thinking that the data in not stationary as there is a jump in the mean due to the break, thereafter the data could go back to being perfectly stable. Nelson and Plosser (1982) put forward the idea that the shocks or breaks to the time series are permanent. Perron (1989, 1990) countered by stating that macroeconomic time series may indeed be subject to breaks but that these breaks were temporary disruptions to a deterministic trend.

The graphs of both the raw and logged data, figures 5.0 and 5.1, show that there is some form of break in the trend, as is likely in the oil market, then one can proceed in all likelihood that there is a structural break in the data, more formal tests of this will be examined in section 4.12.

This is crucially important with time series especially variables in a commodity such as oil. The strategic importance of this commodity and the level of political interference, writ large in chapter 2 of this study, means that the data is prone to exogenously generated shocks. It is arguable that in many cases that despite these shocks that the inherent qualities of the variable do not change and that once absorbed the data could then revert back to a predictable behavioural pattern, with all the memory characteristics of a stationary process.

In order to test this idea further the data was subjected to a further set of tests using the Breakpoint unit root test in EViews. This test is essentially a process that involves an innovation outlier or an adaptive outlier with breaks in either the trend, the intercept or both. The data in this study has been subjected to all of the above tests to examine if once the data has been detrended and breaks accounted for if the variable contains a unit root. This allows the researcher to test if the break occurs slowly, an innovation outlier, or immediately, an adaptive outlier. Does the break consist of a level shift, a break in the trend or both? The model below, (3), accounts for a trend and intercept with a break in the trend due to an innovation outlier

$$y_t = \mu + \beta t + \theta DU_t\,(T_b) + \gamma DT_t\,(T_b) + \omega D_t\,(T_b) + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + u_t \tag{3}$$

Where y_t is the series in the current period, DU_t is the intercept coefficient, DT_t is the trend coefficient, D_t is the trend break coefficient and T_b are one time breaks in each of the associated variables. There is also a one period lag of y αy_{t-1} plus the sum of changes in lagged values of y, $\sum_{i=1}^{k} c_i \Delta y_{t-i}$, plus an error term. So long as the terms that include the breaks (T_b) do not equal zero then there are breaks in the series.

4.9 Cointegration

The use of cointegration analysis and that of the Error Correction Model has seen many developments and modifications to the original theory. First introduced by Granger (1981) it has been further developed by Engel and Granger (1987), Engel and Yoo (1987,1991), Philips and Ouilaris (1990), Stock and Watson (1988), Philips (1991), Johansen (1988) and Johansen and Juselius (1990), Pesaran and Shin (1996).

Engle (1981) indicated that the standard differencing approach to non-stationary data may in fact overlook something that is important. That there may be a linear combination of the time series that are in fact stationary without recourse to differencing. This linear combination may represent a long-term relationship between the variables. Two variables may be individually non-stationary but the difference between the two may in fact be stationary.

A quick example here will suffice, if we accept that WTI is qualitatively superior to all other benchmarks in this study and because of this Brent trades at a discount to this. Given these differences, Brent could trade at 80% of the price of WTI and no matter what paths these two variables follow, this long-term rule of thumb of Brent is 80% of the price of WTI holds. This differential would then be stationary.

Moving this into the error correction process, establishing long term relationships between variables in this study and exploring how that relationship deals with short term shocks is an area that is worth investigating as in the case of this study it affords the researcher the ability to examine periods where the strategic imperative of key players changes and assess the impact that this has on the long-term relationship across the market. That is to say in the basis of our prosaic WTI/Brent model, is how quickly does the market move back to the 80% differential and what happens if the differential changes to 90%, a structural break? Is this strategy, demand or supply?

Two, or more, time series variables are said to be cointegrated if the linear combination of the two-time series is stationary, whilst the individual variables themselves may not be stationary.

$$y_{1t} = \mu + \alpha\, y_{2t} + \varepsilon_{t1}, \qquad t = 1, \ldots\ldots\ldots\ldots, n, \tag{4}$$

Where the time series y_{1t} and y_{2t} are non-stationary and e_{t1} is the errors from the regression which are in fact stationary, I(0). The intercept is represented by μ and the coefficient α is that which represents the relationship between the two variables.

There are many traditional methods for testing the level of cointegration within a time series, the Johansen method, the Engle Granger 2 step process and the Philips-Ouliaris cointegration test. The seminal work of Soren Johansen (1988) in the area of cointegration gave researchers the ability to track more than one cointegrating variable within the same model when the Engel Granger 2 step model and the Philips-Ouliaris model could only able to deal with one cointegrating relationship at a time.

Johansen's test is often referred to as a maximum likelihood test (Dwyer, 2015), which in prosaic terms seeks to find the answer that is the closest to being correct, as opposed to the ordinary least squares regression, which seeks to find the answer which is the least wrong. In the literature the relationship between the variables is often described as asymptotic whereby the relationship between the variables will never be precise or exact but will be as close as one can get. The Johansen's cointegration test is in fact two tests, the maximum eigenvalue test and the trace test. The former is important to discuss as it addresses the central idea that there is a stationary relationship between two, or more, nonstationary variables. The eigenvalue is the transformative value or coefficient. In this case if we were to say that there was a consistent long-term relationship between two variables then the eigenvalue is that which converts the two nonstationary time series into a stationary vector, it is the constant difference between the two variables over the long run, the 80% trading relationship of Brent to WTI discussed earlier. The function of the trace test is to examine the null hypothesis of cointegrating vectors (Hjalmarsson and Österholm, 2007).

The popularity of the test notwithstanding, as in any line of investigation the more a test is used the more its weaknesses or limitations become apparent. The Johansen model is able to use data that is non-stationary but all variables need to be of the same order of integration for the results to be meaningful. It cannot, however, deal with data of different orders of integration and as discussed, section 4.8.2, the presence of structural breaks can confound and lead to mis-specification and the use of Johansen when a more appropriate test could be used to deal with data with differing levels of integration in the one operation. It is in this instance that the researcher requires a test that can deal with data that is either I(0), I(1) or both. This is where the ARDL bounds test performs an important function.

In examining the literature relating to time series analysis and cointegration, the evolution of the ideas, approaches and finding/solving problems is amazing as the pure econometric research probes, prods and problem solves over time. No more so than in relation to the presence of structural breaks and how that may affect our diagnostic testing and model selection, see section 4.8.2. Basic cointegration models assume the cointegration relationship remans static over the time period when in actual fact we may be looking at something that changes over time and is much more dynamic (Martins and Rodrigues, 2017).

4.10 The ARDL Model

The ARDL bounds test has been popularised by the work of Pesaran and Shin (1995) in presenting a solution to that of potentially ambiguous results from unit root/stationarity tests. This ambiguity has been sufficiently dealt with, see section 4.8.2.

The ARDL bounds test, however, is able to produce such results when the data is either I(0) or I(1). It, however does not work when the variables are I(2). However, as Narayan and Smyth (2007) conclude one is unlikely to encounter data that is I(2) in the global energy markets, but comforting as this may be, stationarity/unit root tests are central to the choice of the ARDL model and therefore must be still carried out despite the likelihood of the data not being I(2). The model works on the null hypothesis that there is no long-run equilibrium relationship between the variables. The alternative is that there is a long-run relationship and the variables are therefore cointegrated. It is a single equation approach to cointegration. In any model this increased flexibility is important in delivering robust results.

4.10.1 ARDL Bounds Test and ECM Form

The power of the Auto Distributed Lag (ARDL) model for cointegration lies in the F-test bounds test. This can tell the researcher if there is a long-run cointegrating relationship between the variables. In addition to the this the test statistics of the ARDL model provide useful information regarding the short and long-run aspects of the model.

The notation for the ARDL model is laid out below.

$$Y_t = \gamma_{O_1} + \sum_{i=1}^{P} \delta_1 \; Y_{t-1} + \sum_{i=0}^{q} \beta'_i \; X_{t-1} + \varepsilon_{it} \tag{5}$$

The variable Y_t is essentially determined by a vector of variables that can be both stationary and non-stationary, these variables can also be cointegrated. The equation states that the value of Y_t is a function of lagged values of itself, denoted by the summation $\sum_{i=1}^{P} \delta_1 \; Y_{t-1}$ This is where δ_1 is the coefficient and Y_{t-1} are lagged values of the benchmark in question. The second part of the equation, $\sum_{i=0}^{q} \beta'_i \; X_{t-1}$, is a vector of current and past values of the other variables, which are multiplied by the coefficient, β'_i. What is important to note is that the lags on the dependent and the independent variables may not be the same length. The error term, ε_{it}, is serially uncorrelated and independent.

$$LX_t = \gamma_{0i} + \delta_t LX_{t-i} + \sum_{i=1}^{q} \beta_i' \,(LY_t + LZ_t + LW_t + LU_t + LV_t + LY_{t-i} + LZ_{t-i} + LW_{t-i} + LU_{t-i} + LV_{t-i}) + \varepsilon_{it} \tag{6}$$

The test applied in the framework of this study follows the above framework, (6), for each variable. In this example the log of benchmark X is the dependent variable with all others the explanatory variables. The value of LX_t in the current period *t* is determined by an unspecified number of lags of itself, LX_{t-i}, plus the current values of the explanatory variables and the appropriate number of lags of these variables plus an error term. In chapter 6 these explanatory letters are replaced by the logged values of the benchmarks in the study.

The bounds test where the autoregressive aspect, contained in the title shows that the dependent variable is correlated with lags of itself and the distributed aspect of the title explains that the dependent variable is also influenced by lags of the dependent variables.

The bounds test has the ability not only to test the question of whether the variables in the model are cointegrated but also to imply a direction of causality from the independent variables to the dependent variable. The short-run causal effects which are represented by the T-statistic, if these are significant for each independent variable then this points strongly to some causality in the relationship between variables.

The bounds test is based upon the following “conditional ECM” (Pesaran et al, 2001)

$$\Delta y_t = \beta_0 + \sum_{i=1}^{p} \beta_i \, \Delta y_{i\,t-1} + \sum_{J=1}^{J} \gamma_j \, \Delta x_{1\,t-j} + \sum_{K=1}^{K} \delta_k \, \Delta x_{2\,t-k} + \theta_0 y_{t-1} + \theta_1 x_{1\,t-1} + \theta_2 x_{2\,t-1} + e_t$$

(7)

The term, (7), essentially test the short-run and long run aspects of the model, where we test the terms $\theta_0 y_{t-1} + \theta_1 x_{1t-1} + \theta_2 x_{1\,t-1}$ to establish if there is a long-run cointegration. The null hypothesis (7.1) posits that there is no relationship between the coefficients in the long run, whereas the alternative, (7.2) would state that there is so long as they do not equal to zero.

$$H_0 = \theta_0 = \theta_1 = \theta_2 = 0$$

(7.1)

$$H_1 = \theta_0 = \theta_1 = \theta_2 \neq 0$$

(7.2)

Once the F-statistic, or the Wald Test, exceeds the critical value, in this case, then the results are deemed to be significant and the presence of cointegration is confirmed. The cointegrating vector can then be used in an Error Correction Model so that the short and long run dynamics of the model can be observed. Similar to the Johansen test for cointegration the trace and eigenvalue statistics determine if there is a single cointegrating vector or not.

The specific model used that is referred to in chapter 5 is the Case 3 unrestricted and no trend which is specified in the following way

$$\Delta y_t = \alpha_0 + b_0 \, y_{t-1} + \sum_{j=1}^{k} b_j \, x_{j,t-1} + \sum_{i=1}^{p-1} c_{0,i} \, \Delta y_{t-i} + \sum_{j=1}^{k} \sum_{lj=1}^{qj-1} c_{j,} \, l_j \, \Delta x_{j,t-lj} + \sum_{j=1}^{k} d_j \, \Delta x_{j,t} + \varepsilon_t$$

(8)

The term Δy_t is the change in a given benchmark, the dependent variable, which is equal to a constant plus past values of the dependent variable, y_{t-1} , multiplied by the coefficient b_0 , plus the sum of previous values of other explanatory benchmark variables, $b_j\, x_{j,t-1}$ multiplied by their individual coefficients plus the sum of changes in the price of the dependent variable, plus the sum of the changes in price of the explanatory variables. The final summation term is the sum of the changes in the current period for the independent variables in the equation system. The last term is the errors.

4.11 Break Points

As has been noted throughout, break points are important factors when using time series data. We can use techniques that treat the data as a whole and act as if they were not there. The alternative is to embrace the breaks, statistically establish their presence and use these dates, what came before and after, as they add to our understanding of the market and its dynamics. Using the relationship between Brent and WTI as an example it is clear from Fig. 2.7 that Brent's relationship to WTI changes in the time frame, this is backed up in the literature that indicates WTI decoupling from the global system as it was beset by logistical issues, which then results in Brent trading at a premium to WTI. This hints strongly at a structural break. Failure to establish the break(s) can lead to mis-specification of the model and inferences that clearly are inaccurate, or in the case of forecasting, make predictions based on past data that are plainly wrong (Prodan, 2008). On another level, applying dummy variables and treating the data as whole in the haste to infer about the sample as a whole could be another case of valuable information being discarded.

With a commodity as prone to political interference and manipulation as oil there is likely to be more than one structural break, which adds to the complexity of building a model. Gregory and Hansen (1996) suggested methods for dealing with one structural break in a single cointegrating relationship but could not accommodate presence of several structural breaks within a multivariate times series model. Their method has a three-pronged approach of incorporating breaks in the intercept, breaks in the coefficient and changes in both coefficient and the intercept (Johansen et al., (2000), Giles and Godwin, 2012). Segmenting the time series in order to incorporate the break in the data could be considered appropriate should the case of spurious non-cointegration become an issue with the use of dummy variables to account for the breaks used to account for the new regimes (Crafts and Mills, 2017).

This research eschews these approaches for a number of reasons. Firstly, the use of the ARDL method and the bounds test is more appropriate given the presence of breaks and the nature of the data. Secondly, these modifications mainly work on the basis that the exact dates of the breaks are known, a more appropriate method given the variables and the time frame is one that does the identification process for you. Lastly, there is a balance to be struck between results that are meaningful and a model that accounts for every eventuality.

The problem with these models is that they can become ends within themselves. The important thing is to create a model that is both accurate but has a degree of parsimony so that meaningful but readable/useable results are the outcome.

4.12 Bai -Perron Break LS

The methods outlined above create methodological rabbit holes from which the researcher may not re-appear with meaningful, straightforward, results. Fitting a multivariate model with numerous breaks and consequently a number of dummy variables may present one such rabbit hole. Using the work of Bai-Perron (1998, 2003) it is, however, possible to overcome these complexities and produce results that are straightforward but very rich in information. As the previous two sections have outlined, structural breaks present issues in terms of the validity of the unit root/stationarity results which can lead to using unsuitable tests for cointegration and in modelling these breaks, sometimes more than one within a multivariate system.

Once the bounds test has determined that there is a cointegrated relationship between the independent and dependent variables the value in the ECM output is considerable. Using statistically significant variables, at the 5% level, in a multiple regression can yield interesting results.

A common way to test for multiple breaks is to perform this in context of an OLS framework popularised by Bai and Perron (1998, 2003). The benefits of this testing approach are manifold. The tests are implemented on the ECM model, which is a stationary linear combination and therefore the Bai Perron test is appropriate. Firstly, testing using these methods can establish structural breaks when the precise break dates are unknown. Other tests for structural breaks work on a confirmatory basis, whereby the break is already known, and the test confirms or rejects that date.

The test used in this study is the test of the sequential l versus l+1 breaks where there is a null hypothesis of l breaks with an alternative that l+1 breaks exist. The alternative is that more than one break has occurred. The variables have all been differenced so that they are all of the same order of integration which thus avoids the risk of spurious regression.

The Bai-Perron Break LS test works on the basis of a standard multiple least squares regression. In it we have T periods and M breaks essentially giving us M+1 regimes giving (T_j, T_j+1,…….T_j – 1) regimes.

$$y_t = X_t' \beta + Z_t' \delta_t + \varepsilon_t \tag{9}$$

Used in context of a multiple regression the Bai-Perron Break LS test in E-Views is able to establish those break dates. After each break date we have a new regime and the output from this test allows us to examine the statistical significance of each variable in each regime. Moreover, by running a multiple regression and saving the residuals for each variable the speed of adjustment to disequilibria can be monitored in each regime too. This allows us to examine the idea that with increased financialisation has come greater ability to arbitrage deviations from long-run equilibria, or that the increased complexity of refining capacity means that arbitrage opportunities are quickly snuffed out by eager refiners. These are later developments which could indicate that those regimes closer to the end of the sample period exhibit faster correction of errors.

The break dates established by the testing output have also been put through less econometrically but nevertheless important tests to verify their validity. Graphing both raw data and logs of the data can establish the presence of breaks and their dates. Secondly, each of the break dates from the Bai-Perron output is tested so that it can be corroborated against events in the oil market. A search of news databases such as Bloomberg or Reuters in and around these dates can tell us a great deal about the impact of events such as OPEC announcements, as in that of November 2014. Indeed, in later regimes across all blends this date may prove to be pivotal, although given the use of monthly data there may be a small lag from event to break date in the data.

The use of this testing method is an important part of the research study. Once cointegration has been established it is important to study the interplay between blends and to examine how these relationships change from regime to regime. This is a valuable contribution to the literature, moreover when this is reviewed in context to the strategic plays within the oil market it may provide some rich insights into the success of the strategic plays of some of the industry's important players.

The test uses the differenced variables, differences of LWTI etc., as specified in the ECM output of the ARDL Bounds test. Firstly, running an OLS regression containing these variables and saving the residuals from this test as a variable allows us to examine the error correction. With the risk of multicollinearity amongst the explanatory variables the HAC Newey test criteria was applied to provide a more robust standard error and produce more accurate P-values, in appropriate cases. Section 5.4 walks the reader through the practicalities of this approach.

4.13 ARDL v VAR

The choice of model can be complicated by what one requires it to do. The interplay between a multivariate system of benchmarks could be examined using a SVAR model. The work of Toda and Yamamoto (1995) (TY hereafter) and their seminal paper on using the VAR process and causality when dealing with cointegrated variables provides one such avenue. The limitations of the VAR time-series workhorse had been identified by Park and Philips (1989) and Sims, Stock and Watson (1990), the TY paper proved seminal in its ability to find a way through this conundrum with cointegrated variables. The TY approach augments the basic VAR structure and allows the researcher to test for causality among a system of variables that are cointegrated. The principle causality test used across many econometric studies is the Granger causality test, however there are limitations in using this test when dealing with variables that are either integrated or cointegrated.

A Granger causality test examines if one variable causes another, that is if the future values of Y can be better predicted using past values of X and Y rather than the past values of Y on its own. In cases where X and Y are integrated in any way, the power of the test is low in power as the results may not follow a standard normal distribution.

As in the cointegration literature it is common to use the VAR structure to analyse the causal relationship between various blends of crude oil and stock markets or other commodities. Some studies examine the causal relationship between crude and petroleum related products or markets, (Han et al 2016). This could provide an interesting route for this research study but there are crucial reasons for using and ARDL approach and not the TY VAR structure.

The choice of the ARDL model is reasonably simple as there is a mix of I(0) and I(1) variables which only the ARDL bounds test allows. In short, the ARDL model is selected for the Bounds test as it is based on an ARDL model. Thereafter there are several benefits to the ARDL model that extend beyond that ability to test for cointegration via the bounds test. The ECM output shows the causality by identifying those variables that are statistically significant in determining the price of the dependent benchmark variable. In addition, this study seeks to clearly analyse how the variables perform when each variable is the dependent one, the detail is important, some methods such as VAR are championed for the lack of requirement to specify dependent and independent variables. Perhaps a method such as this would produce a set of results that show how LWTI is dominant but much would be missed in this case. The detail is important, we require to show different blends affect each other in each system. Does LWTI impact LBrent? Does it impact LBonny? We need to be clear which variables are in which systems as this will go a long way to answering the question of whether the global oil market is indeed "one great pool".

4.14 Fitted Values

The predictive powers of the model specification are tested by plotting the actual values of each variable against the predicted values determined by the model for each regime in the Bai Perron Break Least Squares model. This form of hindcasting was to confirm the explanatory power of the models to predict the values of each variable. From this, deviations from the actual and predicted values are clear, some of these are very interesting and fit with the chronology of events in the global oil market. The fitted values for each regime have been formulated for all variables, which has produced some very interesting results when compared to the actual values.

4.15 Methodological Approaches in literature

The cannon of literature that was discussed in Chapter 3 of this study, involves a number of techniques. Kaufmann and Banerjee (2014) use Engle Granger 2 step and ADF tests on pairs of OPEC and non-OPEC blends, around 30 individual blends, using daily closing prices over an eight-year period. Gullen (1997,1999) uses the Johansens's technique on weekly closing prices of 18 blends grouped by API gravity over the period 1991-1996. Bentzen (2007) uses a Vector Error Correction model using daily closing prices over the period 1987 to 2004.

Few studies have been conducted using the ARDL bounds test approach within the area of oil benchmarks. As noted much of the studies in relation to oil markets tend to examine one or two global blends, such as WTI or Brent with another non-crude oil variable. This can range from other commodity prices, to stock market indices and the movements of GDP.

The point has been made elsewhere but is nevertheless worth reiterating. This study is an examination of an aspect of the global oil market using techniques that are suitable to the data and the question being posed. It is not an exploration of one econometric technique versus another in the context of global oil benchmarks. This is not meant to disparage this line of academic enquiry as without that fine body of research an applied study such as this would be significantly weaker.

4.17 Data sample and sources

The time frame of reference for this data was initially from January, 1990 until December, 2018. This however, has been truncated to accommodate the availability of monthly prices for the African blend, Bonny Light, which then takes the study period from June, 1996 until December, 2018. This time frame is significant as it spans different regimes in the global oil sector and incorporates different uses of technology, the global financial crash, the World Trade Centre attack in September 2001 and the advent of fracked US tight oil as a major market presence from 2011 onwards. The sample period therefore allows us to examine major demand and supply factors that have affected the global oil market through an eventful period.

Importantly, the time frame of the study tracks the period from the first initial increases in US LTO production through to May 2018. The significance of the cut-off date is that oil prices beyond this point increased due to political events such as the US withdrawal from the Iranian nuclear deal and the re-imposition of economic sanctions which would potentially curb Iranian exports, at the same time the increased tensions in Syria post 2018, (whilst this had been ongoing since 2011 the tensions between the US and Russia/Syria/Iran increased in 2019), threatened a wider conflagration that resulted in upward pressure on oil prices. There is also the US imposition of sanctions on Venezuelan exports in August 2019 which impacted the market price for certain types of oil. The decision to exclude these events from the sample is so that interplay of the oil market since the shale oil revolution can be measured on a business as usual basis, if such a thing exists in the global oil market, without the overlay of geopolitical events. The time period does not cover the extraordinary collapse in prices following the declaration of the Covid-19 pandemic and the shutdowns across most of the world.

4.17.1 Frequency of the data

The frequency of the data is monthly, with the closing spot price on the first day of each month used. The data is priced in dollars. Using monthly prices eliminates noise from the higher frequency data over a longer period of time.

There is a degree of concern that the frequency of data is not too spread apart as the model would not be able to monitor the error correction process (Harris et al, 2005). That said, the use of daily closing prices may result in a degree of noise due to over trading that comes with examining high frequency data which obscures the signal which lower frequency data can hopefully provide. As the final results will show this is not an issue as the Break LS tests were able to provide robust and interesting results in this regard.

4.17.2 Spot Prices

The use of spot prices in this study on their own goes against the grain of much of the recent research within the area. Many studies examine cointegration across different commodities and those within the oil market examine cointegration across different time periods, spots and futures. This study concentrates on the spot market for good reason as Kaminska (2013) points out in the Financial Times “it is where financial speculation may meet physical reality”. The studies examining price discovery in spot and futures markets and cointegration between these markets may tell us a lot about the efficiency and the process but by including the paper market, futures, we can tell much about speculation but the spot market, the wet market, provides us with a picture that is about the actual supply and demand of the commodity. This is the market for physical delivery. Moreover, if the data from these tests can be interpreted in light of the strategic interplay within the market then surely it is better to strip out the noise of the futures markets and concentrate on the signal of the spot price where only those with skin in the physical game operate?

4.17.2 Data Sources/software

All of the tests conducted in this study were conducted using Eviews statistical software. The closing price data has been sourced from the Datastream databases, whilst other data, such as oil demand and supply, featured in chapter 2, has been sourced from a variety of sources the US Energy Intelligence Agency, the International Energy Authority and the BP statistical review.

4.18 Benchmark Selection

The selection of variables for this study was of key importance. The more narrowly one selects the benchmark variables, very similar grades etc., the stronger the tendency to skew the results and prove that the global oil market is “One great pool”. Another issue could stem from choosing minor regional blends of crude, whilst this would be a worthwhile exercise in some instances they do not fit in this study. The examination of the relationships is against the backdrop of major change in the oil market and therefore requires blends that can be considered global and those which might compete with each other for benchmark status or be displaced by the changing role of some benchmarks.

The sections, 4.18.1-4.18.7, present some specific background to each of the benchmark variables used in the study. This helps the reader by understanding the quality of the oil but also the markets they serve and any competitive pressures or recent changes. There is some duplication from chapter three, but this is minimised by focussing on the less well-known blends (i.e. other than WTI and Brent).

The spot prices of the following benchmarks, Brent, WTI, Dubai-Oman blend, the OPEC basket, Bonny Light from Nigeria and the Mediterranean Russian Urals were used in the study. These are all significant reference pricing benchmarks. The variables reflect a spread of global blends each of which is important in the global oil economy with sizeable markets. As noted, Brent and WTI are seen as truly global benchmarks which are referenced against for many off-exchange transactions.

4.18.1 West Texas Intermediate

WTI is used as a reference for trades in the USA. It is a light sweet crude and is used for oil that is processed out of Cushing Oklahoma in the USA. As a land borne crude it is more problematic and costly to ship than Brent. Its inherent qualities of being light and sweet make it popular for refining into gasoline. The US government decision to allow exports, December 2015, has changed the dynamic of this blend as it is now shipped globally.

4.18.2 Brent

The Brent blend is sometimes affixed with the acronym BFOE, this means Brent, Forties, Osberg, EkofisK. These are the fields that operate in the North Sea between the north-eastern coast of Scotland and Norway. The Brent that is mentioned in global news report is in fact a blended average of prices from these fields. As has been mentioned previously Brent being a reference primarily for trades in Europe but is used as a reference for a significant number of transactions globally. It is relatively light and has a low sulphur content and as it is seaborne it is has proven to be a more reliable benchmark than WTI.

4.18.3 Dubai blend

The Dubai blend is the benchmark for trades in the middle east. It's growing importance is reflective of the increased trade that occurs between Asian markets, China and India notably, and Persian Gulf producers. The establishment of Dubai/Oman futures contract may also be significant in the significance of this benchmark. Dubai is a medium sour crude, as has been discussed at length it serves as a pricing benchmark for sales in the expanding Asian market.

4.18.4 OPEC basket

As is denoted by the name this variable is a basket of blends, a weighted composite price index of a number of blends of oil produced by OPEC members. The point to note is that the composition of this basket and the weightings is subject to periodic review and renewal. The last review took place in 2005 when the basket was expanded from seven crude oil types to thirteen. There is no uniformity in terms of the types of oil with heavy and crude blends alike, such as Iran Heavy and Basra Light making up the basket. In this study it serves as a reminder of how OPEC blends interplay with global benchmarks.

4.18.5 Urals Mediterranean

Urals (Mediterranean) Novo is a Russian blend of oil that is medium sour. This blend of Urals is also referred to as Mediterranean as it has been historically sold to refiners in the Mediterranean via the Black sea port of Novorossiysk. It is a heavier crude with a higher sulphur content than other blends in the study. It should be noted that the prices quoted for Urals Mediterranean used in this study follow the convention of Cif, which means Cost, Insurance Freight, which as it says is the cost of buying, transporting and insuring a barrel. This is due to shipments from this port being historically unreliable with significant time delays when foreign tankers collected the oil from the Black Sea, the pricing convention that has stuck includes delivery and insurance.

The use of Mediterranean Russian Urals is due to its significance in a price setting capacity in studies conducted by Wlaslowski et al (2011). Its inclusion is also designed to capture the relationship between different blends and the impact that pricing decisions have on Russian produced crude and vice versa. Russian blends are not prominent in existing empirical work on the oil market, the focus is on North American blends, in no small part due to the availability of pricing data. The role of Russian crude is an overlooked relationship in the literature and whilst not the central focus of this it may illuminate this area of the oil market and provide the rationale for further study beyond this work.

4.18.6 Bonny Light

Finally, Bonny Light is a Nigerian light crude oil that is exported globally, it has a high API gravity and is produced in the Niger Delta in and around the city of Bonny, hence the name. Given its inherent qualities it is a high yielding crude that has been popular with US refiners (Gupte and Tronche, 2020); this popularity extended worldwide as products such as gasoline and jet fuel, which command higher prices in the market, can be efficiently derived from Bonny Light. Given its quality it usually trades at a premium to Brent but in times of supply gluts lack of storage space in Nigeria means that it can be heavily discounted to Brent in order to compete with deeply discounted sour blends (Lehane, 2020). Times have changed for Bonny Light producers. Once the darling of U.S. refiners, Bonny has had to find new markets in Europe due to the US shale revolution. It is still popular with Indian and Indonesian refiners, but as the US now exports, Bonny and light US crudes are in direct competition across the globe. The scale of the challenge to make up for lost US revenues is stark, in the last 10 years, according to the US EIA, sales to the US fell from 36.4 mbpd in 2010 to 5.6 mbpd in January 2019 (Browning, 2019).

Conclusion

In summary this chapter works from the following standpoints. The ontological approach is positivist stance, the study makes use of time series data from six global crude oil benchmarks over a 22-year period. Prior to testing for cointegration it is important to test the data for stationarity and the presence of unit roots. The basis of a cointegration study is establishing the presence of a long-run, stationary, cointegrating relationship between the variables. A conventional testing method is the Johansen's test, however it is not applicable in every situation. Where there are structural breaks in the time series data the diagnostic power of the stationarity test can be compromised. In cases such as this, alternative methods are sought, one such method is the ARDL bounds test, as put forward by Pesaran and Shin (1996). In addition to this test the ARDL bounds test statistical output is able to specify an ECM structure that is the basis for further study. Using the Bai-Perron Break LS test in EViews the ECM data can then be modelled in a Bai-Perron Break LS test to identify structural breaks, the components of the system in each regime and the speed of adjustment to the breaks in the regimes. The output from these tests can then be fitted in order to test the predictive power of the Break LS output against the actual values of the dependent variable.

Chapter 5: The relationship between oil benchmarks 1990-2018

5.1 Research Introduction

This chapter examines the relationships between certain crude oil benchmarks over the period from 1996 to 2018. The study of cointegration is central to the research aims of the project as it assesses the extent to which the benchmarks move together and play a role in determining the price of each other. This methodological examination of the time series data takes a structured approach and follows conventional processes in establishing the nature of the data and then using the appropriate tests to pose the central question.

This chapter rigorously tests the idea of relationships between the variables. The examination of the monthly closing prices for six globally traded benchmarks affords the researcher the ability not only to provide a more up to date examination of the relationship between blends but to examine the changing dynamics of the oil market.

This chapter revolves around the selected policy themes.

The idea that the global oil market is "one great pool" (Adelman, 1990), has spawned a literature of its own, which underpins the rationale for this study. The countervailing argument that the differences in quality result in barriers to the cointegration of the market across all oil types is an equally strong consideration in framing the argument and determining appropriate aims and objectives.

The extent to which there are genuinely global benchmarks is an essential question for researchers and market analysts. There is a sense that some blends are true bellwethers and have an impact on all oil prices. The literature and the business press suggest that WTI and Brent are prominent, with all other blends subordinate to the movements of these relevant benchmarks. This chapter contributes to this debate.

This chapter also looks at changing dynamics of the oil market, the increase in US supply and Asian demand, and provides the opportunity to reassess the dynamics of the market. In addition to assessing the number and nature of the interconnections with blends such as WTI and Brent, the impact those blends produced by OPEC and KSA are worthy of re-examination in light of new patterns of demand and supply. It also includes Russian crude oil prices to address a weakness in the existing literature.

In arriving at these conclusions, econometric testing was conducted on six global benchmarks and their relationship to each other. The benchmarks chosen provide not only a geographic spread in terms of country of origin and markets served but also in terms of the differences in viscosity and sulphur content which determines the price and export markets.

Prior to examining the data for cointegration the variables are tested to establish the presence of unit roots then to identify the degree of integration. Methodologically, the chapter is informed by the work of Pesaran and Shin (1996) as their work demonstrates how to investigate a system of cointegrated variables when the intricacies of each variable render the use of simple econometric techniques, Engle-Granger or Johansen's technique, inappropriate. This study uses the Autoregressive Distributed Lag (ARDL) model bounds test. These results from this test allows us to examines the long-run nature of each model by looking at the error correction model (ECM) embedded in each system. The test results of the ECM inform a Bai-Perron regression, to test for breaks in the relationship between the variables. The researcher is thus able to examine break dates, the behaviour of the variables and speed adjustment from short-run disequilibria to the long-run equilibrium in each regime.

The main findings of the analysis of the research data are as follows

- There is evidence of cointegration across all blends within the sample
- Those relationships are stronger where the blends are close substitutes
- Brent is the global benchmark and is cointegrated with all but one of the blends
- West Texas Intermediate is cointegrated with fewer benchmarks
- There is evidence to support the strategic shift in policy by OPEC in 2014 to target WTI
- The Dubai blend is more global than WTI as it is cointegrated with more benchmarks
- There is evidence of cointegration of those blends that are either regionally segmented in terms of the markets that they serve or in terms of the inherent qualities of the oil

The chapter focusses solely on the results. It is broken into five sections firstly an examination of the inherent qualities of each blend, stationarity/unit root tests and the quest to specify the correct number of lags in the model. The second section, analyses the cointegration and error correction tests. The third section examines the graphed data, both in log form and in its unaltered state to establish the presence of structural breaks. The fourth section builds on this discussion by looking, econometrically, for structural breaks within the equation systems for each individual blend, assesses the size of the coefficients and the speed of the error correction process in each regime. The fifth section fits the values predicted by each model in the study against the actual value to assess its predictive ability. In addition, benchmarks that are deemed significant and sizeable in the equation system are tested against the actual values of the variable to ascertain if this provides a more reliable heuristic in terms of determining price. The chapter concludes on a discussion of the significance of the results considering the results in context of the salient points from the extant literature and in context of the global oil market.

Part I: Inherent qualities, Unit roots, stationarity and lag selection

5.2 Inherent Qualities

In terms of the API gravity and the sulphur content the table (5.0) indicates the inherent qualities of the oil and highlights the extent to which any of these blends are, easily, substitutable for each other and therefore present arbitrage opportunities that would allow disequilibria to quickly correct. A full discussion of qualitative oil differences is available in chapter 3.1.

Table 5.0: Qualitative differences

Blend	API %	Sulphur Content
Bonny Light	33.4°	0.16%
Brent	38.4°	0.37%
Dubai/Oman	31^0	2%
Urals Mediterranean	31.7°	1.35%
WTI	39.6^0	0.24%

Table 5.0, above, demonstrates that the blends of oil are relatively close in terms of API, whilst there is a greater degree of separation with regard to sulphur content. The keen eyed will observe that there are no statistics for the OPEC basket, this is due to the mixed bag of blends that make up this basket, whilst all blends that trade are indeed composites there is sufficient

uniformity to average these out whereas the OPEC basket is something of a moveable feast with different blends composing the basket over time. A fuller discussion of each blend can be found in chapter 4.18.

5.2.1 Stationarity - Augmented Dickey Fuller tests.

The challenge with time series data is to establish the presence of unit roots and the order of integration of the data in order to select to correct method and avoid spurious regressions and cointegrations. The logs of five oil benchmarks, WTI, Brent, Urals Mediterranean, Dubai, Bonny Light and the OPEC basket from June 1996 until November 2018 were tested using the ADF and the KPSS tests in Eviews. They are referred to with the prefix of L to denote this, which will be the convention from this point onwards. The results from the ADF test and the KPSS test confirm that the data is I(1), stationary at the first difference level of integration, but crucially for the ARDL model not I(2), given the choice of the ARDL model to examine the degree of cointegration that the data is not integrated to the level of I(2) is important as the ARDL bounds test cannot process time series that is I(2). Below, tables 5.1-5.5 present test statistics for both the ADF and KPSS tests at both the level and first difference, the tests presented here were initially conducted with no trend/ intercept. The lag length for the ADF tests was zero, with an automatic selection of 15 lags based on the Schwartz Information Criteria. As part of the testing process and to be sure that there was no hint of ambiguity data generating processes including trends and intercepts were also conducted but there was very little difference to the data and nothing to suggest anything other than the data being of the order of first difference.

Table 5.1: Augmented Dickey Fuller Test: No trend and No intercept

Benchmark	Integration	Test Stat	1% level	5% level	10% level	P-Value
LWTI	Level	0.312369	-2.57369	-1.94201	-1.61591	0.7753
LBrent	Level	0.450099	-2.57369	-1.94201	-1.61591	0.8108
LDubai	Level	0.393578	-2.57369	-1.94201	-1.61591	0.7967
LOPEC	Level	0.389135	-2.57369	-1.94201	-1.61591	0.7955
LUrals Med	Level	0.475467	-2.57369	-1.94201	-1.61591	0.8170
LBonny Light	Level	0.4800	-2.57369	-1.94201	-1.61591	0.8181

Table 5.2: Augmented Dickey Fuller test statistics No Trend, No Intercept

Benchmark	Integration	Test Stat	1% level	5% level	10% level	P-Value
LWTI	1st difference	-14.3476	-3.45463	-2.87212	-2.57248	0.0000
LBrent	1st difference	-13.2875	-3.45463	-2.87212	-2.57248	0.0000
LDubai	1st difference	-13.2414	-3.45463	-2.87212	-2.57248	0.0000
LOPEC	1st difference	-13.9254	-3.45463	-2.87212	-2.57248	0.0000
LUrals Med	1st difference	-15.7601	-3.45463	-2.87212	-2.57248	0.0000
LBonny Light	1st difference	-15.7140	-3.45463	-2.87212	-2.57248	0.0000

Table 5.3: Augmented Dickey Fuller Test: trend and intercept

Benchmark	Integration	Test Stat	1% level	5% level	10% level	P-Value
LWTI	Level	-2.03979	-3.9925	-3.4266	-3.13655	0.5764
LBrent	Level	-1.94219	-3.9925	-3.4266	-3.13655	0.6295
LDubai	Level	-2.093	-3.9925	-3.4266	-3.13655	0.5469
LOPEC	Level	-2.09493	-3.9925	-3.4266	-3.13655	0.5458
LUrals Med	Level	-1.9366	-3.9925	-3.4266	-3.13655	0.6325
LBonny Light	Level	-1.8951	-3.9925	-3.4266	-3.13655	0.6543

Table 5.4: Augmented Dickey Fuller Test: trend and intercept

Benchmark	Integration	Test Stat	1% level	5% level	10% level	P-Value
LWTI	1st difference	-14.3347	-3.9925	-3.4266	-3.13655	0.0000
LBrent	1st difference	-13.279	-3.9925	-3.4266	-3.13655	0.0000
LDubai	1st difference	-13.2279	-3.9925	-3.4266	-3.13655	0.0000
LOPEC	1st difference	-13.9073	-3.9925	-3.4266	-3.13655	0.0000
LUrals Med	1st difference	-15.7413	-3.9925	-3.4266	-3.13655	0.0000
LBonny Light	1st difference	-15.6954	-3.9925	-3.4266	-3.13655	0.0000

Table 5.5: Kwiatkowski-Phillips-Schmidt-Shin test statistics No Trend

Benchmark	Integration	LM Value	1% level	5% level	10% level
LWTI	1st difference	0.091345	0.739	0.463	0.347
LBrent	1st difference	0.101781	0.739	0.463	0.347
LDubai	1st difference	0.085763	0.739	0.463	0.347
LOPEC	1st difference	0.081043	0.739	0.463	0.347
LUrals Med	1st difference	0.08258	0.739	0.463	0.347
LBonny Light	1st difference	0.084241	0.739	0.463	0.347

The data was then subject to a unit root break point test as outlined in Perron (1996) with the data generating process examining the data in context of innovative outliers where there is some sort of shock to the system that affects all observations thereafter. The results from these tests did not conclusively prove that the data was I(0) when we account for the break but in the confidence levels it did not conclusively lead to a rejection of the null hypothesis that there a unit root is present in the data.

It is this ambiguity that casts a degree of uncertainty on the results of the ADF and KPSS tests as the power of these tests in the presence of a structural break has been well documented, see 4.8.2.

Table 5.6: Break Point Unit Root Test: Trend and Intercept - Break in Trend: Innovation Outlier

Benchmark	Integration	T-Stat	1% level	5% level	10% level	P-Value
LWTI	Level	-4.68606	-5.34759	-4.85981	-4.60732	0.0801
LBrent	Level	-4.65094	-5.34759	-4.85981	-4.60732	0.0879
LDubai	Level	-4.92695	-5.34759	-4.85981	-4.60732	0.0408
LOPEC	Level	-5.12561	-5.34759	-4.85981	-4.60732	0.0225
LUrals Med	Level	-4.56586	-5.34759	-4.85981	-4.60732	0.1160
LBonny Light	Level	-4.4410	-5.34759	-4.85981	-4.60732	0.1527

Table 5.6 clearly illustrates the ambiguity in the test results. Using a trend and intercept with an innovation outlier as part of the data generating process the results showed that there was a break in each variable but could not overwhelmingly confirm that there is evidence of a unit

root once breaks in the data have been accounted for. LWTI and LBrent show test results between the 5% and 10% critical values, that is these stats are less than the critical value at the 5% level but greater than the critical values and the 10% level. The probabilities in both cases are above 5% but below 10%.

When the results for LDubai and LOPEC are examined the idea that some of these variables may in fact be I(0) once structural breaks have been accounted for, becomes stronger. In each variable the T-statistic that is greater than the critical value at the 5% level and a robust probability below the 5% level. In all, it is this ambiguity that lends weight to the ideas that the variables may not be I(1) as the test results from the KPSS and ADF strongly suggests, and that the presence of breaks may weaken the diagnostic power of these tests. It may be that there are periods when the data is stationary and others when it not, from I(0) to I(1) as it were. In this case the use of the ARDL Bounds test for cointegration is appropriate given its ability to process data that is both I(0) and I(1) whilst producing meaningful results.

The Johansen cointegration test for robustness purposes. Appendix table A.1.20 reports the trace test results. In general, the test report four cointegrating vectors, which is 1 cointegrating vector less than expected. This may be due to the power problems and size distortion cointegration tests suffer from in the presence of structural breaks (Maddala and Kim, 1999).

5.2.2 Lag structure

The lag length selection is important in determining the structure of the model as it is not just the values in the current period but those across several periods that can impact the change in price of a variable in the current period. Therefore, choosing the correct number of lags to include in the model is important, using the ARDL framework and the Maximum number of lags in both the dependent and independent variables the is an important part of the process. Firstly, given that the frequency of the data is monthly a clear starting point was to introduce twelve lags into the model. The desire for the residuals to be "well behaved" means completely that they are random and do not having any serial correlation or show hetroskedasticity. The first of these is the most important as it the residuals today are related to the residuals yesterday (or last month etc.) it means that there is something important missing from our model. The Breusch-Godfrey serial correlation LM test was used as was the ARCH heteroskedasticity test was also used, where the test results indicated that there was no serial correlation or heteroskdeasticity was present in the model this allowed me to reduce down the number of lags in the model and then test again. In the end this led to all variables testing for no more than one lag of each variable with the exception of LBrent which used a maximum of 3 lags in both the dependent and independent variables in the testing criteria.

5.3 The ARDL Bounds Test

The selection of the bounds test as the principal method for cointegration has been discussed in chapter 4.10. The first step in the process was to test for the long-run relationship using the bounds test for cointegration. Whilst the ARDL may show a short-run relationship, is there a long-run relationship between the variables. Using the correct lags of both the dependent and independent variables in the model is important in simplifying the model. Using the lag length structures the models were created using the ARDL bounds test in EViews. This used each variable with no more than one lag for all variables with the exception of LBrent, with three lags.

A key element of this procedure is to examine the long run relationship between the variables by computing the Bounds F- Statistic. Each of the variables was subjected to this test in order to establish the presence of a long-term relationship. The F-statistic test output provides with two sets of significance statistics that cover for the possibilities if the variables are stationary or difference stationary, I(0) or I(1) respectively. If the value of the F-statistic is greater than the upper bound of 5% then we can conclude that there is a long-run relationship between two or more variables in question.

Table 5.7: Bounds F-test Null Hypothesis: No levels relationship: 269 Observations

Benchmark	F-statistic	10%		5%		2.50%		1%	
LWTI	6.476897	2.26	3.35	2.62	3.79	2.96	4.18	3.41	4.68
LBrent	8.923656	2.26	3.35	2.62	3.79	2.96	4.18	3.41	4.68
LDubai	16.82788	2.26	3.35	2.62	3.79	2.96	4.18	3.41	4.68
LOpec	24.3656	2.26	3.35	2.62	3.79	2.96	4.18	3.41	4.68
LUrals Med	25.62167	2.26	3.35	2.62	3.79	2.96	4.18	3.41	4.68
LBonny	19.85543	2.26	3.35	2.62	3.79	2.96	4.18	3.41	4.68
k		5	Asymptotic: n=1000						

The results of the bounds tests, table 5.7 above, clearly demonstrate that each variable, or benchmark, is cointegrated with one or more of the other variables in the study. The figure $K = 5$ demonstrates the number of cointegrating stochastic trends in the data, five which is a strong indicator of the cointegrated nature of the data. Note that all variables in the study, in their log form were included in the initial computation. The measure of determining if there is cointegration is via the F-statistic is if the F-statistic is greater than the figure is the column marked I(1) then there is cointegration. If it is lower than the figure in column I(0) then there is no evidence of any cointegrating relationships and if the F-statistic is between the two figures then it becomes a more involved process to prove one way or another that the existence of relationships. Fortunately, the F-statistics for all prove beyond doubt the existence of relationships between all of these variables. Prosaically, there is a statistically long-term relationship between the variables in each of the equation systems.

5.3.1 Long run ECM

With the lag length structures the models were created using the ARDL test in EViews. This used each variable with no more than one lag for all variables with the exception of LBrent. Bounds test results conclusively proving that there is a long-run relationship between the variables, the next step is to examine those variables that are part of the cointegrated system for each benchmark. To examine both the short and long-run systems. The convention in this section will be to reduce the equation for each blend down to its statistically significant parts and progress the analytical discussion from there. Full tables of the results are obtainable at the end of the chapter.

It is worthy of restating that the form presented as part of the ARDL model is the Error Correction model. The model is determined by lagged values of the dependent variable, lagged values of the explanatory or independent variables, this represents the long-run dynamics within the system, then we have the short run dynamics which is represented by the change in the dependent and the independent variables. The long-run dynamics are noted by (-1) appended to the variable whilst the short-run dynamics of the model are denoted by the prefix (D) on each variable. As noted the joy of the ARDL bounds test model is that this is all contained within one equation. For a fuller examination of the notation readers should consult Chapter 4.10.1. The ARDL equation system will be examined on a benchmark by benchmark basis using the decomposition $Z_t = Z_{t-1} + \Delta Z_t$. That is the reciprocal of the ARDL output is presented.

How we interpret the data is thus. The specification and the estimation of the Long-run ARDL model allows us to examine those variables that are estimated to be significant and the short-term EC form, the second table for each variable for sections 5.3.1.1 – 5.3.1.7, provides a further check on the cointegration of the variables within the system. If the cointegrating equation is both negative, which means that it is correcting back to a long-run equilibrium, and that statistic had a probability value below 0.05% then this will provide further evidence to support the Bounds test results. A discussion of the size and the direction, positive or negative, will be entered into when the equation systems are discussed in their regimes, sections 5.3.1.1 – 5.3.1.7.

5.3.1.1 LWTI

Table 5.8: LWTI Long-Run ARDL Model

Variable	C	LWTI(-1)	LBRENT(-1)	LDUBAI(-1)	LOPEC(-1)
Coefficient	0.067764	-0.230152	0.1389	-0.204728	0.28816
Std. Error	0.018349	0.0408	0.073901	0.08162	0.093026
t-Statistic	3.693031	-5.641029	1.879536	-2.508319	3.097619
Prob.	0.0003	0	0.0613	0.0127	0.0022

Firstly, there are relatively few variables that have some influence in the pricing of LWTI. If we adopt a coefficient at the 5% level as significant and anything between this and 10% being of interest then all of the variables included this model are either of significance or of interest in the pricing of LWTI. All three blends have a positive on WTI in the long run. The remaining blends in the sample for this study have no impact of WTI. The biggest standout, admittedly of little surprise, is LBrent, which is clearly significant in terms of its P-value.

Essentially the price of LWTI is influenced by LBrent, LDubai and LOPEC in the long run. This covers the bases of the major price shapers in the global oil market, with Brent, OPEC and the rising star of Dubai all accounted for.

The short-run run output is captured in the following output table, 5.9.

Table 5.9: LWTI ECM regression

Variable	Coefficient	Std Error	P-value
C	0.067764	0.011077	0.000
D(LBrent)	0.489058	0.092047	0.000
D(LOPEC)	0.413501	0.075979	0.000
D(LDubai)	0.092305	0.073396	0.2097
CointEq(-1)	-0.230152	0.036568	0.000

These test results echo the importance of LBrent, LOPEC and LDubai, in the long-run but not the short-run, to the performance of LWTI. There may be qualitative differences between these blends but as LBrent is pivotal to global pricing, LDubai represents sales to Asia and LOPEC the blended price of the world's largest oil trading bloc there are no real surprises in this output. The error correction model for LWTI over the entire sample time frame shows some points of interest. The short-run speed of adjustment (i.e. the correction to the long-run relationship between all other blends and LWTI). It implies that 23.02% of the discrepancy from the long-run relationship is corrected every month. This also means that the correction mechanism is relatively fast – it takes nearly five months for the shock to die off. The relationship between LWTI and LDubai is interesting that whilst is significant at the 5% level in the ECM output however when we examine the short-run ECM form the P-Value suggests that this is not a relationship that is in any way statistically significant, however it is an important long-run factor.

The tests were examined for the presence of serial correlation and heteroskedasticity using the Breusch-Godfrey serial correlation LM test and an Arch test for Heteroskedasticity, with the results showing no presence of serial correlation in the residuals and being homoskedastic.

5.3.1.2 Brent

Table 5.10: LBrent Long-run ARDL Model

Variable	C	LBRENT(-1)	LWTI(-1)	LDUBAI(-1)	LOPEC(-1)	LBONNY(-1)	D(LBRENT(-1))	D(LBRENT(-2))
Coefficient	-0.008236	-0.288161	0.052978	0.119564	-0.129436	0.331949	-0.16704	-0.161109
Std. Error	0.011013	0.04437	0.02666	0.045841	0.062914	0.068392	0.054433	0.051897
t-Statistic	-0.747859	-6.494436	1.987181	2.608215	-2.05733	4.853615	-3.068749	-3.104415
Prob.	0.4552	0	0.048	0.0096	0.0407	0	0.0024	0.0021

As noted the LBrent bounds test included 3 lags in order to eliminate heteroskedasticity and serial correlation within the residuals. This makes for a long equation tracking the long and short run forms within the model. An analysis of the system of equations for Brent demonstrates that the number of benchmarks that are significant increases markedly from WTI. The picture in this equation system is evenly spread out with most blends exerting some influence in both the short and the long-run. Potentially the reason for this could be the role that Brent plays globally. As a seaborne crude rather than a land-borne crude such as WTI it has not been beset with the potential bottlenecks that WTI has and is therefore a more reliable benchmark to price against. What we see here and, in this test, across all blends is that Brent is statistically significant in the pricing of all blends and as a global benchmark it too absorbs price information from a wider range of blends than WTI.

When we examine the short-run form ECM, table 5.11, the following statistically significant, at the 5% level, output has been derived. The cointegrating equation is negative and statistically significant and indicates that 29% of the error in the system is corrected within one month.

Table 5.11: LBrent ECM regression

Variable	Coefficient	Std. Error	P-Value
C	-0.008236	0.001657	0.0000
D(LBrent(-1))	-0.167040	0.052608	0.0017
D(LBrent(-2))	-0.161109	0.050506	0.0016
D(LWTI)	0.147672	0.031849	0.0000
D(LWTI(-1))	0.064236	0.033732	0.0580
D(LWTI(-2))	0.056050	0.033602	0.0966
D(LDubai)	0.329304	0.036978	0.0000
D(LOPEC)	0.278945	0.056624	0.000
D(LOPEC(-1))	0.093134	0.045424	0.014
D(LOPEC(-2))	0.079997	0.043721	0.0685
D(LBonny)	0.230970	0.045645	0.0000

CointEq(-1)	-0.288161	0.038993	0.000

As we will see throughout this study, LBrent is tied to many blends, its performance is a significant determinant of the price of other blends but there is also strong evidence of feedback loops from those blends back to LBrent. As befits a global blend it has a truly global complexion. The residual tests for serial correlation and heteroskedasticity showed no presence of either.

5.3.1.3 LDubai

Table 5.12: LDubai Long-run ARDL Model

Variable	C	LDUBAI(-1)	LBRENT(-1)	LOPEC	LURALS	LBONNY(-1)
Coefficient	-0.011722	-0.489522	0.364637	0.36562	0.198108	-0.39975
Std. Error	0.013965	0.051674	0.053372	0.0706	0.067068	0.085705
t-Statistic	-0.839392	-9.473221	6.83198	5.178777	2.953867	-4.664232
Prob.	0.402	0	0	0	0.0034	0

The long-run ARDL model that applies to the Dubai blend shows that a select few of the variable blends have an impact upon its price. Interestingly LWTI is not significant in either the long or the short run, omitted for space from table 5.12. When we examine the short-run ECM output, table 5.13, LOPEC and LUrals are not deemed to be statistically significant. This is a small number of blends that are significant in the long and short-run may stem from the LDubai being used as a pricing tool for sales, on long-term contracts, to Asia. The inclusion of LBrent is an acceptance of the what is happening globally whereas LBonny and LUrals, despite it not being included in the long-run ECM, are to varying extents competitors in the Asian market.

Table 5.13: LDubai ECM regression

Variable	Coefficient	Std. Error	P-Value
C	-0.011722	0.001869	0.000
D(LWTI)	0.055312	0.041958	0.1886
D(LBrent)	0.656935	0.055544	0.0000
D(LBonny)	-0.261172	0.053659	0.0000
CointEq(-1)	-0.489522	0.048254	0.0000

Remarkably, the ECM short-run output suggests that 48% of the errors from model, or deviations from its long-run for are corrected within one month. This again may reflect the nature of the negotiations and the basis upon which contracts are concluded, long-term.

5.3.1.4 OPEC basket

Table 5.14: LOPEC Long-run ARDL Model

Variable	C	LOPEC(-1)	LBRENT(-1)	LDUBAI	LBONNY
Coefficient	0.01407	-0.454552	-0.152469	0.212476	0.354021
Std. Error	0.009701	0.043949	0.036592	0.034487	0.052327
t-Statistic	1.450435	-10.34276	-4.166681	6.161041	6.765529
Prob.	0.1481	0	0	0	0

Trying to examine the precise impact of benchmarks upon the OPEC basket and draw conclusions is more difficult than in the case of a single benchmark. The spread of the basket of blends in terms of their inherent qualities and geographies could mean that on an individual basis the complexity of other models would be more apparent. As they are all composed together it is harder to ascertain those benchmarks that are significant in the price discovery process.

Intuitively the composition of the cointegrated system, that is the explanatory variables/blends, for LOPEC makes sense. Blends included in the OPEC basket are pricing from LBrent which is common across all blends in the study, and LWTI and LUrals. These blends can be seen as proxies for the largest producers, see Figure 2.2, USA and Russia and as a KSA blend is included in the OPEC basket it lends weight to the sense that they are the biggest producers in the world and consequently the benchmarks are significant. With regard to the extant studies and the omission of Russian crude in many studies, this result illustrates the importance of its inclusion in this study. Russia is one of the top oil producers and as such OPEC blends are incorporating information from this particular blend into its pricing calculations.

Table 5.15: LOPEC ECM regression

Variable	Coefficient	Std. Error	P-Value
C	0.014070	0.001542	0.000
D(LWTI)	0.104673	0.028469	0.0003
D(LBrent)	0.187453	0.045539	0.0001
D(LUrals)	0.150639	0.028145	0.000
CointEq(-1)	-0.454552	0.037236	0.000

5.3.1.5 Urals Mediterranean

Table 5.16: LUrals Long-run ARDL model

Variable	C	LURALS(-1)	LWTI(-1)	LDUBAI(-1)	LOPEC(-1)	LBONNY(-1)
Coefficient	-0.018137	-0.573174	-0.09306	0.126166	0.261983	0.229619
Std. Error	0.01135	0.050044	0.024942	0.04329	0.057542	0.078941
t-Statistic	-1.598046	-11.45339	-3.731125	2.914451	4.552872	2.908727
Prob.	0.1113	0	0.0002	0.0039	0	0.0039

The statistical output from tables 5.16 & 5.17, illustrates that LUrals is cointegrated with a most of the variables in the study. The output as part of the bounds test shows that LWTI is statistically significant whereas the long-run ECM form marks it as statistically insignificant. Equally this form has dropped LDubai and LOPEC from the equation. From the short-run ECM table we can see that LWTI is not significant but the speed of adjustment at 57% within one month is the fastest within all of the models in the study

Table 5.17: LUrals ECM regression

Variable	Coefficient	Std. Error	P-Value
C	-0.018137	0.001884	0.000
D(LWTI)	-0.004399	0.033579	0.8959
D(LBrent)	-0.165351	0.034008	0.000
D(LBonny)	0.772699	0.0.034008	0.000
CointEq(-1)	-0.573174	0.045788	0.000

5.3.1.6 Bonny Light

Table 5.18: LBonny Long-run ARDL Model

Variable	C	LBONNY(-1)	LWTI(-1)	LBRENT(-1)	LDUBAI(-1)	LOPEC(-1)	LURALS(-1)
Coefficient	-0.005291	-0.596162	0.089007	0.153155	-0.13881	0.126182	0.373402
Std. Error	0.009839	0.058819	0.022104	0.04009	0.036951	0.056354	0.049918
t-Statistic	-0.537773	-10.13557	4.02671	3.820262	-3.756581	2.239103	7.480378
Prob.	0.5912	0	0.0001	0.0002	0.0002	0.026	0

The close relationship exhibited in both systems of equations for Urals and Bonny Light could imply that for buyers there is a high level of substitutability between these two blends, however the inherent qualities of the oil do not indicate that these are close substitutes with some similarities in terms of gravity but marked differences in sulphur content. Benchmarks such as Brent and WTI do feature, are statistically significant, but if we examine the coefficients in table 5.18, LUrals in the LBonny system is far greater than that for any other variable. Looking at the results of the LUrals system the same can be said of LBonny within the LUrals system. It is clear that there is a strong relationship between the two blends, one that is stronger than that for any other LUrals or LBonny relationship. The underpinning rationale is not borne out of marked similarities in the inherent qualities of the oil but more in terms of the markets that each blend is competing over.

Table 5.19: LBonny ECM regression

Variable	Coefficient	Std. Error	P-Value
C	-0.005291	0.001113	0.0000
D(LWTI)	0.000393	0.029652	0.9894
D(LBrent)	0.233229	0.045616	0.0000
D(LOPEC)	0.355168	0.028792	0.0000
D(LUrals Med)	0.587390	0.054098	0.0000
CointEq(-1)	-0.596162	0.054098	0.0000

Overall, when examining the statistical output from the error correction modelling of these benchmarks the general points that can be made are the following.

Brent is significant in the cointegrated systems of all dependent variables.

WTI is not consistently represented through the systems of equations, it only features in a statistically significant way for Brent and the OPEC basket.

The Dubai blend whilst an important benchmark for pricing crude sales to Asia from the Persian Gulf it lacks the ubiquity of a truly global blend such as Brent.

There is evidence that LBonny and LUrals are closely linked despite inherent differences

The cointegrating variables in all systems are negative and statistically significant which supports the F-Statistic bounds test results.

5.4 Structural Breaks

Examining the data visually, Fig 5.0 & 5.1, identifies points in the data over the sample period when there is clearly a break from the observable trending pattern.

Figure 5.0: Sample oil prices 1996-2018

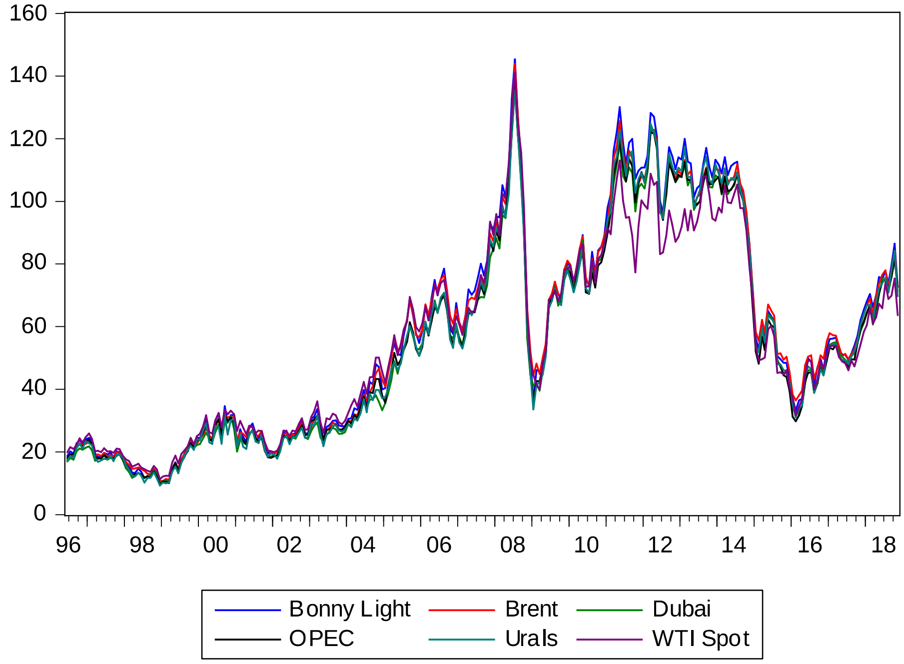
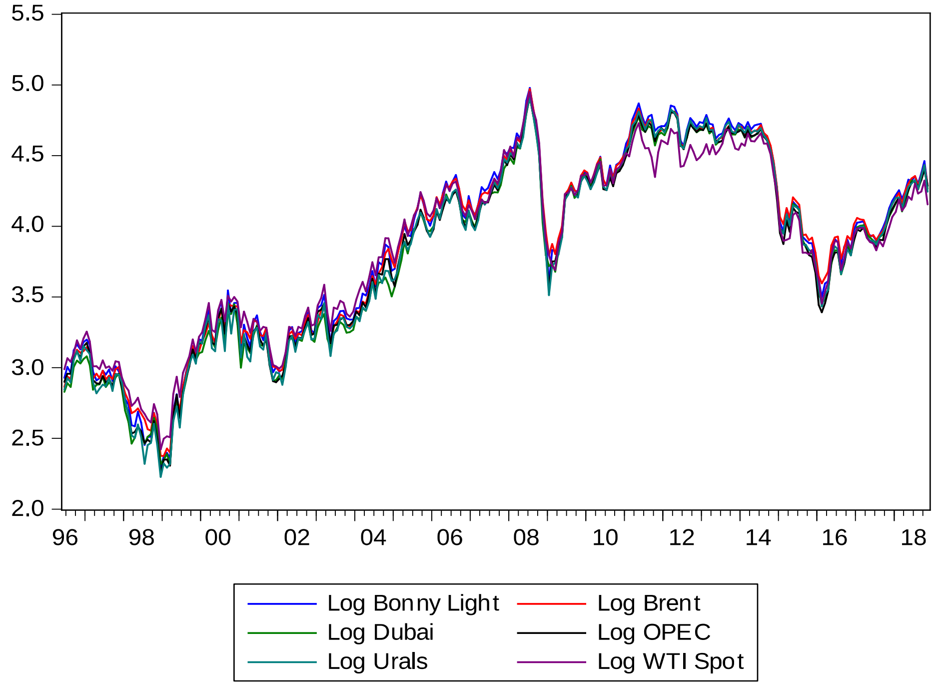


Figure 5.1: Sample oil price Logs 1996-2018



The clearest deviation is the period between 2008-2009 when all oil prices were affected by the financial crash. This is a break that affects all variables in the study and not the relationships between them, therefore it may not be the case that the Bai-Perron break tests pick this up as a break as we are testing for breaks in the relationship or in the systems for each variable. That said in the run up to this period there are indications that Brent oil is trading at a premium, albeit small, to the market. The next point of interest is the behaviour of WTI, from 2011 through to mid-2014 when the benchmark clearly deviates from other benchmarks and is trading at a discount to other blends. From this point on towards the end of the sample period the benchmarks lock into the same pattern although Brent, again, seems to be trading at a premium to the other blends.

Given the evidence presented in chapter two of this report this visual data confirms market reports of a dislocation in the relationship between WTI and the market due to logistical issues. With WTI moving back into step with the other blends it would appear that these issues were solved and that trade was flowing once more. That said given the inherent qualities of the two major benchmarks, the poorer quality of Brent relative to a sweeter crude such as WTI then the former should trade at a discount to the latter. However, on close examination of the time series data presented in the chart the evidence points to Brent still trading at a premium to WTI.

An important point to note prior to establishing break points in the data is that when a break point such as 2008/9 stands out it may not represent a break in the relationship between the variables. Certainly, it is a breakpoint in each individual time series but does that reflect a break in the cointegrated relationship between the variables in each model?

5.5 Multiple Regression Bai-Perron Break Test

The establishment of single equations for each variable in the study provides interesting information. In order to take the testing of this one step further the examination of how these models perform over time and where the structural breaks occur is important to examine as it provides some indication over how these models have changed over time and the speed with which they realign after a period of disequilibrium.

Using the Break LS function which is essentially a regression using the Bai Perron break test is a neater and clearer way to examine the interplay between the variables in each system over time. It can incorporate structural breaks in each system of equations thus allowing us to compare how these regimes change over time.

The simpler way to deal with the presence of breaks is to use the ECM output in the Break LS function on EViews which essentially provides a multiple regression with breaks tested for using the Bai-Perron test for multiple break dates, as used in section II of this chapter. This involved differencing the logged values of each variable specified in the ECM output in an OLS multiple regression and saving the residuals. The appropriate variables along with the residuals were then modelled using the Break LS function to establish the presence of breaks in each cointegrated system and using the residuals the speed of correction to the long-run equilibrium in each regime if appropriate.

Given the number of variables and lags that have to be fitted into this model to test for cointegration, there is a danger that the model could become over parameterised, essentially too many things going on, in order to make sense of the results and there is also the risk of multicollinearity where there is a significant degree of intercorrelation between the variables which makes trying to assess the impact that one variable has within the model a fruitless task. This dealt by the use of the HAC Newey test criteria to apply a more robust standard error and produce more accurate P-values. This step was only necessary in one regime of Dubai.

Another point of note before we consider the results is the choice of variables in the equations for each variable. The long-run form output as established in section 5.3 of this chapter, has been used as a base, however there is a balance to be struck between overparameterisation and parsimony. In most cases sticking to the long run output enables us to eliminate what is not important, on the other hand this may go too far and we are essentially omitting variables or their lags that may determine the (change in) price of a variable. The changing nature of the models could mean that variables are significant in one period and not in another and it is important to capture this as it may point to some of the strategic shifts that we see within the global oil market. Equally, there is no harm in including variables if they turn out to be insignificant in all regimes of the model. They can simply be eliminated from our final analysis.

Prior to examining the test results from each regime, the key points to note from this test is the significance of the variables, the break points and the performance of the residuals in both regimes. The results are presented in terms of statistical significance, this in the main is at the

5% level, however there are a number of variables that have been included as they sit just above this cut off level, these are denoted by ** for probability values at the 5% confidence level and * for those at the 10% level. A fuller examination of the results for each benchmark and regime can be obtained by going to Appendix 3, at the end of this chapter. All models were tested for serial correlation and homoskedasticity. In the tables the variables are pre-fixed with D to denote that they have been differenced, in the discussion thereafter the D has been dropped and the variables are referred to in their logged format, LWTI etc.

5.5.1 Break LS results Analysis

Table 5.20: SupF test/Double Maximum test results

	Global L Breaks vs none			Sequential Sup F test (L vs L+1)			
Blend	Sup F test	UDMAX	WDMAX	0 vs 1	1 vs 2	2 vs 3	3 vs 4
LWTI	25.156*	33.352*	33.352*	33.352*	17.975		
LBrent	46.403*	71.34*	71.34*	71.34*	32.435*	14.145	
LDubai	38.379*	33.344*	40.334*	33.344*	26.201		
LOPEC	48.865*	46.554*	48.865*	46.554*	21.608		
LUrals	29.399*	41.18*	41.18*	41.18*	17.675		
LBonny	32.573*	36.993*	38.285*	36.993*	24.6599		

As can be seen in table 5.20 two tests were performed on each equation system for each variable. The Global L breaks versus none tests the null hypothesis of no breaks versus in favour of a single break. In each system we can see that the test results are clearly greater than the critical values as laid out by Bai-Perron (2003) and are significant at the 5% level. This show that there is a significant break in each system.

The significance of the test results using the sequential L vs L+1 test explores the significance of the break dates. As we can see from table 5.20 this shows that there is one significant break in each equation system with the exception of LBrent which has two significant breaks.

5.5.1.1 WTI

Table 5.21 LWTI Break LS Results

LWTI 1996M09 – 2008M09	
Variable	Coefficient
D(LBrent)**	0.406256
D(LDubai(-1))*	-0.156445
D(LOPEC)**	0.563240
RESIDWTI(-1)**	-0.332534
LWTI 2008M10 – 2018M11	
D(LWTI(-1))**	0.518214
D(LBrent)**	1.079063
D(LDubai(-1))*	-0.293521
RESIDWTI(-1)**	-0.692983

The LWTI model has been expanded in order to accommodate more lags of the variables as when testing in the long-run form the results were tested for serial correlation and heteroskdasticity. On both tests the test statistics were out suggesting that there was the evidence of both within the model. Rather than choose the HAC Newey West conditional parameters which can accommodate serial correlation, the parsimony of the model suggested that the number of lags could be included to eliminate the chance that the residuals were picking up on key elements missing from the model. Lags were added, according to the ARDL specification, table 5.8. This produced a model that was significant and satisfied the criteria of no serial correlation in the residuals and homoskedastic.

As can be seen with the regression output by looking at the P-values in the table for values around the 95% cut off level, in both regimes the lag of LWTI is statistically significant, whilst the current value of LBrent is significant in the pricing of LWTI. Thereafter what is notable in terms of the significance of variables in the cointegrated relationship with LWTI is the one period lag of LDubai.

Might the change in significance of the LDubai(-1) in relation to WTI in the second regime be indicative of the changes that we see in the global oil market? The emergence of fracking and the US market's increasing oil self-sufficiency which could in large part underline this diminished role for LDubai(-1) in the pricing considerations for WTI.

In terms of the break point the significance of the two regimes and the break date points the global financial crash, although how much of this applies singularly to LWTI is debatable. An examination of the graphs, Fig 5.0 & 5.1, for all benchmarks in the study shows the importance of this event. Further discussion of the break dates is undertaken is section 5.5.2.

An analysis of the residuals in these systems allows an assessment of the speed of adjustment to deviations and reversion to the long-run equilibrium. The two regimes show a contrast in that adjustment process with the speed of adjustment being twice as fast in the second regime compared to the first, 69% compared to 33% of the deviation corrected within one period. Potentially, the increased information flows due to financialisation, discussed in chapter 2, may play a part but this requires more evidence from other (benchmark) regimes to be fully considered.

5.5.1.2 Brent

Table 5.22 LBrent Break LS Results

LBrent 1996M11 – 2000M05	
Variable	Coefficient
D(LWTI)**	0.619403
D(LWTI(-1))**	0.339929
D(LDubai)**	0.560786
D(LOPEC(-1))**	-0.427022
D(LBonny)**	-0.235086
RESIDBR(-1)**	-0.625817
LBrent 2000M06 – 2005M05	
D(LWTI)**	0.351000
D(LOPEC)**	0.282141
D(LDubai)**	0.234103
RESIDBR(-1)	-0.001932
LBrent 2005M06 – 2018M11	
D(LWTI)**	0.083862
D(LDubai)**	0.351873
D(LOPEC)**	0.304392
D(LOPEC(-1))**	-0.237344
D(LBonny)**	0.195466
RESIDBR(-1)**	-0.667079

Given that LBrent is an important global benchmark, perhaps THE global benchmark, it is not surprising that the model has more variables, lagged variables included, than other dependent variables in this study. When examining table 5.21, above, there are a number of interesting points, firstly the relationship with LWTI. Whilst still statistically significant the strength of the coefficient is weakening from regime to regime. Is this part of the decoupling of LWTI from the global oil pricing system as US producers, distributors and refiners grappled with increased US supply? This phenomenon occurred from 2011 onwards, so it does chime with events but there is a large period when there was no apparent reason for the decline in the strength of the LWTI coefficient in this regime.

The model suggests that three regimes and two structural breaks over the entire sample period. As we progress through three regimes, the number of statistically variables that increases. LDubai variable remains statistically significant in all regimes, whereas the OPEC basket, LOPEC, does not feature in the first regime, only its lagged value is statistically significant, but does so in the second and strengthens in the third regime.

The speed of adjustment from disequilibrium back to equilibrium is varied. The speed in the first and third regimes is largely consistent, the second regime is not statistically significant which may point to partial cointegration across the entirety of the sample period.

5.5.1.3 LDubai

Table 5.23: LDubai Break LS Results

<table>
<tr><td colspan="2">LDubai 1996M09 – 2006M02</td></tr>
<tr><td>Variable</td><td>Coefficient</td></tr>
<tr><td>D(LDubai(-1))**</td><td>0.0.803133</td></tr>
<tr><td>D(LBrent)**</td><td>0.552332</td></tr>
<tr><td>D(LBrent(-1))**</td><td>-0.568658</td></tr>
<tr><td>D(LOPEC)**</td><td>0.460105</td></tr>
<tr><td>D(LBonny(-1))**</td><td>-0.230178</td></tr>
<tr><td>RESIDDUB(-1)**</td><td>-0.886274</td></tr>
<tr><td colspan="2">LDubai 2006M03 – 2009M05</td></tr>
<tr><td>D(LBrent)**</td><td>0.88798</td></tr>
<tr><td>D(LBrent)**</td><td>0.485686</td></tr>
<tr><td>D(LOPEC)**</td><td>0.319409</td></tr>
<tr><td>RESIDDUB(-1)**</td><td>-0.884304</td></tr>
</table>

LDubai may be a new “global” benchmark given the level of demand from Asian nations and the role that this blend plays in pricing these long-term transactions. In terms of systems of equations for LDubai from the first to the second regime there are fewer blends that are important, and statistically significant. LBrent is clearly very important in determining the price of the LDubai in each regime in terms of the coefficients and significant P-values. LBonny is statistically significant in the first regime but not the second.

The adjustment to disequilibria is in direct contrast to all other blends in the study. The speed of adjustment weakens in the third regime. This is somewhat surprising as the establishment of a futures contract, in 2008, would allow for greater depth to the market with increasing numbers of participant both trade and speculative. Increasing prominence in referencing other transactions and a futures market present arbitrage opportunity for speculators and trade participants and hence a quickening speed of adjustment through all regimes may have been expected. That said the adjustment is still relatively quick which tends to reject the findings of Ghassan and Banerjee (2015) who contend that OPEC produced crude is somewhat slower to react to shocks than non-OPEC produced crude. The timing of the structural break will be examined in section 5.5.2.

5.5.1.4 OPEC basket

Table 5.24: LOPEC Break LS Results

LOPEC 1996M06 – 2003M08	
Variable	Coefficient
D(LDubai)**	0.306575
D(LWTI)**	0.452659
D(LBonny)**	0.302002
RESIDOPEC(-1)**	-0.261451
LOPEC 2003M09- 2018M11	
D(LOPEC(-1))**	0.428152
D(LBrent(-1))**	-0.433740
D(LBonny)**	0.200805
D(LBrent)**	0.444760
D(LUrals)**	0.281867
RESIDDUB(-1)**	-0.714524

As has been explained previously the nature and the variance of the OPEC basket makes it difficult to see this as a benchmark in the same way as LBrent or LWTI, all benchmarks are baskets of different oils but LOPEC is a basket of many different sorts, viscosities, countries of origin and sulphur contents. That said, it does provide useful information for the purposes of this study in terms of how much attention the market pays to it, which has increased importance due to the historical role of OPEC in the market.

The statistical output from this test has some very interesting results. Firstly, the absence of LBrent as statistically significant in the first regime whilst LWTI reverses this position from being statistically significant in the first to insignificance in the second regime. This could be interpreted as tacit recognition of LBrent being the global benchmark. However, as section 5.5 will show the relationship between LOPEC and LWTI should not be discounted given the strategic shift in OPEC policy in 2014.

The break date is not in line with any major geopolitical or oil market event. The 2003 invasion of Iraq had been concluded by the point of the only break and there are no other events in this year that would obviously point to a break. The speed of adjustment to errors in the long-run relationship are worthy of note with a 71% correction rate in the second regime compared to 26% in the first regime. Again, this provides some support for Ghassan and Banerjee (2015) in the first regime but is contradictory in the second.

5.5.1.5 LUrals Med

Table 5.25: LUrals Break LS Results

LUrals 1996M09 – 2001M03	
Variable	Coefficient
D(LBrent)**	-0.296937
D(LBonny)**	1.142133
RESIDWTI(-1)**	-0.165130
LUrals 2001M04 – 2018M11	
D(LUrals(-1))**	0.396329
D(LDubai)**	0.232127
D(LOPEC)*	0.134568
D(LBonny(-1))**	-0.441298
D(LBonny)	0.757745
RESIDWTI(-1)**	-0.725193

When the model and breaks for the LUrals blend of oil the following points are noteworthy. In the first regime that runs from 1996 until 2001 there are few blends that are statistically significant. In the second regime the lags of LBonny becomes more important with the lags of this blends having a statistically significant impact on LUrals. Examining the break dates in terms of market events shows nothing remarkable about this date but given the economic turmoil in Russia in the late 1990s this could be heralded as the point where the infrastructural investments that had been made throughout the 1990s were starting to bear fruit and Russian oil went global. The speed of adjustment to imbalances in the long-run equilibrium increases markedly from one regime to the next. The gaining strength of Urals, in this regime and others, may be attributable to the reliability and increased supply in key markets as a result of infrastructure investment and the Baku to Novorossiysk pipeline with its connection to the wider world in the Black Sea.

5.5.1.6 LBonny

Table 5.26: LBonny Break LS Results

LBonny 1996M06 – 2006M05	
Variable	Coefficient
D(LBrent)**	0.22644
D(LOPEC)**	0.524241
D(LUrals)**	0.47545
D(LDubai)*	-0.091311
RESIDBON(-1)**	-0.6106
LBonny 2006M06 – 2018M11	
D(LUrals)**	0.791930
D(LBonny(-1)**	0.55753

D(LBrent)**	0.1956
D(LDubai)**	-0.140386
D(LOPEC)**	0.161737
D(LOPEC(-1))**	-0.352235
RESIDBON(-1)**	-1.007

There is one regime over the sample period for Bonny Light. The curious question in all of this is the close relationship between LBonny and LUrals. As we have noted the substitutability of these blends is limited but sales into the (Southern) European market, and perhaps Asia, should not be overlooked when examining the reasons for this close relationship.

The speed of adjustment of the errors in the long-term relationship is also worthy of discussion. This is between the first and second regimes. The second regime is statistically significant with 100% of the errors were corrected within one period, one month. This increase in the speed of adjustment in in line with almost all other blends with speed increasing towards the end of the sample period and the era of increased financialisation.

5.5.2 Break Dates

The significance of the structural break dates across all variables to which our attention must turn. The break dates across the systems for each variable do not point to one defining moment in which the global system changed for all of these variables in the same way. This may be indicative of a market that on one hand is cointegrated but with nuances particular to each blend, so there is no one seismic event that affect all of the variables in the same way, such an event as we can see from the 2008 financial crash can affect all variables but thereafter such events do not unify the market responses. The impact of exogenous factors is something that we must always allow for, indeed Feuki et al (2018) found that in a study of global oil production over the period 2005-2016 that 30-35% of the fluctuations in oil prices in the global oil market could be attributed to what could be deemed to be supply and demand factors, thereafter it was the prospect of shocks in the future, financialisation, the impact of shale oil in press reports. The point in relation to the causes of structural breaks is one that has been emphasised throughout this study, that oil prices are a story of supply and demand and yet so much more. That some factors result in short term errors from the long-run equilibrium relationship whilst other events can have a more lasting impact, a structural break, is clearly not an exact science. What follows below is a contextual analysis of events occurring around the time of the structural breaks in each equation system. The purpose of this research is not an event study and therefore we must examine the evidence perhaps more in circumstance than in causation.

The global financial crash features heavily in the structural break for WTI. This marks the end of the Great moderation in the US and other economies and the changes. The Great Moderation is a period of change in terms of the dynamic impact of rising oil prices on the global economy, in that it is seen as inflationary however in the period up to the financial crash and the commodity supercycle the impact on inflation was more muted than in previous periods (Nakov and Pescatori, 2009). With the financial collapse this period and the period of rising oil prices came to an end which marks a break in the pricing of WTI.

The break dates associated with Brent are interesting. If we examine the period around the 2000 this is a period when there was genuine concern regarding the supply of oil to make up the Brent benchmark (Barrett, 2012). The May/June 2005 structural break occurs at the point when the 2005 US energy policy Act was going through the legislative process, which mandated the mixing of (Corn-based) ethanol into gasoline in the US market and granted US producers subsidies along with royalty reductions on drilling from marginal wells(CRS, 2005). In all this was designed to wean the US off of imports of foreign produced oil, notably exports from the Persian Gulf.

The structural break in the pricing system for the Dubai blend relates to the announcement of the establishment of the Oman crude oil futures contract in June 2006. This ability to discover prices and for traders in this market to either speculate or cover positions is a significant step forward in the Dubai market and that of the global oil market and has been amply covered throughout this research report.

The year 2003 features in the breaks for LOPEC. This coincides with the beginning of conflict in the Gulf with the second Iraq war, which whilst is eventful for the poor people in that area may have short term effects on the oil market. The greater significance, according to Simmonds (2007) is the peaking of production in Mexico, the United Kingdom and Indonesia which marked the beginning of the upward movement in global prices, or “price gouging”.

April 2001 is an important point for Russian oil. Overall the 1990s had been a period of restructuring and 1998 to 2001 marks a set of changes that galvanise Russian oil, (Hill and Fee,

2002) as increasing oil prices against a weakened rouble resulted in significant investment in the Russian oil market. Russian oil majors, Lukoil, TNK and Yukos increased production between 20-40% over that period and by 2002 Russia would overtake KSA to be, temporarily, the world's largest producer of oil. Seven OPEC meetings throughout 2001 pushed for production cuts, the first of which was 16th March 2001 in Vienna at which Russia, Norway and Mexico were called on to cut production in the face of falling oil prices. This may provide some rationale for the structural break in the data in the following month, whilst the final agreement on very moderate non-OPEC production cuts was eventually agreed in December 2001 (Riding, 2001).

The March 2005 structural break for Bonny light can be cast against the backdrop of oil prices broke through the significant $50 per barrel in that month. There is also confirmation of the changing shape of Nigerian oil with the exploration and production licenses being entirely bought up by Chinese and Indian oil companies in May 2006. This was in return for promises of investment in infrastructure and followed on from a state visit by Chinese President, Hu Jintao, in April of that year (IHS Markit, 2006). Whether this is significant enough to mark a structural break in the pricing of Bonny Light and its interaction with other variables is perhaps debatable but a clear pivot in the direction of the Nigerian oil market is suggested by these events in the months preceding the structural break.

5.5.3 Break Test Conclusion

The statistical output of this set of tests across all benchmarks presents increased evidence of cointegration but the idea of one great pool may not be as strongly supported. It paints a shifting picture from regime to regime across all blends. The changing composition can be attributed in part to the changes that have taken place in the wider market. There is some but not overwhelming evidence throughout the regimes of the weakening influence of LWTI.

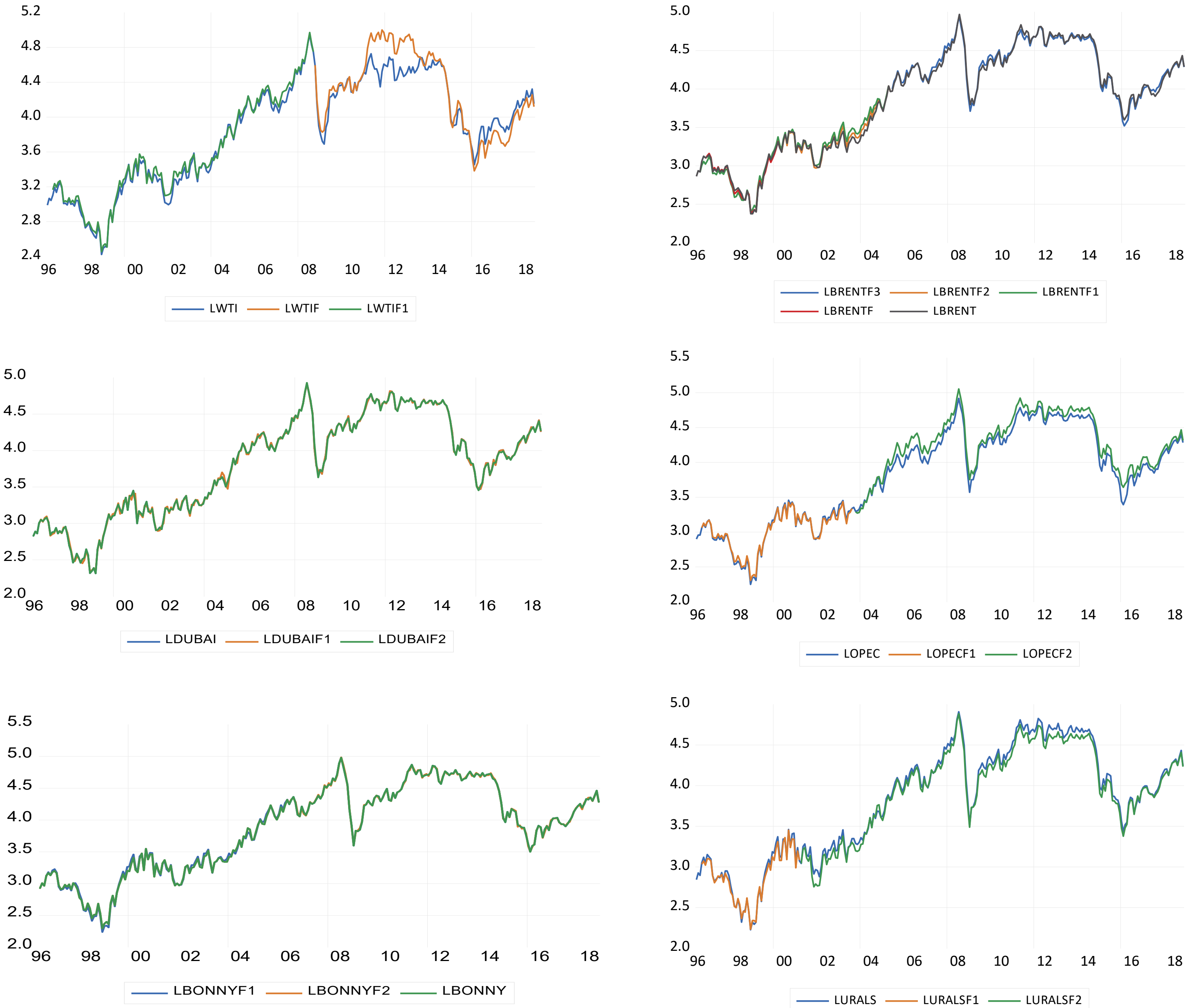
The role of LUrals is also important to note. In three out of five dependent variable systems it is statistically significant in at least one or more of the regimes, later dated regimes especially. LBrent and LWTI are not influenced or cointegrated with LUrals, there is no relationship. Given that we are examining the cointegrating relationships for evidence of "one great pool" this appears to contradict this idea. In the conclusion the implications of this observation will be fully considered.

The speed of correction from one regime to another is of interest. Mostly through the regimes the speed of correction to errors/deviations from the long-run equilibrium increases. There are some regimes that stand out when it appears that the errors are not corrected however as these coefficients are not statistically significant we can perhaps put forward the idea that these were periods when the market may not have been fully cointegrated and therefore we have data that is neither negative or statistically significant.

5.6 Fitted Values

In a final analysis the forecast capacity of the model was tested with predicted values across all the regimes of the sample period for each dependent variable compared to actual values of the logged variables. This has highlighted some interesting points that confirm some of the findings from the literature but moreover shows much about the strength and changing nature of the key relationships between blends. In the next page graphs for each variable and its predicted values are shown. What then follows, breaks with the convention of this chapter and only considers variables where there are points of note that helps with the analysis. Generally, the graphs of the forecast values, predicted by the model, and the actual values illustrates the power of the model to predict. In most models there are some deviations but largely both lines of the graph traverse a similar path, to such an extent in most periods that they are indistinguishable.

Fig 5.2: Fitted Values



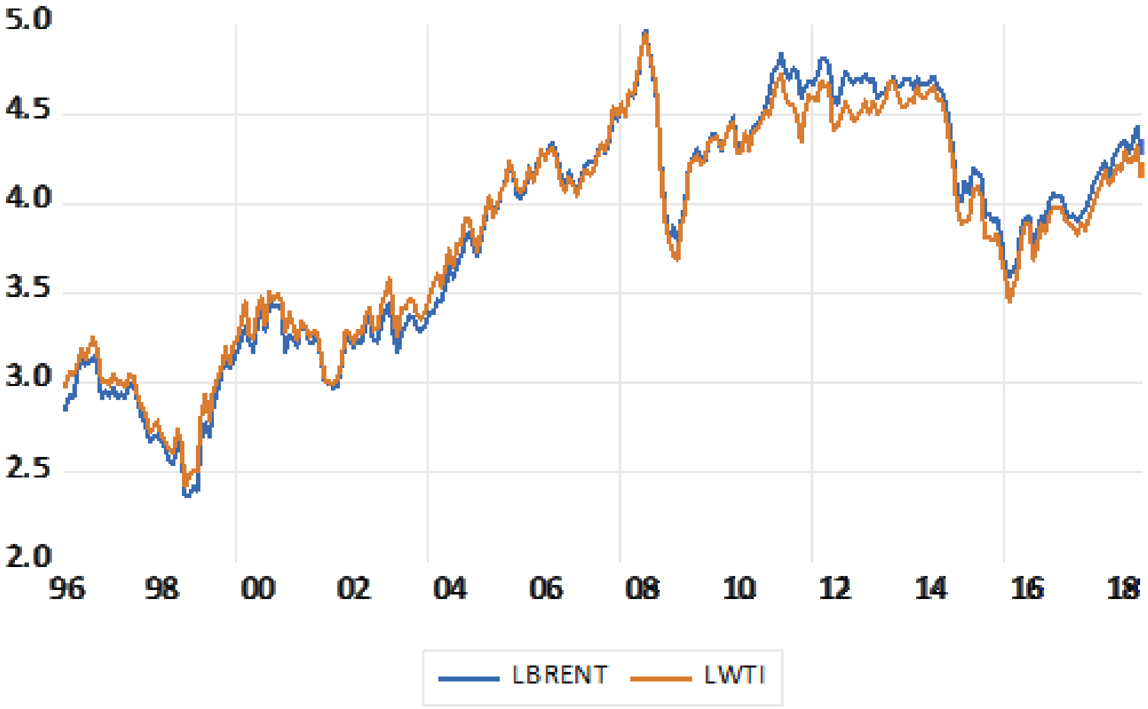
5.6.1 Anomalies

If we examine the graph below, figure 5.3, that illustrates the fitted values of LWTI against its actual values then we can see that largely the model we have constructed on the basis of the ECM from the ARDL output is a very good indicator of what happens with the LWTI. However, there is a glaring anomaly, that is the period from 2010-14. The deviation between the actual and the fitted values, as predicted by the performance of the dependent variables, coincides with the point at which vast deposits of US LTO were discovered. As noted in chapter 3 this is the period when WTI de-coupled from the global oil market in terms of cointegration as the pipeline and refining capacity constraints choked WTI supply and it was not regarded as a reliable benchmark by the market to price from.

Figure 5.3: LWTI fitted and actual values

The importance of Brent to the price of WTI, figure 5.4, is also worthy of note, with the log of Brent, replacing the fitted values of LWTI. From the graph, below, the extent of the cointegration of the two blends is illustrated but in that crucial period of 2010-2014, the deviation between LBrent and LWTI is not as stark as the full model, which admittedly only contains one other significant variable, the lag of LDubai. How this could be interpreted is that LBrent as a heuristic can be a quick indicator of what happens to LWTI. Indeed, this is a familiar theme that we will see across almost all variables in the study. LBrent, as has been repeatedly commented upon, is the global benchmark. It may also be put forward that the real change came with the US LTO revolution, as it has confirmed Brent's status as the dominant global benchmark. This may not chime with writers such as McNally (2016) who question the dominance of Brent, but this notion, currently, is not borne out by the evidence.

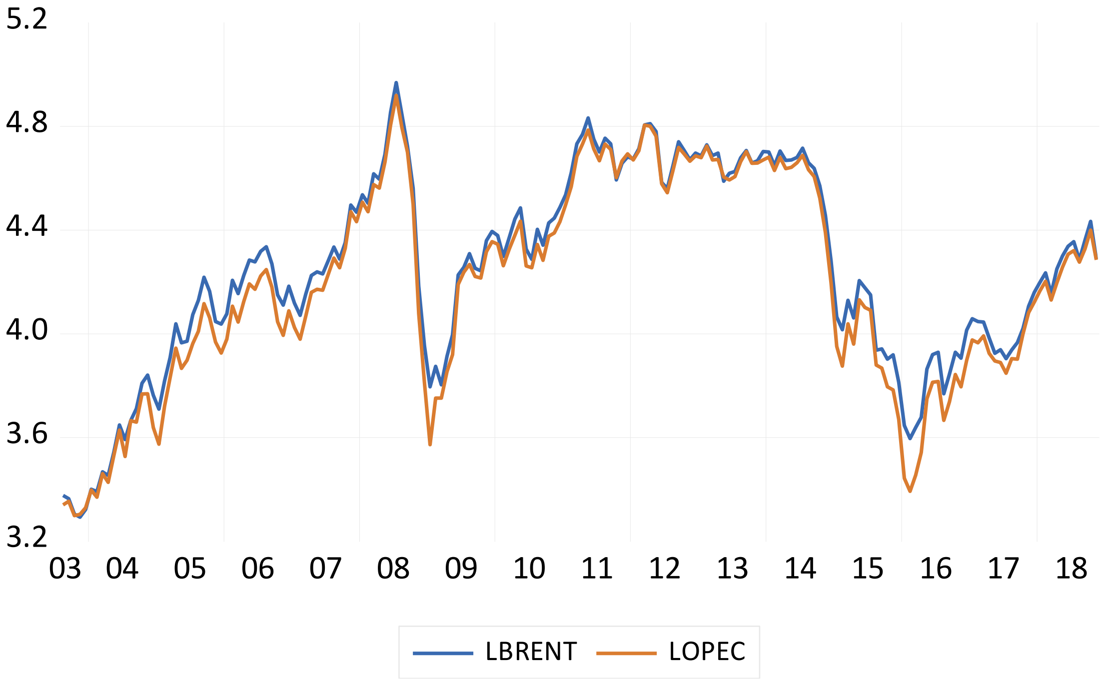
Figure 5.4: LBrent v LWTI



The fitted values of LBrent versus the actual value of LBrent, again illustrates the predictive power of the model. There is slight deviation in some periods but overall, especially in the last regime the predicted and actual values are in closely in step with each other. As noted previously the power of LWTI across the three regimes of LBrent does decrease but nevertheless it is a powerful indicator in the first two regimes.

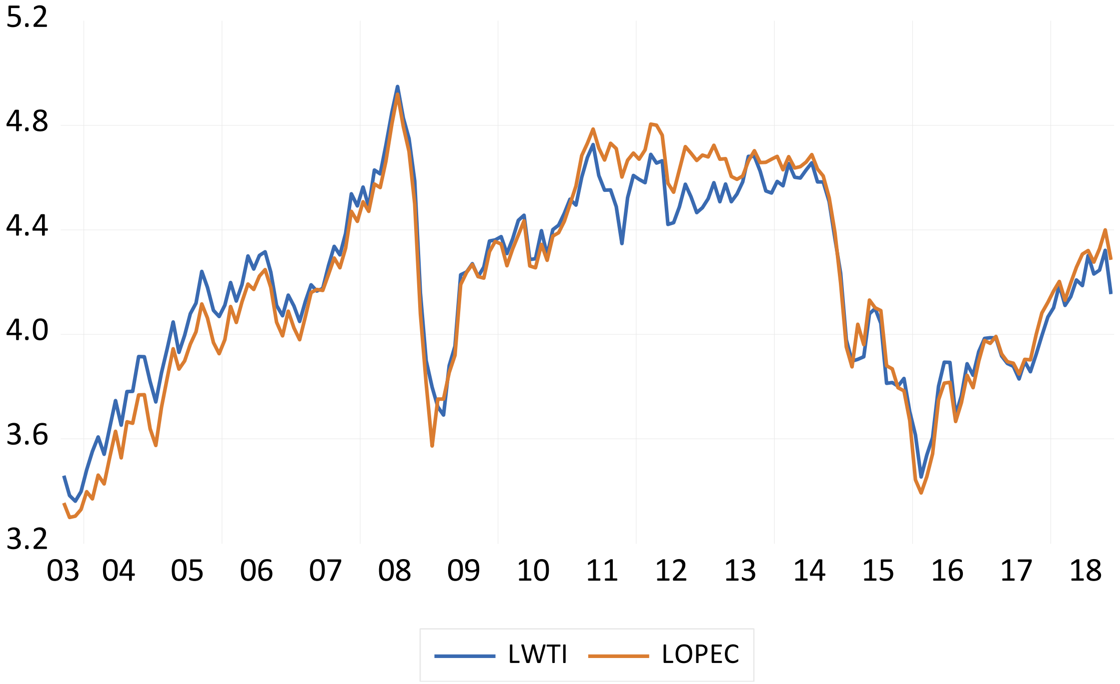
An examination of the LOPEC highlights some interesting findings. The fitted values, again, show a model specification with high predictive power. In line with the previous analysis, the predictive power of LBrent, as it is established as a global blend, relative to LOPEC is very interesting. As discovered from the Break LS tests, there are two regimes over the sample period for LOPEC. In the first of these LWTI is also a strong and statistically significant factor in determining the change in price for LOPEC. In the second regime its power fades, however an examination of the performance of LOPEC/LBrent and LOPEC/LWTI tells a somewhat different story and one that confirms the impact of strategic shifts in OPEC policy.

Figure 5.5: LBrent v LOPEC 2003-18



As can be seen from the graph above, figure 5.5, both benchmarks follow similar paths, with some periods of small divergence, however the period from 2011 through to mid-2014 LOPEC and LBrent are indistinguishable from each other. From mid-2014 something within the relationship appears to change. There is a rather large divergence that runs through until mid-2017. If we then examine the LOPEC/LWTI relationship from 2014 onwards there is closer relationship, much closer that that between LOPEC/LBrent.

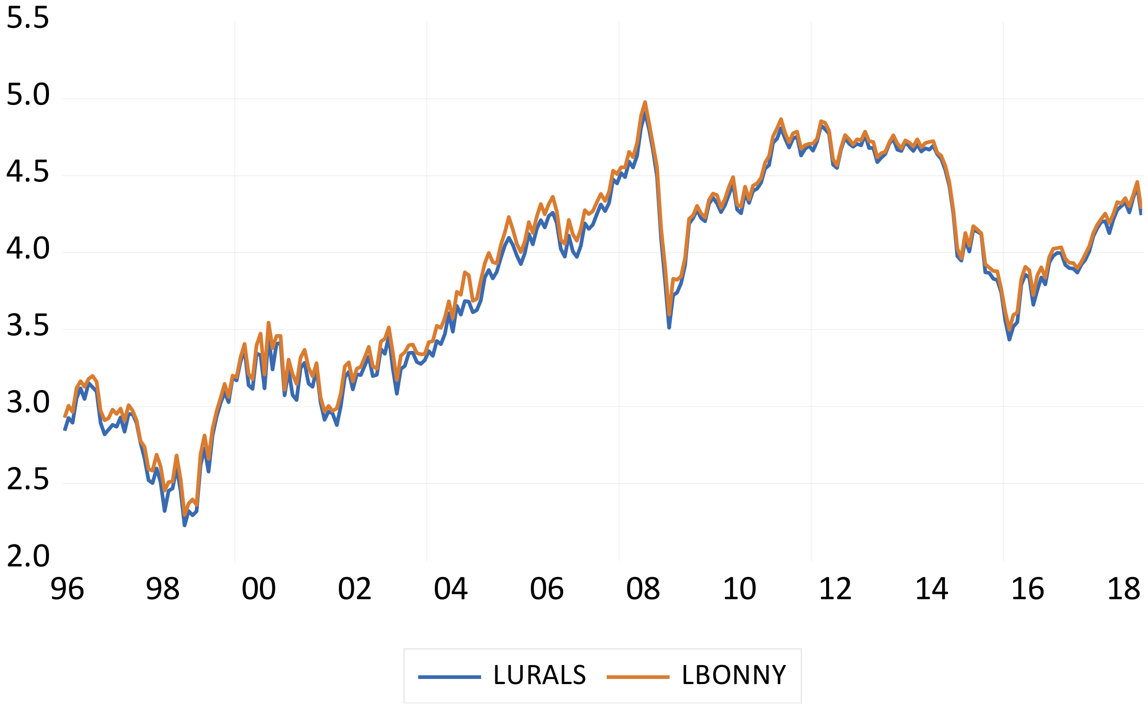
Figure 5.6: LWTI v LOPEC 2003-2018



Indeed, this change in the relationship coincides with the OPEC announcement of no production cuts. Figure 5.6 perhaps suggests that the members of OPEC were pricing more in reference to LWTI than LBrent over this period. A break LS regression was conducted using LOPEC and LWTI over the sample period 2013-2018, indeed it found that a statistically significant structural break occurred in August 2014. Furthermore, if we refer back to figure 5.5, the relationship between DLOPEC and DLBrent appears to occur around July 2017 happens at the same time as OPEC and KSA abandon the price war policy and opt for production cuts, in effect they stop targeting WTI to the extent that it had previously been doing. A resumption of business as usual? Whilst this precedes the actual OPEC announcement it is unlikely to be coincidence.

The benchmarks, LWTI, LBrent, LDubai and LOPEC from the regimes identified and the graphs in this section are cointegrated with each other. The case of LUrals Med and LBonny is a different proposition. As the graph, Figure 5.7, below, indicates there is a strong relationship between the two blends, prior to the financial crisis there is some divergence, however from 2008 onwards both benchmarks are hand in glove in terms of following the same price path. As has been mentioned this is interesting given that there are qualitative differences between the two blends and is driven more by the markets in which they compete. The increase in US production has forced Nigerian production to compete in different markets than it had prior to the increase in US production which may be reflecting in its ever-closer relationship to LUrals, that is they are competing in the same markets.

Figure 5.7: LBonny v LUrals 1996-2018



5.7 Conclusion

Working through the various steps of the research process using the data on the benchmarks from the global oil industry has provided valuable insights into the functioning of the global oil market. The extent to which the global oil market is a series of interlinked markets with very strong connections from one to the other is clear. That all the blends in the study are cointegrated provides support for the idea first put forward by Adelman that the market is "one great pool". That said there is also robust evidence to suggest that this idea has some limitations. Blends that compete in the same markets, in part due to the refinery constraints of those markets, may also show, but not necessarily so, strong similarities in terms of the inherent qualities of viscosity and sulphur content are more cointegrated, and the coefficients within these regimes serve to highlight the strength of those relationships. Urals and Bonny Light exemplify this point in relation to market served rather than the inherent qualities argument.

These findings support Gullen's work (1997,1999), and points more strongly at the nuance with some evidence of cointegration but a stronger link between similar types of oil, i.e. in terms of viscosity and sulphur content or selling to the same market.

There is overwhelming evidence that Brent is the global benchmark. It is statistically significant across all blends and nearly all regimes within those blends. Speculators looking for cues as to price movements in blends of oil should look at Brent, alone it is a strong predictor of how other blends will perform. This does support the "one great pool" idea. If there is unity in the market it is because blends and benchmarks that could be considered to be globally or regionally important are all pricing from movements in Brent. What they are not doing is pricing from each other. When Brent is removed from the equation the picture becomes more nuanced. Similarities or more importantly similar markets look to driving the relationships.

This then leads to the next point regarding WTI as a benchmark. WTI is a well referenced benchmark in the terms of the US market but on the basis of the results from this study there are fewer statistically significant, cointegrated relationships than may have been expected at the outset. Its ubiquitous presence in previous studies could be questioned, outwith studies of regional US blends. The historical bottlenecks at Cushing Oklahoma look to have had a major impact on it decoupling from the cointegrated system, at this point it was no longer a reliable benchmark, its price contained more information about US supply squeeze than the state of the market globally. If we are searching for a before and after effect of the light tight oil discoveries in terms of WTI being more cointegrated and important in terms of the number of relationships, strength and significance of the coefficients then so far there is little evidence here to suggest a step change. This is likely to change as high yielding US oil competes globally, especially after the Covid-19 pandemic when there is likely to be increased competition for a smaller demand.

Reboredo's (2011) contention that there is bidirectionality between the big blends, WTI and Brent is supported by this study. Indeed, the evidence of Brent's diminishing role as a benchmark for the global market is countered completely by the evidence presented here. Indeed, it could be said that WTI's role is diminishing. Section 3.2.1 called for the relationship between Brent and WTI to be re-examined. The causal relationship between the two remains strong. The relationship beyond this, for WTI, as has been discussed is not as strong as anticipated. That said, given the relationship that Brent has with other blends it may be that it is acting as some form of conduit. The price of a wider variety of blends is reflected in the price of Brent which in turn is reflected, strongly, in the movement in price of WTI. The reverse scenario where the price of WTI amplifies through to other global blends is also plausible given the strength of that relationship.

Fattouh (2010), Wilmot (2013), Kaufmann and Banerjee (2014), as has been noted at several points, counter the idea of the global market “one great pool” idea with one that displays a greater understanding not only of the qualities of the oil but also of the refining constraints. Their idea of a market segmented by inherent qualities or other factors is borne out by the research. The links between blends such as Urals and Bonny Light highlight this clearly. The systems of cointegrated blends attributed to each of these blends within these systems is strong in terms of the coefficients and their significance. Indeed, in later regimes, post structural break, the relationship has either become stronger or maintained its intensity.

The importance of the Dubai blend was the subject of speculation in chapter two of this study due to the increasing demand from key export markets in China and India. There is evidence to suggest that Dubai is of global significance evidenced by the number and strength of its cointegrated relationships. That said, it is not on a par with Brent in terms of its reach and importance within all regimes.

The role of Russian crude, LUrals in other systems, the regimes and the strength of the coefficients is such that it offers support for those studies that have modelled the performance of Russian blends Wlaslowski et al (2011). Going forward, Russian blends should be looked at more closely in oil studies, it is clear that Urals Mediterranean is linked into the global system and that it is a benchmark that could potentially vie with Dubai or even WTI for global status given the importance of Russian output. That Urals is linked into the system is one part of the story, the relationship with Bonny Light is very interesting. The evidence from the insularity of the Urals/Bonny light nexus might suggest this.

Examining the OPEC basket does not provide much support either way as it is a composite of a number of blends with different qualities serving different markets. The importance in referencing term of the OPEC basket (Reborerdo, 2011; Gullen 1997, 1999, Bentzen 2007) being a major reference point is not supported by this research. The evidence in this study in terms of the number of cointegrated systems in which it features or the strength of those relationships in terms of the size of the coefficients and the P-Values does not support the OPEC basket as a global benchmark. If anything, the evidence here tends to point to is its importance being overshadowed by the Dubai blend.

Close attention was paid to the speed of correction as it had been anticipated that due to the increased financialisation in the sector that later regimes would exhibit stronger corrective qualities. As evidenced by the statistical output evidence of this is supported by the evidence but not overwhelmingly.

In summary these results tell us that Brent is the global benchmark, that WTI became less important in the global benchmarking system when supply could not get to market due to capacity constraints. The study tells us the Dubai and the reliance of the Asian market on exports priced against this blend makes it a factor of some significance in the pricing of other blends. That said, Russian oil is of equal importance and the real impact that we from the US LTO revolution is on Nigerian light crude, Bonny Light. It has been displaced on US and now international markets.

Chapter 6: Conclusion

6.1. Introduction

This research has been several years in its design and execution. In many ways the reductivist nature of econometrics and economic analysis prepares the researcher to distil years of work into a short summary and provide an exit route for the reader. The conclusion to this research is not an end in itself but a point at which inventory is taken. The ideas in this study continue and will change as exploring, prospecting, drilling and refining crude oil continues incessantly. The market, this complex system that absorbs and attenuates change, through the innumerable feedback loops, is constantly evolving. There is a symmetry to this idea in that nature of the time series data, like the market, is non-stationary.

6.2 The changing market

Chapter two examined the changes that have happened in the global oil market. This in itself is worthy of the scope of a PhD study. The scale of the change in the period, 2010-19 has made this one of the most important in the history of the oil market. The discovery of vast resources in the US is one of the most significant innovations since the Connecticut prospectors called for Whisky barrels to store this thick black substance that came out of the ground in the 1800s. At the risk of being sensationalist this is nothing short of a revolution. The US, in the space of less than 20 years, will go from one of the world's largest importers of oil to potentially its largest exporter. In October 2014, when OPEC and KSA did not respond with supply cuts to boost price, it signalled the start of a war. Three years later when the governments of KSA and the Russian Federation agreed to production cuts was this in effect an act of surrender? Was this the point that KSA and OPEC realised that its power to manipulate was forever diminished? Chapter three ended on a question relating to the power of OPEC/KSA and whether the results of this study would point to evidence of waning power. In generating headlines and catchy titles questions like this are perhaps disingenuous, as they are by definition almost impossible to answer in a market such as this. KSA lacks an official spot price and its moves are usually signalled rather than trumpeted so providing a definitive answer to this question is on balance not possible as any answer will be accompanied by caveats, qualifications and present circumstantial evidence. By examining the relationships between OPEC, WTI and Brent, we can clearly identify points in time of great importance, but what the data cannot tell is whether the era of KSA/OPEC dominance has passed. This point will be returned to again and again but it should not detract from what we can say without equivocation that the global oil market is irrevocably changed.

There have also been more subtle, but nonetheless dramatic, changes on the demand side of the equation. The growth of Asian economies provides a counterpoint to the declining northern hemisphere demand due to a justifiable preoccupation with the devastating effects of the impact of burning fossil fuels such as oil. With this comes an increasingly important benchmark, Dubai. This is used as a reference point for trades from the Persian Gulf into Asia. This importance has been underlined by the development of a futures market, which allows price discovery and for traders to cover short positions. This innovation is evidenced by the increasingly tight relationship this blend has with other blends in the sample.

The role that Russia plays in the global oil market is often overlooked. That it is consistently one of the top three producers of crude oil does not lead to the inclusion of its benchmark blends in many of the existing studies. Russian oil companies have imported Western capital and know-how in order to modernise its industry in terms of drilling, distribution and refining. The popular press tends to focus on the routing of pipelines through disputed territories. Russian oil may well be a strategic weapon, but it is nevertheless an important component of the global energy system, the point in relation to its gas exports is more acute. No study that examines the global oil market is complete without reference to Russian oil.

Finally, the changes in the market have to be considered against the backdrop of increased financialisation. The proliferation of trading platforms has enabled oil and its derivative products to be traded anywhere and at any time. The increase in participation in the market has led to a concomitant increase in the availability of quality data. Without borrowing too much from the analysis of the results, the speed of adjustment to deviations from the long-run equilibria and the, visual, tightening of the relationship between the blends presents evidence of this phenomena. This does however come at a cost in terms of the noise. Traders speculating on the thermals of price movements make the signal of what is going on almost imperceptible, given the noise of keyboard warriors and market traders intent on making a killing before they have to take physical delivery of 42 gallons of the thick black stuff.

6.3 The gaps in the literature

From the literature, we find debate regarding the extent to which the global oil market is cointegrated. The differing academic views of the world oil market stem from the work of Adelman (1984) and Weiner (1991). Each sets out a thesis of the oil market and counter-thesis with Adelman characterising this market as “one great pool”, while Weiner later (1991) points to a more nuanced picture due to the differences in API gravity and sulphur content, that have been discussed thoroughly in chapter two.

The evidence over the intervening time has swung one way and another. The nuances develop and many researchers find evidence that synthesises the two contrary arguments. Gȕllen (1997, 1999) finds the middle ground with evidence of globalisation but also presents evidence that blends of crude with similar qualities do move together, especially when the prices increase. Rodriguez and Williams (1993) partly reject the regionalisation hypothesis to identify periods of global oil prices and a “homogenous world oil market”. Fattouh (2010) Kaufmann and Banerjee (2014) put forward arguments that cast doubt upon the “one great pool” typography and support the idea of inherent differences being an explanatory factor in oil price movements and causal relationships. Bentzen’s (2007) cointegration study like Gȕllen (1997, 1999) finds the middle ground. The evidence of this study if it were to take a position in this debate it would be that of Gȕllen (1997, 1999). This is not an either-or debate, this is a bigger picture with nuances.

The idea of a supreme or truly global benchmark is also another area of debate in the literature. Evidence points at various points to WTI decoupling from cointegrated relationships, Ji and Fan (2015), finds that prior to 2010 WTI acted as a price setter but since then this role has vested more with Brent. In the period 2000-2010, WTI was not in step with other blends. The partial decoupling of WTI from the global pricing is an important takeaway point. There is strong evidence from this study to support this idea. There is also compelling evidence to show that Brent has taken on this global price setting role. Going forward, WTI as an export blend may shift this dynamic but the oft-mentioned structural bottlenecks that beset its supply will need to be a thing of the past if it is to replace the more reliable Brent. As has been mentioned, the omission of Russian blends from existing studies presents an incomplete picture and it is one that this study has aimed to address.

6.4 The Methodology

A key learning from this entire process has been how the nature of the data and the presence of structural breaks can affect the choice of methods and ultimately the validity of the results. The stationary cointegrating relationship between two or more time series variables is a neat concept and it is one that fits well with the oil market and the qualitative differences in crude drilled across the globe. There is something reflexive about these ideas that become self-correcting, the law of one price where disturbances to equilibrium correct through market arbitrage but no more than the qualitative rules of thumb will allow for. For economists these are simple yet powerful ideas like a ball in a bowl being disturbed then coming to rest at either an existing or a new point of balance, equilibrium. But for these infrequent disturbances, is this a (set of) relationship(s) that is/are static through time?

Fortunately, econometric techniques offer an insight into this process of disturbance and coming to rest. Stationarity tests can be an important first step but there is certainly scope to dwell on the results and the concept of stationarity. There seems to be something contradictory between the dynamism of a market and a long-term equilibrium to which prices revert back, like a parameterised straight jacket. There are no upper or lower bounds on prices themselves but upper and lower bounds on where prices are in relation to each other. The choice of spot prices as the variable under investigation also fits with this idea. The thoughts of Kaminska (2013) in the Financial Times are worth reiterating at this juncture; the spot market is where reality is met, where the speculation of the futures markets gives way to physical output ready for delivery, this is the point where the ball in the bowl stops rolling.

Cointegration immediately brings to mind the Johansen approach or Engle Grange but as the data and the purpose of the study become more complex the suitability of these methods begins to wane. The search for a suitable method ended with the ARDL bounds test and introduced the seminal work of Pesaran and Shin (1996). The ARDL Bounds test is a Swiss Army knife of a test. It provides so much useful data. Establishing long-run cointegrating relationships whilst providing the short-run error correcting form model of that cointegrating relationship. It is also able to work with nuances of orders of integration, stationary at the level or first differences. Whilst this may seem to render the requirement for stationarity tests somewhat mute, there is great value to be had in these preliminary tests, notwithstanding ensuring that the data is not stationary at the second difference level or that structural breaks do not lead to erroneous conclusions and mis-specification of cointegration tests. The use of EViews has also been important as its development of the ARDL tests allows the researcher to forgo separate lag length criteria tests and conduct them within the ARDL testing framework.

The importance of breaks and the different regimes in the study was built on the back of the model specified by the ARDL Bounds test ECM output. This is the point where the econometric output and the knowledge of the market could meet to deliver analysis that moved beyond the simple idea of cointegration across the entire sample but into the regimes. Moreover, where did those break dates sit with the chronology of market events? To what extent did the residuals correct in those regimes; fully, partially or not at all? Did the correction speed increase as the market became overtly financialised and awash with data?

Then as a means of checking how good these models were the visual investigation of fitted values were used. Creating graphs with the values of the dependent variable predicted by the model then fitting this against the actual values was a perfect way in which to end this study. Where the fit was seamless provides comfort, where there is divergence further investigation into the market. The results were rigorously checked at each stage for heteroskedasticity and the serial correlation of the errors. This divergence provided opportunities to examine the oil market in greater detail.

6.5 Results and Analysis

The results of this study present an interesting picture when compared firstly to the existing literature and then when placed in context of the changes in the market. There is also the idea posited at various points in the work that the results may be able to tell us something about the power of KSA and OPEC. At the risk of repeating section 6.2 it is worth restating that the strategic play of 2014 was probably an attempt to wrest control of the market and reassert dominance over an energised US LTO sector. As the chronology of events in chapter 2 makes clear, this policy failed. We shall ultimately consider if the results from chapter 5 can clarify this picture, as without clear cut evidence it is difficult to confirm if KSA dominance is unchanged or in decline.

The results show that in all six benchmarks there is a cointegrated system with the remaining benchmarks in the study. The evidence shows that in each of these systems that not all of the other five variables are statistically significant. The benchmark that incorporates most information from other blends is Brent but even in this system there is an omission, Urals.

Some benchmarks, WTI, react to relatively few other benchmarks. However, the important point is that all of these systems incorporate Brent in a statistically significant way. It is the global benchmark; the evidence from this study clearly proves this and its reliability as a pricing yardstick for off-exchange transactions is supported, especially given the information from other benchmarks that is processed into its price. No other benchmarks in this study have the same level of penetration into the market or processing power.

At the beginning of the study, the role of Dubai was questioned, given the increased importance of the Asian market and that this is a benchmark that could not thrive without KSA support. Geography does play its part but KSA's use of the DME futures contract in its pricing does lend the Dubai benchmark weight, and therefore called for a close examination of the its importance. The results highlighted that the Dubai spot price is an important factor in determining the prices of other blends in the study, whilst it may lack the ubiquity of the Brent blend in the equation systems for the benchmarks studied the evidence does supports the idea that this is a blend of global importance.

The Russian benchmark, Urals Mediterranean, is another case in point. With Russia being a top three producer, it has the potential to move the market. What this study has underlined is the need to examine Russian blends more closely. The evidence suggests that like the Dubai blend, Urals price movements do factor in the price determination process of many, but not all, blends in the study. This is undoubtedly a contribution to the understanding of the market. Previous studies do not focus in on the contribution of Russian oil to the global market as fully as one may expect, given its production levels. As has been discussed this may have more to do with the availability of credible price data at the time. What is also of interest is the structural break that occurred in towards the turn of the century and the number of other blends that then became explanatory factors in the pricing of Urals thereafter. Urals was now more cointegrated with the global system possibly reflecting the increased export horizons of Russian oil companies and its need for more reference points.

When we examine the results in context of the literature, the aim was always to update and add to the debate. The debate on "one great pool" versus regionalisation is nuanced. There is cointegration in all systems, the Bounds test and the cointegrating equations unequivocally prove this but thereafter the picture is mixed. Benchmarks are cointegrated with those blends that have competitive implications, that is that are the same quality and can be swapped if the price is right or they seem to be competing in similar markets. This backs up the nuanced or synthesised findings of researchers that developed on Adelman's (1984) work by incorporating chemistry into an economist's understanding of the thresholds to cointegration and why the law of one price arbitrage might not completely eliminate all price deviations. Certainly, the errors corrected in the regimes identified by this study but not completely. This points to the thresholds of refining cost and transportation. The speed of the error correction did increase throughout the regimes, there were some anomalies but, on the whole, the idea that increased financialisation, through increased data flows, leads to faster elimination of errors in the system is supported.

Do these results point to a shift in power in the global market? The answer is circumstantial. The evidence alone, and perhaps the way the study was framed, cannot deliver a definitive answer to this question. In part, this comes down to the role that benchmarks play and the opaque nature of the market. KSA through its state-owned company, Aramco, deliberately keeps the market guessing. There is no Saudi spot price that can be priced from, Aramco uses a variety of benchmarks to price from depending on the market it is looking to sell to. It prefers to sell on the basis of long-term contracts with monthly adjustments based on what is happening in the market. In this study we have, perhaps, two proxies for a KSA spot price, the OPEC basket and the Dubai spot price. The relationship between the latter and KSA strategic policy is looser than the former. The OPEC basket does include KSA crude in its calculations, but it is one of many and therefore difficult to isolate. Trying to capture the pressure point through KSA's influence could be measured is not an easy task, monthly loading prices at one juncture looked to be the conduit but financial journalists and the oil and gas trading houses that provided the data, regarded these as inconsequential in their pricing and trading decisions and hence not that important to KSA. What is observable from the data is that the OPEC basket has influence as it is an explanatory variable in other cointegrated systems, the Dubai spot price influence has been discussed towards the beginning of this section.

The change in the pattern of supply comes from the USA so what of the influence of its key benchmark, WTI? To date there is no significant change in the break or change in the relationship that occurred around 2010/11. Changes in US production levels may have collapsed prices between 2010-14 but WTI as an explanatory variable, features significantly in fewer cointegrated systems. This is perhaps is greater evidence of the issue of bottlenecks and the reliability of the seaborne Brent than of the impact the US has had overall. This is a dynamic situation and is likely to change for two reasons. Firstly, WTI is becoming an international crude, its previous relevance was as a benchmark for sales into the US market. The US market has more than enough domestically produced crude to satisfy current and future demand. Its producers now have to export as they have no choice. It is survival and they cannot afford to play the strategic long game of a nationally owned oil company with substantial reserves of cash and oil. The US LTO producers have shareholders, bondholders, covenants on loans, they have to produce or perish. Already US light crude is penetrating into Asian markets and traders are including WTI prices in their calculations. Changes in refining capacity now allow different grades of crude to be processed without the cost implications of before. In five years from now an update of this same study may show that WTI is as ubiquitous an explanatory variable as Brent today, as US exports penetrate globally. That there is no evidence of increasing WTI traction, currently, could be taken as business as usual but everything else from supply, demand, the changing composition of the regimes for each variable in this study point to something different.

The second reason is the initial public offering of Aramco. This should let in the light of analysis, at least some of it, to the machinations of the Saudi oil industry. To be a publicly listed company requires a legally binding level of disclosure which promises a trove of information for market analysts to examine. This may remove some of the mystique from KSA's operating policy and allow us to specify the extent of its power and the conduits through which it exercises this power. The public offering has been delayed due to Covid-19, and the market conditions not being right – that is the oil price is too low for investors to justify the premia that the KSA government is seeking. The future promises much in the way of greater information and more angles to study.

6.6 Implications

What do these findings suggest for the traders, market observers and the industry? For traders these findings provide a range of factors to consider beyond the simplistic "supply and demand" when assessing the direction of future prices. That these prices are taking their cues from each other in the web of feedback loops that exist within the oil market and traders should look beyond "oil" and examine the substitutability between blends in markets where they compete for sales. The changes in supply and demand will ultimately change the nature of these pricing calculations to include blends that serve growing markets and to understand these markets, the pattern of demand and the refining constraints will have to be more fully factored in than before as a competing number of blends chase sales.

6.7 Conclusion

This is in the future and for the present we must consider that these results have taken place in the context of some very unusual times. Since 2004 oil prices have been on a rollercoaster, the peaks have quickly led to troughs, recoveries lead to collapses. Governments flush with the commodity super cycle profits expanded their geopolitical influence only to be confronted by a falling market price and sizeable hole in their fiscal budgets. This is the story of oil, a blessing and a curse. Perhaps when the oil age gives way to the solar age the need for games and posturing that proves so fascinating will disappear and our behaviour will seem as irrational as the good folk of Amsterdam speculating on tulip bulbs in the 1630s?

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Paragraph 5.5.1 has been added which discusses the results and significance of the SupF and double maximum results

For variables, LDubai and LBonny, this means one less statistically significant break than previously reported.

The output from these tests in Tables, 5.22 And 5.25 Have been updated to reflect this. The corresponding fitted values graphs in Fig 5.2 have been updated to reflect these changes in LOPEC and LDubai.

Paragraphs have been added to section 5.5.2 which examine the dates of the break dates across all models. It aligns the breaks in some variables to some market events, changes in the market and political/economic events. Thereafter it concludes that there are exogenous factors that cannot be picked up by the model or explained with reference to events.

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Charts and tables

Fig 2.1. Global oil consumption, BP.com, data available at https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html [Accessed: 1st May 2018]

Fig 2.2 Chinese and Indian energy demand, BP.Com, data available at https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html [Accessed: 10th May 2018]

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Fig 2.4. EIA.Com, 2018, Index of open interest contracts, source data EIA.Com, available at https://www.eia.gov/finance/markets/crudeoil/financial_markets.php

Fig 2.5. EIA, 2017. US Crude oil production forecast. Available at https://www.eia.gov/outlooks/aeo/ {Accessed: 30th May, 2018]

Fig 2.6, EIA.Com, Saudi Arabian Imports to the USA as a percentage of US consumption, data sourced from EIA.Com, data available at https://www.eia.gov/dnav/pet/PET_MOVE_IMPCUS_D_NUS_NSA_MBBL_M.htm [Accessed: 15th may, 2018]

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Fig 2.8. WTI/Brent spot prices. Source data EIA.Com, available at https://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm [Accessed: 27th May, 2018]

Fig 2.9. US oil company debt service ratios, graphic sourced from EIA.Com, available at https://www.eia.gov/todayinenergy/detail.php?id=22992 [Accessed: 30th May 2018]

Fig 2.10. US rig count, graphic sourced from EIA.Com, available at https://www.eia.gov/todayinenergy/detail.php?id=33332 [Accessed: 30th May, 2018]

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Appendix A

A.1 Long-run ARDL Results

Table A1.1 LWTI

Variable	C	LWTI(-1)	LBRENT(-1)	LDUBAI(-1)	LOPEC(-1)	LURALS	LBONNY	D(LBRENT)	D(LDUBAI)	D(LOPEC)
Coefficient	0.067764	-0.230152	0.1389	-0.204728	0.28816	-0.04149	0.030762	0.489058	0.092305	0.413501
Std. Error	0.018349	0.0408	0.073901	0.08162	0.093026	0.089978	0.110758	0.105549	0.083872	0.115361
t-Statistic	3.693031	-5.641029	1.879536	-2.508319	3.097619	-0.461115	0.27774	4.633482	1.100548	3.584413
Prob.	0.0003	0	0.0613	0.0127	0.0022	0.6451	0.7814	0	0.2721	0.0004

Table A1.2 LBRENT

Variable	C	LBRENT(-1)	LWTI(-1)	LDUBAI(-1)	LOPEC(-1)	LURALS	LBONNY(-1)	D(LBRENT(-1))	D(LBRENT(-2))	D(LWTI)
Coefficient	-0.008236	-0.288161	0.052978	0.119564	-0.129436	-0.08564	0.331949	-0.16704	-0.161109	0.147672
Std. Error	0.011013	0.04437	0.02666	0.045841	0.062914	0.053239	0.068392	0.054433	0.051897	0.033642
t-Statistic	-0.747859	-6.494436	1.987181	2.608215	-2.05733	-1.608606	4.853615	-3.068749	-3.104415	4.389552
Prob.	0.4552	0	0.048	0.0096	0.0407	0.109	0	0.0024	0.0021	0

Variable	D(LWTI(-1))	D(LWTI(-2))	D(LDUBAI)	D(LOPEC)	D(LOPEC(-1))	D(LOPEC(-2))	D(LBONNY)
Coefficient	0.064236	0.05605	0.329304	0.278945	0.093134	0.079997	0.23097
Std. Error	0.036519	0.035044	0.042248	0.066708	0.049141	0.045962	0.063927
t-Statistic	1.759003	1.599428	7.794625	4.181587	1.895245	1.740507	3.613006
Prob.	0.0798	0.111	0	0	0.0592	0.083	0.0004

Table A1.3 LDUBAI

Variable	C	LDUBAI(-1)	LWTI(-1)	LBRENT(-1)	LOPEC	LURALS	LBONNY(-1)	D(LWTI)	D(LBRENT)	D(LBONNY)
Coefficient	-0.011722	-0.489522	-0.036022	0.364637	0.36562	0.198108	-0.39975	0.055312	0.656935	-0.261172
Std. Error	0.013965	0.051674	0.031	0.053372	0.0706	0.067068	0.085705	0.045593	0.064773	0.080512
t-Statistic	-0.839392	-9.473221	-1.16202	6.83198	5.178777	2.953867	-4.664232	1.213176	10.14205	-3.243903
Prob.	0.402	0	0.2463	0	0	0.0034	0	0.2262	0	0.0013

Table A1.4 LOPEC

Variable	C	LOPEC(-1)	LWTI(-1)	LBRENT(-1)	LDUBAI	LURALS(-1)	LBONNY	D(LWTI)	D(LBRENT)	D(LURALS)
Coefficient	0.01407	-0.454552	0.007359	-0.152469	0.212476	0.026969	0.354021	0.104673	0.187453	0.150639
Std. Error	0.009701	0.043949	0.022505	0.036592	0.034487	0.053971	0.052327	0.030549	0.053273	0.045773
t-Statistic	1.450435	-10.34276	0.326971	-4.166681	6.161041	0.499699	6.765529	3.42635	3.518743	3.290983
Prob.	0.1481	0	0.744	0	0	0.6177	0	0.0007	0.0005	0.0011

Table A1.5 LURALS MED

Variable	C	LURALS(-1	LWTI(-1)	LBRENT(-1)	LDUBAI	LOPEC	LBONNY(-1)	D(LWTI)	D(LBRENT)	D(LBONNY)
Coefficient	-0.018137	-0.573174	-0.09306	0.050241	0.126166	0.261983	0.229619	-0.004399	-0.165351	0.772699
Std. Error	0.01135	0.050044	0.024942	0.047241	0.04329	0.057542	0.078941	0.036411	0.057062	0.051144
t-Statistic	-1.598046	-11.45339	-3.731125	1.063503	2.914451	4.552872	2.908727	-0.120811	-2.897752	15.10843
Prob.	0.1113	0	0.0002	0.2885	0.0039	0	0.0039	0.9039	0.0041	0

Table A1.6 LBONNY LIGHT

Variable	C	LBONNY(-1)*	LWTI(-1)	LBRENT(-1)	LDUBAI**	LOPEC(-1)	LURALS(-1)	D(LWTI)	D(LBRENT)	D(LOPEC)	D(LURALS)
Coefficient	-0.005291	-0.596162	0.089007	0.153155	-0.13881	0.126182	0.373402	0.000393	0.233229	0.355168	0.58739
Std. Error	0.009839	0.058819	0.022104	0.04009	0.036951	0.056354	0.049918	0.031602	0.053351	0.058639	0.039336
t-Statistic	-0.537773	-10.13557	4.02671	3.820262	-3.756581	2.239103	7.480378	0.012436	4.371575	6.056902	14.93248
Prob.	0.5912	0	0.0001	0.0002	0.0002	0.026	0	0.9901	0	0	0

A1.2 Break LS Results

Table A1.7 LWTI 1996M09 - 2008M09 -- 145 obs

Variable	C	D(LWTI(-1))	D(LBRENT)	D(LBRENT(-1))	D(LDUBAI(-1))	D(LOPEC(-1))	D(LOPEC)	RESIDWTIJ27(-1)
Coefficient	0.000844	0.088742	0.406256	0.027382	-0.156445	-0.009533	0.56324	-0.332534
Std. Error	0.00275	0.367165	0.106912	0.232279	0.09455	0.180248	0.09213	0.385159
t-Statistic	0.306954	0.241696	3.799918	0.117883	-1.654634	-0.052891	6.113561	-0.863367
Prob.	0.7591	0.8092	0.0002	0.9063	0.0992	0.9579	0	0.3888

Table A1.8 LWTI 2008M10 - 2018M11 -- 122 obs

Variable	C	D(LWTI(-1))	D(LBRENT)	D(LBRENT(-1))	D(LDUBAI(-1))	D(LOPEC(-1))	D(LOPEC)	RESIDWTIJ27(-1)
Coefficient	-0.000925	0.518214	1.079063	-0.417218	-0.293521	0.23531	-0.074347	-0.692983
Std. Error	0.002894	0.245495	0.144575	0.221995	0.131792	0.159934	0.134118	0.250682
t-Statistic	-0.319631	2.110892	7.463697	-1.8794	-2.227158	1.471292	-0.554338	-2.764396
Prob.	0.7495	0.0358	0	0.0613	0.0268	0.1425	0.5798	0.0061
R-squared	Adjusted R-squared	S.E. of regression	Sum squared resid	Log likelihood	F-statistic	Prob(F-statistic)	Mean dependent var	S.D. dependent var
0.897799	0.891691	0.031861	0.254788	549.5787	146.9956	0	0.004163	0.09681
AIC	Schwarz criterion	Hannan-Quinn criter.	Durbin-Watson stat					
-3.996844	-3.781878	-3.910494	2.037985					

Table A1.9 LBRENT 1996M11 - 2000M05 -- 43 obs

Variable	C	D(LBRENT(-1))	D(LBRENT(-2))	D(LWTI)	D(LWTI(-1))	D(LDUBAI)	D(LOPEC)	D(LOPEC(-1))	D(LOPEC(-2))	D(LBONNY)	RESIDBRJ27(-1)
Coefficient	-0.001863	0.177273	-0.054733	0.619403	0.339929	0.560786	-0.018062	-0.427022	0.073612	-0.235086	-0.625817
Std. Error	0.002553	0.241115	0.103545	0.114816	0.1332	0.085716	0.177811	0.200545	0.094715	0.106637	0.289632
t-Statistic	-0.729773	0.735222	-0.528589	5.39473	2.552008	6.542368	-0.10158	-2.129309	0.777195	-2.204534	-2.160735
Prob.	0.4663	0.4629	0.5976	0	0.0114	0	0.9192	0.0343	0.4378	0.0285	0.0317

Table A1.10 2000M06- 2005M05 - 60 obs

Variable	C	D(LBRENT(-1))	D(LBRENT(-2))	D(LWTI)	D(LWTI(-1))	D(LDUBAI)	D(LOPEC)	D(LOPEC(-1))	D(LOPEC(-2))	D(LBONNY)	RESIDBRJ27(-1)
Coefficient	0.00228	-0.266133	-0.036236	0.351	0.11322	0.234103	0.282141	0.223001	0.038374	0.023548	-0.001932
Std. Error	0.002222	0.184238	0.097073	0.078045	0.086176	0.065859	0.127185	0.14303	0.08531	0.070174	0.207965
t-Statistic	1.02581	-1.444507	-0.37328	4.497431	1.313813	3.554617	2.218349	1.559119	0.449826	0.335568	-0.009289
Prob.	0.306	0.1499	0.7093	0	0.1902	0.0005	0.0275	0.1203	0.6533	0.7375	0.9926

Table A1.11 2005M06 - 2018M11 162 obs

Variable	C	D(LBRENT(-1))	D(LBRENT(-2))	D(LWTI)	D(LWTI(-1))	D(LDUBAI)	D(LOPEC)	D(LOPEC(-1))	D(LOPEC(-2))	D(LBONNY)	RESIDBRJ27(-1)
Coefficient	-0.000842	0.344142	-0.029681	0.083862	-0.06543	0.351873	0.304392	-0.237344	0.008715	0.195466	-0.667079
Std. Error	0.001304	0.142926	0.072582	0.037111	0.049011	0.053484	0.067835	0.097105	0.06798	0.04895	0.166029
t-Statistic	-0.645477	2.407825	-0.408929	2.259732	-1.335009	6.578977	4.487272	-2.444211	0.128206	3.993133	-4.017847
Prob.	0.5193	0.0168	0.683	0.0248	0.1832	0	0	0.0153	0.8981	0.0001	0.0001
R-squared	Adjusted R-squared	S.E. of regression	Sum squared resid	Log likelihood	F-statistic	Mean dependent var	S.D. dependent var	Akaike info criterion	Schwarz criterion	Hannan-Quinn criter.	Durbin-Watson stat
0.969351	0.965124	0.016434	0.062656	730.3339	229.3028	0.004389	0.087998	-5.262897	-4.81712	-5.083791	1.909275

Table A1.12 LDUBAI 1996M09 2006M02

Variable	C	D(LDUBAI(-1))	D(LBRENT)	D(LBRENT(-1))	D(LOPEC)	D(LURALS)	D(LBONNY)	D(LBONNY(-1))	RESIDDUBJ27R1(-1)
Coefficient	0.000309	0.803133	0.552332	-0.568658	0.460105	0.102381	-0.141180	-0.230178	-0.886274
Std. Error	0.002355	0.207789	0.088209	0.174948	0.107749	0.080767	0.108538	0.073595	0.209832
t-Statistic	0.131183	3.86513	6.261635	-3.250434	4.270136	1.27603	-1.300744	-3.17625	-4.223723
Prob.	0.8957	0.0001	0.000	0.0013	0.0000	0.2061	0.1945	0.0020	0.000
R-squared	Adjusted R-squared	S.E. of regression	Sum squared resid	Log likelihood	F-statistic	Prob(F-statistic)	Mean dependent var	S.D. dependent var	Akaike info criterion
0.936451	0.932112	0.024703	0.151952	618.5805	215.8364	0	0.005254	0.094811	-4.98731
Schwarz criterion	Hannan-Quinn criter.	Durbin-Watson stat							
-4.246894	-4.401586	2.166988							

Table A1.13 LDubai 2006M03 - 2018M11

Variable	C	D(LDUBAI(-1))	D(LBRENT)	D(LBRENT(-1))	D(LOPEC)	D(LURALS)	D(LBONNY)	D(LBONNY(-1))	RESIDDUBJ27R2(-1)
Coefficient	0.000334	0.277006	0.887976	-0.170834	0.319409	0.011702	-0.184337	-0.07838	-0.884304
Std. Error	0.001999	0.255635	0.114171	0.245879	0.119585	0.13685	0.128755	0.080921	0.281075
t-Statistic	0.16689	1.0836	7.777582	-0.694788	2.670972	0.0.085509	-1.431688	-0.968599	-3.14615
Prob.	0.8676	0.2796	0	0.4878	0.0081	0.9391	0.1535	0.3337	0.0019
R-squared	Adjusted R-squared	S.E. of regression	Sum squared resid	Log likelihood	F-statistic	Prob(F-statistic)	Mean dependent var	S.D. dependent var	Akaike info criterion
0.936451	0.932112	0.024703	0.151952	618.5805	215.8364	0	0.005254	0.094811	-4.98731
Schwarz criterion	Hannan-Quinn criter.	Durbin-Watson stat							
-4.246894	-4.401586	2.166988							

Table A1.14 LOPEC 1996M09 2003M08

Variable	C	D(LOPEC(-1))	D(LBRENT(-1))	D(LDUBAI)	D(LBONNY)	D(LWTI)	D(LBRENT)	D(LURALS)	RESIDOPECJ27R1(-1)
Coefficient	-0.000695	0.09452	-0.092265	0.306575	0.302002	0.452659	-0.088435	0.045344	-0.261451
Std. Error	0.001944	0.07918	0.088821	0.064768	0.085156	0.067203	0.091075	0.068508	0.144645
t-Statistic	-0.357226	1.193735	-1.038776	4.733446	3.546451	6.735676	-0.971018	0.661883	-1.807534
Prob.	0.7219	0.2363	0.3022	0	0.0007	0	0.3347	0.5101	0.0747
R-squared	Ad R-squared	S.E. of regression	Sum squared resid	Log likelihood	F-statistic	Prob(F-statistic)	Mean dep var	S.D. dep var	AIC
0.977319	0.9749	0.017743	0.023611	224.2374	403.9736	0	0.004562	0.111993	-5.124699
Schwarz criterion	H-Q criter.	Durbin-Watson stat							
-4.864255	-5.020003	2.105611							

Table A1.15 LOPEC 2003M10 2018M11

Variable	C	D(LOPEC(-1))	D(LBRENT(-1))	D(LDUBAI)	D(LBONNY)	D(LWTI)	D(LBRENT)	D(LURALS)	RESIDOPECJ27R2(-1)
Coefficient	-6.88E-05	0.428152	-0.43374	0.041306	0.200805	0.048773	0.44476	0.281867	-0.714524
Std. Error	0.001274	0.112414	0.119943	0.050656	0.068797	0.035739	0.071303	0.072875	0.137319
t-Statistic	-0.054055	3.808702	-3.616208	0.815421	2.918822	1.3647	6.237576	3.867801	-5.203381
Prob.	0.957	0.0002	0.0004	0.416	0.004	0.1741	0	0.0002	0
R-squared	Adjusted R-squared	S.E. of regression	Sum squared resid	Log likelihood	F-statistic	Prob(F-statistic)	Mean dependent var	S.D. dependent var	Akaike info criterion
0.9683	0.966835	0.017107	0.050627	486.7957	660.5621	0	0.005118	0.093934	-5.250503
Schwarz criterion	Hannan-Quinn criter.	Durbin-Watson stat							
-5.092063	-5.186273	1.963598							

Table A1.16 DLURALS MED 1996M06 - 2001M03

Variable	C	D(LURALS(-1))	D(LWTI(-1))	D(LDUBAI)	D(LOPEC)	D(LBONNY(-1))	D(LBRENT)	D(LBONNY)	RESIDURALJ27(-1)
Coefficient	0.000221	-0.246587	-0.062297	-0.145752	0.224517	0.268863	-0.296937	1.142133	-0.16513
Std. Error	0.002905	0.229557	0.093398	0.100124	0.147892	0.257076	0.115585	0.106414	0.237518
t-Statistic	0.076081	-1.074188	-0.667005	-1.455718	1.518119	1.045851	-2.568982	10.73287	-0.695232
Prob.	0.9394	0.2838	0.5054	0.1467	0.1303	0.2966	0.0108	0	0.4876

Table A1.17 LURALS MED 2001M04 - 2018M11

Variable	C	D(LURALS(-1))	D(LWTI(-1))	D(LDUBAI)	D(LOPEC)	D(LBONNY(-1))	D(LBRENT)	D(LBONNY)	RESIDURALJ27(-1)
Coefficient	0.000265	0.396329	0.032869	0.232127	0.134568	-0.441298	-0.10439	0.757745	-0.725193
Std. Error	0.001473	0.20206	0.033831	0.059939	0.079656	0.198608	0.087441	0.057599	0.217976
t-Statistic	0.180023	1.961442	0.971577	3.872751	1.68937	-2.221954	-1.193825	13.15547	-3.326947
Prob.	0.8573	0.0509	0.3322	0.0001	0.0924	0.0272	0.2337	0	0.001
R-squared	Adjusted R-squared	S.E. of regression	Sum squared resid	Log likelihood	F-statistic	Prob(F-statistic)	Mean dependent var	S.D. dependent var	Akaike info criterion
0.964993	0.962603	0.021385	0.113868	657.0989	403.7531	0	0.005051	0.110581	-4.787258
Schwarz criterion	Hannan-Quinn criter.	Durbin-Watson stat							
-4.545421	-4.690113	2.00871							

Table A1.18 LBONNY LIGHT 1996M06 - 2006M05

Variable	C	D(LBONNY(-1))	D(LWTI)	D(LBRENT(-1))	D(LDUBAI)	D(LOPEC(-1))	D(LURALS(-1))	D(LBRENT)	D(LOPEC)	D(LURALS)	RESIDBONJ27(-1)
Coefficient	0.000129	0.121102	-0.065624	-0.066945	-0.091311	0.023671	-0.091353	0.226444	0.524241	0.475455	-0.61063
Std. Error	0.001639	0.19387	0.065486	0.064187	0.055227	0.091566	0.123391	0.074188	0.085434	0.043366	0.207372
t-Statistic	0.078428	0.624654	-1.002104	-1.042962	-1.653364	0.258513	-0.740354	3.052313	6.136184	10.96373	-2.944614
Prob.	0.9376	0.5328	0.3173	0.298	0.0995	0.7962	0.4598	0.0025	0	0	0.0035
R-squared	Adjusted R-squared	S.E. of regression	Sum squared resid	Log likelihood	F-statistic	Prob(F-statistic)	Mean dependent var	S.D. dependent var	Akaike info criterion	Schwarz criterion	Hannan-Quinn criter.
0.97634	0.974312	0.01733	0.073578	715.3978	481.4382	0	0.004946	0.108126	-5.193991	-4.898412	-5.075259
Durbin-Watson stat											
2.071766											

Table A1.19 LBONNY LIGHT 2006M06 - 2018M11

Variable	C	D(LBONNY(-1))	D(LWTI)	D(LBRENT(-1))	D(LDUBAI)	D(LOPEC(-1))	D(LURALS(-1))	D(LBRENT)	D(LOPEC)	D(LURALS)	RESIDBONJ27(-1)
Coefficient	-0.000344	0.557527	-0.023208	0.005613	-0.140386	-0.352235	-0.242993	0.195604	0.161737	0.79193	-1.007061
Std. Error	0.001418	0.241385	0.040021	0.083968	0.06619	0.108359	0.173738	0.102425	0.084563	0.067314	0.256792
t-Statistic	-0.242631	2.309698	-0.579892	0.06685	-2.120947	-3.250643	-1.39862	1.909718	1.91262	11.76469	-3.921703
Prob.	0.8085	0.0217	0.5625	0.9468	0.0349	0.0013	0.1632	0.0573	0.057	0	0.0001
R-squared	Adjusted R-squared	S.E. of regression	Sum squared resid	Log likelihood	F-statistic	Prob(F-statistic)	Mean dependent var	S.D. dependent var	Akaike info criterion	Schwarz criterion	Hannan-Quinn criter.
0.97634	0.974312	0.01733	0.073578	715.3978	481.4382	0	0.004946	0.108126	-5.193991	-4.898412	-5.075259
Durbin-Watson stat											
2.071766											

Table A1.20 Johansen Cointegration Test Results

Series: LWTI LBRENT LDUBAI LOPEC LURALS LBONNY

Lags interval (in first differences): 1 to 4

Unrestricted Cointegration Rank Test (Trace)

Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	0.183953	146.7848	95.75366	0
At most 1 *	0.126015	92.91468	69.81889	0.0003
At most 2 *	0.089337	57.22117	47.85613	0.0052
At most 3 *	0.076106	32.42195	29.79707	0.0244
At most 4	0.03361	11.44518	15.49471	0.1856
At most 5	0.008961	2.385409	3.841465	0.1225

Trace test indicates 4 cointegrating eqn(s) at the 0.05 level

* denotes rejection of the hypothesis at the 0.05 level

**MacKinnon-Haug-Michelis (1999) p-values