Essays on the relationship between Oil and Financial Markets

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The thesis is submitted in partial fulfilment of the requirements

for the award of the degree of

Doctor of Philosophy

of the University of Portsmouth

Faculty of Business and Law

Economics and Finance Subject Group

Portsmouth, United Kingdom

October 2019

Abstract

This thesis contains of three empirical essays on the area of energy economics. In particular, we investigate the impact of oil price changes on the financial market performance and generally the relationship between oil markets and financial markets. During the last two decades, the examination of this relationship has received particular attention by the research community, however, research in this area is still growing. Indeed, oil price peaks and troughs create uncertainty to the financial markets and therefore a link between the two markets is continuously set and requires further attention.

A plausible explanation regarding the growing popularity of research in this area can be attributed to the fact that oil price fluctuations have been noteworthy increased since the recent global financial crisis of 2007-2009. In addition, financial markets seem to be significantly affected by developments created during this period, since financial institutions collapsed. Furthermore, the financialisation (increasing speculative trading) of the oil market which coincides with this period suggests that oil futures derivatives are considered as financial assets by market participants. Therefore, this research choice based on the fact that these two markets appear to be highly linked the recent years. Overall, the latest developments suggest that the relationship between oil markets and financial markets may potentially change. Subsequently, the aim of this study is to enhance the existing literature by investigating changes in the patterns between the two markets.

To this end, we employ monthly data available from commercial data suppliers such as Thomson-Reuters or Bloomberg. Regarding the time period, both the beginning period and the end period of our sample depend on the needs of each empirical chapter and the data availability. In terms of econometric methods, the chosen frameworks vary in order to

accommodate each empirical study specific requirements. In this regard, we employ a battery of single-equation multiple linear regression models, a Scalar-Baba-Engle-Kraft-Kroner (BEKK) model and a structural vector autoregressive model (SVAR). All three static and time-varying specifications have been well explained by the existing literature, are well-matched with the economic theory and have been adopted by many authors in their research.

The first empirical chapter examines the determinants of WTI/Brent oil futures price differential and the globalisation-regionalisation hypothesis in the oil futures market. The findings suggest that the WTI/Brent oil futures price differential is influenced by crude oil-market specific (convenience yield, consumption, production) and oil-futures market specific (open interest, trading volume) determinants. In addition, the oil futures market appears to be regionalised in the short-run.

The second empirical chapter examines the time-varying correlation between oil price shocks and the 10-year sovereign yield spread of core and periphery countries in the EMU. The results reveal that the correlation between sovereign yield spreads and oil price shocks is indeed time-varying and show heterogeneity among the three oil price shocks (supply-side, aggregate demand, precautionary demand). Specifically, the correlation varies between positive and negative areas. Furthermore, even though the correlation patterns are constantly low or zero prior to the Great Recession, a change is revealed in the post-2008 period, when correlations become moderate and more volatile.

The third empirical chapter investigates the origins of precautionary demand in the oil market and its effects on stock market returns and volatility in the US. The precautionary demand is disaggregating into two components, the precautionary demand shock based on the convenience yield and the idiosyncratic oil price shock. The results demonstrate that oil price changes are affected in a smaller magnitude by precautionary demand shocks, whereas the largest effect is generated by idiosyncratic oil price shocks. Furthermore, stock market returns and stock market volatility are affected differently by these two shocks before and after the Great Recession of 2007-2009.

Overall, the findings of this study contribute to the existing oil-related literature by filling voids and provide avenues for further research in the attention of researchers. In addition, our results may be of interest to energy investors and financial traders since oil market is appeared to be financialised the recent years and the oil futures market-related products are considered as financial assets.

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Declaration

Whilst registered as a candidate for the above degree, I have not been registered for any other research award. The results and conclusions embodied in this thesis are the work of the named candidate and have not been submitted for any other academic award.

Word count: 71,235

Abbreviations

BEKK = Baba-Engle-Kraft-Kroner

BLS = Bureau of Labor Statistics

CFTC = Commodity Futures Trading Commission

CPI = Consumer Price Index

DJ = Dow Jones Industrial Average Index

ECB = European Central Bank

EAPP = Expanded Asset Purchase Programme

EIA = Energy Information Administration

EMU = Economic and Monetary Union

ICE = Intercontinental Exchange

IMF = International Monetary Fund

LIBOR = London Interbank Offered Rate

NBER = National Bureau of Economic Research

NYMEX = New York Mercantile Exchange

QE = Quantitative Easing

OECD = Organisation for Economic Co-operation and Development

OPEC = Organization of the Petroleum Exporting Countries

S&P 500 = Standard and Poor’s 500 Index

SUR = Seemingly Unrelated Regression

SVAR = Structural Vector Autoregression

US = United States

VIX = Volatility Index

VXD = Dow Jones Industrial Average Volatility Index

WTI = West Texas Intermediate

Acknowledgements

I would like to express my deep appreciation to my supervisors' Dr Renatas Kizys and Professor George Filis for their valuable continuous support, guidance, patience and enthusiasm that I received during the long journey of my PhD study. It is clear that I could not have finished my study without their encouragement. They were always there to listen to my ideas and to give advice. They provided me valuable feedback throughout the continuous discussions in our meetings. Also, I greatly appreciate the support received from Professor Christos Floros during the first year of my study. Overall, I am grateful to my supervisors who shown the necessary understanding in periods in which my progress was not the anticipated since I needed to cover parts in theory at which my knowledge was limited. Further, in the first periods of my teaching activities in which I needed to distract from my research in order to provide high quality teaching for the Subject Group of Economics and Finance at Portsmouth University and International College Portsmouth (ICP).

Specifically, I am grateful to Dr Renatas Kizys who commenced as first supervisor a year after the beginning of my PhD and he involved and provided feedback to my work directly. Dr Renatas Kizys helped me to expand my knowledge in econometrics by improving my ability to explain the practical side of my research. All supervisory meetings took place in a professional environment and were beneficial to my professional development. His recommendation to pay attention in each detail to all empirical chapters improved my consideration to write academic papers.

Furthermore, I have the pleasure to know Professor George Filis from my postgraduate study at Portsmouth University over the period 2009-2011. Professor George Filis was my supervisor in my master dissertation and his support was very important in order to submit a good quality dissertation in September 2011. Moreover, I appreciate the advice and the research direction provided by Professor George Filis in the beginning of 2012 to prepare my PhD proposal with aim to endorse my application which has been finally accepted. Last but not least, I recognise his support although from distance until the thesis submission given that he was not with Portsmouth University the last years. Overall, his advanced knowledge in the research field of energy economics contributed to my ability to understand in a more detail the relevant subject.

I also appreciate the provided feedback by Professor Christos Floros which was beneficial in order to improve further the quality of my PhD proposal during the summer of 2012. Furthermore, I recognise his contribution to provide me the initial direction to proceed my study during the first months. Last but not least, I value his recommendation to nominate me as a potential lecturer at the University of Portsmouth which resulted in getting teaching hours and the beginning of my teaching career.

I would like to gratefully and sincerely thank Dr Chris Reid (Subject Group of Economics and Finance) and Mr Bill Moore (Manager of academic services at the International College of Portsmouth, ICP) for their trust in offering me the opportunity to teach in higher education. My involvement to teaching activities from the first semester of my doctoral work contributed further to my personal academic development. Furthermore, the income earned was crucial in order to pay my tuition fees, my living expenses and to make savings in case of any unexpected healthy issues and make myself financially independent. My PhD study would not have been possible to finish without their trust and support.

I would like to express my warmest gratitude to those academic staff at the Subject Group of Economics and Finance and the School of Languages and Area Studies, at the University of

Portsmouth, that they trusted me to deliver the seminars of their units. Specifically, I acknowledge Dr Konstantinos Vergos, Dr Adam Cox, Mr Paul Lovejoy, Ms Sheila Dutton, Dr Robert Gausden and Dr Oksana Dalton. More specifically, I would like to acknowledge further Dr Robert Gausden for his willingness to review my thesis and provide me essential comments in the mock viva.

Overall, during my five-year working commitment at Portsmouth University, I have collaborated with members of academic staff and I have the opportunity to join academic discussions and explore ideas on common subjects. Once again, I would particularly like to acknowledge Dr Robert Gausden for his guidance and constant feedback related to the delivery of my teaching duties. The total collaboration with my colleagues has decisively improved my ability to deliver high quality teaching and research. As a result, my hard work commitment to support to the best of my abilities my Department and deliver the required expectations to a high standard rewarded during the summer of 2018, since my application for the Teaching Fellow position at the University of Portsmouth was successful.

I would like to mention my appreciation to Portsmouth Business School for being supportive of my study by giving me funding to participate in a conference and in a workshop, the provided facilities to collect my data and the allocation of a desk.

I would like to give special thanks to the participants of the conferences and staff seminars in which I presented my work for their valuable suggestions. All empirical chapters (3, 4 and 5) have benefited from the panel’s comments. Regarding my Chapter 3, which is published to the *International Journal of Banking, Accounting and Finance* (IJBAAF), I would like to thank two anonymous referees and the editor Dr Ioannis Chatziantoniou.

Last but not least, I am particular grateful to my family for their constant understanding over the years, to my friends in Cyprus, Greece, and the UK and my fiancée Evangelia Thomadakis for her patience and encouragement. Finally, I would like to dedicate to my young daughter Christina for the strength given me to be able to complete my thesis.

Dissemination

Empirical study related to this thesis is published to the following journals:

Filippidis, M., Kizys, R., Filis, G. & Floros, C. (2019). The WTI/Brent oil futures price differential and the globalisation-regionalisation hypothesis. *International Journal of Banking, Accounting and Finance*, *Vol. 10*, *No. 1*, pp.3-38

DOI: 10.1504/IJBAAF.2019.099309

Empirical study related to this thesis is under review to the following journal:

Filippidis, M., Filis, G., & Kizys, R. "Oil price shocks and EMU sovereign yield spreads".

Under review to Energy Economics.

Empirical study related to this thesis is presented to the following conferences:

(2019) "Oil price shocks and EMU sovereign yield spreads", presented at the 10th International Research Meeting in Business and Management (IRMBAM), IPAG Business School, Nice Campus, July 2019, France

(2019) "Oil price shocks and EMU sovereign yield spreads", presented at the 7th International Symposium on Environment and Energy Finance Issues (ISEFI), IPAG Business School and the Paris Dauphine University, May 2019, France

(2018) "Financial effects of precautionary demand for oil", presented at the 16th INFINITI Conference on International Finance, 11-12 June, Poznań University of Economics and Business, Poland.

(2016) "The WTI/Brent oil futures price differential and the globalisation-regionalisation hypothesis", presented at the Portsmouth-Fordham Conference on Banking and Finance, 24-25 September, University of Portsmouth, UK.

(2015) "The WTI/Brent oil futures price differential and the globalisation-regionalisation hypothesis", presented at the 13th INFINITI Conference on International Finance, 8-9 June, University of Ljubljana, Slovenia.

Chapter 1: Introduction

1.1 Research Background

Since the oil price fluctuations of the 1970's, the analysis of the relationship between oil prices and economic activity has received a great deal of attention from academics, researchers, market participants and policy makers. This can be explained by the fact that oil is a basic energy source for the global economy. More specifically, particular attention has been paid to investigating the degree to which developments in the oil market trigger responses from the macroeconomy and financial markets. Overall, the research in this area is still growing and the attention of the researchers has been expanded to new directions in the oil-related literature.

The first general point is that oil is an important input in production and therefore a higher oil price increases production costs, affects negatively firm's output levels and consequently reduces corporate earnings. In addition, due to higher petrol prices and heating oil prices, the consumer's demand (household spending) is expected to decline. The second general consensus is that higher oil prices drive inflation towards higher levels and reduce industrial production as energy factors become more expensive. Due to the lower consumption, a reduction in economic activity is expected and hence a decrease in employment. Higher oil prices may also lead to a reduction in investment due to uncertainty generated in the market. Furthermore, oil price movements are likely to have significant effects on stock market activity. Specifically, higher oil prices affect negatively stock market prices and returns through lower corporate profits and dividends, and increase stock market volatility through investment delays.

Nevertheless, the view concerning the consequences for stock market returns of higher oil prices tends to be different when we consider the status of the country as oil-exporting (oil producer) or oil-importing (oil consumer). Indeed, oil price increases suggest negative implications for oil-importing economies similar to the previous analysis. Pertaining to the oil-exporting economies, oil price increases are anticipated to positively affect the prosperity in these countries through a higher income. Overall, higher oil prices trigger heterogeneous reactions from the stock markets when the aforementioned status of the country is considered. Specifically, a lower (higher) economic activity is expected for oil-importing (oil-exporting) economies given that a higher oil price is regarded as negative (positive) news.

Furthermore, the relationship between oil price fluctuations and stock market activity should be considered not only in static but also in time-varying environments. This differentiation is based on the fact that static approaches consider this relationship as constant over time, whereas time-varying models emphasise heterogeneous patterns during different economic and geopolitical events and at different time periods. Therefore, a time-varying framework is indicative of the fact that this relationship may not be stable but, instead, varies over time.

This thesis attempts to provide additional information on the relationship between oil markets and financial markets. In this regard, a detailed review of the literature is essential to identify gaps or areas in which the literature remains limited. Armed with the key findings of the available literature and focusing on the most recent studies, we indicate three areas for further research. We expect to expand the existing knowledge further by proposing a new direction for the attention of the research. We anticipate that the findings of this study would provide valuable information to academic researchers and energy investors. To this end, we turn to the objectives and contributions in order to underscore the importance of this study.

1.2 Research Objectives and Contributions

The first research objective is related to the examination of the determinants of the WTI/Brent oil futures price differential, and the testing of the *globalisation-regionalisation hypothesis* in the oil futures market. It is worth noting that research into the determinants of oil futures differential is very limited and the *globalisation-regionalisation hypothesis* has received limited attention in the use of oil futures prices. Therefore, we seek to expand the scarce literature on this theme. Turning to the contributions of this study, we employ a set of both oil-market and oil-futures market specific determinants, which have not been explored by the oil related literature before. Moreover, the use of oil futures prices rather than oil spot prices builds on the fact that the former reveals more information in reflecting oil market conditions. Furthermore, we consider the significant divergence between WTI and Brent oil futures prices in late-2010, which caused changes in the crude oil market dynamics. Finally, we concentrate on different futures contracts, such as 1, 3 and 6-month contracts, in order to test futures prices with shorter and longer maturities.

Turning to the second research objective, we examine the time-varying correlation between oil price shocks and the 10-year sovereign yield spread of core and periphery countries in the EMU. Importantly, this study brings together for the first time the disaggregation of the oil price, a time-varying environment and the sovereign yield spreads in the EMU, which is in aggregate the largest oil-importer of the world. More specifically, our contribution to the existing literature is threefold. First, this study sheds new light on the relation between unanticipated changes in the oil price and sovereign yield spreads, measured as the difference in terms of 10-year sovereign bond yields between a member of the European Monetary Union and Germany. Second, this study examines the extent to which the relation between oil price shocks and sovereign yield spreads is driven by the origin of oil price shocks. Third, this study complements the existing literature by examining the relationship between oil price shocks and EMU sovereign yield spreads in a time-varying framework.

The third research objective is to detect the exact origin of the precautionary demand shock in the oil market and then to evaluate the financial effects of this shock on the US stock market block. This research employs the convenience yield in order to capture shifts in precautionary demand which is a strategy that has not previously been adopted in the oil literature. Focusing on the contributions of this study, we disaggregate the precautionary demand shock into two components, namely, the precautionary demand shock (driven by changes in the convenience yield) and the idiosyncratic oil price shock. The purpose of this innovation is to test the convenience yield's ability to act as a good approximation of the precautionary demand shocks. Furthermore, we test the responses of stock market returns and volatility to precautionary demand and idiosyncratic oil price shocks. Finally, due to the fact that oil markets and stock markets are largely affected by the Great Recession, we examine whether our findings regarding the stock market response to aforementioned shocks are qualitatively similar before and after this event.

1.3 Research Structure

Chapter 2 reviews the existing literature. The relationship between oil prices and the macro-economy has received a considerable amount of attention for more than 30 years now and the research in this area is still growing. Specifically, studies in this field mainly concentrate on the link between oil and financial markets. Overall, in this chapter, we attempt to provide a clear overview regarding three strands in the existing oil-related literature. Specifically, we initially define the key terms, then we point out the econometric models and the data that authors used and finally summarise the main findings from the key studies. Given the existing literature and the readily provided information, we are able to clearly identify fields in which this oil-related literature is still silent. Our goal is to identify potential gaps in the literature and fill these voids. In this regard, we emphasise the main issues that the literature has uncovered or revealed in the final part of this chapter. Next, we clearly indicate the choice of our variables, the online databases from which the data are obtained, the time period of our study and the econometric software packages that are used to analyse our data. Last but not least, we provide information on how our econometric approaches employed in the three empirical chapters serve to improve and extend the existing knowledge in the oil-related literature of the relationship between oil prices and financial markets.

Turning to the Chapter 3, we investigate the role of potential determinants of the oil futures price differential between the two major benchmarks of crude oil, namely West Texas Intermediate (WTI) and Brent, and subsequently examine the *globalisation-regionalisation hypothesis* in the oil futures market, based on the WTI/Brent oil futures price differential. This study builds upon a battery of single-equation multiple linear regression models. We employ monthly data over the period from January1993 to December 2016. Our findings suggest that the convenience yield spread, the oil production spread, the oil consumption spread, the open interest spread and the trading volume spread are significant determinants of the WTI/Brent oil futures price differential. We conclude that these physical oil market fundamental factors and the oil futures market variables collectively drive a significant wedge between the WTI and Brent oil futures prices, which is indicative of a regionalised oil futures market in the short-run.

As far as Chapter 4 is concerned, we examine the time-varying correlation between oil price shocks and the 10-year sovereign yield spread of core and periphery countries in the EMU. We employ a Scalar-BEKK framework that is applied to monthly data over the period from January 1999 to January 2016 for the core countries and the period between January 2001 and January 2016 for the periphery countries. Our results reveal that the correlation between sovereign yield spreads and oil price shocks does not remain stable with respect to different time periods. Specifically, the correlation varies between positive and negative values. In addition, the correlations appear to be less volatile in the pre-2008 period and more volatile in the post-2008 period. Finally, we do not observe noticeable evidence of differentiation in the correlation patterns for the core and periphery countries to different oil price shocks.

With reference to Chapter 5, we investigate the origins of precautionary demand and its effects on stock market returns and volatility in the US. We maintain that the precautionary demand shock can be reasonably approximated by unexpected changes in the convenience yield, which reflects the uncertainty about shortfalls of future supply relative to expected demand. To evaluate this, we employ a SVAR model that is applied to monthly data over the period from January 1986 to December 2016. Our models comprise the convenience yield along with the world oil production growth, the real oil returns and the global economic activity index. We show that the convenience yield dominates the precautionary demand shock, with a lesser proportion attributable to idiosyncratic oil price shocks. Furthermore, our precautionary demand shock exerts a positive and significant effect on real oil returns. Our research findings further suggest that stock market returns and stock market volatility are affected differently by precautionary demand and idiosyncratic oil price shocks before and after the Great Recession of 2007-2009.

Finally, Chapter 6 summarises and concludes this study. More specifically, we provide a summary of the key findings obtained from each empirical chapter and present a combination of findings to form a unified entity. Since each empirical chapter is related to different strands of the oil-related literature, the conclusion provides a common ground for the findings documented in each empirical chapter on the relation among oil markets, financial markets and the macroeconomy. In addition, we outline some policy implications and discuss the limitations of this study. Last but not least, we provide avenues for future research for the attention of the research community and market participants.

Chapter 2: Literature Review

2.1 Introduction

This chapter consists of three main sub-sections in which a detailed analysis of the related literature for each empirical chapter is provided (econometric methods, data and research findings). We note that this review includes only papers which are published in top ranked journals. The term "top" considers mainly journals which are standardised as 4* and 3*. Furthermore, some well-regarded 2* journals are also included in this review. In general, all journals are listed in the ABS (Association of Business Schools). In addition, a sub-section related to the identified gaps will be provided. In the final sub-section, we also indicate how our econometric methods help to improve upon the existing methods and results.

2.2 Determinants of oil futures differential and the globalised / regionalised oil market

2.2.1 Definition of the globalised / regionalised oil market

An important question in the oil market literature with significant implications for the energy policy is the extent to which the oil market is globalised or regionalised. According to Adelman (1984), the world oil market is considered as "one great pool", and therefore globalised, whereas Weiner (1991) argues that the oil market is regionalised. The oil market is globalised when the crude oil prices move closely together and regionalised when the crude oil prices move independently of each other. By considering the prices of two similar in quality crude oil benchmarks (e.g., WTI and Brent) in a globalised oil market, their oil price differential is expected to be nearly constant if oil supply and oil demand shocks which have an impact on oil prices in one region (US) are transmitted to another region (Europe) and influence the oil prices there. On the other hand, in a regionalised oil market, the impact of oil supply and oil demand shocks is limited to the particular regions or markets (US and Europe). Thus, a significant variation is anticipated in the oil price differential and suggests that the oil markets are not fully integrated since regional differences exist. Therefore, when the term "globalisation-regionalisation hypothesis" is used by researchers in the oil market, it simply refers to the examinination of the state of the world oil market and consequently to the extent to which the oil market is globalised or regionalised.

2.2.2 Econometric methods and data used

Studies that concentrate on the WTI/Brent price differential include those by Liu et al. (2015), Reboredo (2011), Fattouh (2010), Hammoudeh et al. (2008) and Milonas and Henker (2001). In addition, empirical studies related to the "globalisation-regionalisation hypothesis" include the papers by Kuck and Schweikert (2017), Ji and Fan (2015), Wilmot (2013), Kaufmann and Banerjee (2014), Candelon et al. (2013), Kleit (2001) and Gülen (1997, 1999). By considering the econometric approach, the existing literature indicates different frameworks to test the above hypothesis. On general principles, cointegration tests, regression analysis, correlation analysis and copula analysis have been used among others.

More specifically, Gülen (1997, 1999) uses bivariate and multivariate cointegration tests introduced by Johansen (1988). Furthermore, Kleit (2001) follows an arbitrage cost approach, while Milonas and Henker (2001) choose to estimate various regression models. Hammoudeh et al. (2008) use the Engle-Granger method (1987) and the Momentum-Threshold Autoregressive (M-TAR) model by Enders and Siklos (2001). Moreover, Fattouh (2010) uses standard unit root tests and a Threshold Autoregressive (TAR) process proposed by Caner and Hansen (2001). Reboredo (2011) considers several copula models with time-varying and time-invariant dependence structures. Candelon et al. (2013), propose a technique which allows for testing for Granger causality in down- and up-side risk for multiple risk levels across tail distributions. Finally, Wilmot (2013) employs cointegration tests that allow for endogeneously determined structural breaks.

By considering more recent studies, Kaufmann and Banerjee (2014) use the Engle-Granger cointegration method (1987). Ji and Fan (2015) employ an error correction model, combined with a directed acyclic graph technique in order to construct contemporaneous causal relations. Liu et al. (2015) use three econometric approaches to test for cointegration patterns. Initially, they use Johansen's (1995) test, then they employ Hasbrouck's (1995) Information Shares measure and finally they employ Gonzalo and Granger's (1995) Permanent-Transitory Common Factor Weights to gauge the roles played by WTI and Brent in price discovery between the two crude oil benchmarks. Finally, Kuck and Schweikert (2017) apply a Markov-switching Vector Error Correction (VECM) model to account for potential time-varying adjustment.

In terms of data, authors consider the prices of the two main crude oil benchmarks, namely the WTI and the Brent. Furthermore, regional crude oil benchmarks are also employed such as the Dubai Fateh, the Bonny light (produced in Nigeria), the Tapis (produced in Malaysia), the Oman, the Mexican Maya, the Canadian Lloyd Blend and the Algerian Saharan Blend, among others. Specifically, authors examine the price differential between crude oils of similar (for example, WTI and Brent, or Maya and Lloyd Blend) and different (for example, WTI and Dubai Fateh) quality characteristics.

2.2.3 Empirical findings

The debate regarding the structure of the global oil market begins with Adelman (1984) who uses the interdependence of regional oil prices in order to measure market integration. He claims that the world oil market is one great pool. Nevertheless, evidence of regionalisation is endorsed by Weiner (1991) who provides the first formal empirical analysis and argues that the ensuing effectiveness of energy policies, such as changes in the Strategic Petroleum Reserves in the US, depends on whether such policies pertain to the US market or are internationally transmitted. On the contrary, Gülen (1997, 1999) provides evidence that oil prices in different markets fluctuate closely together, which is indicative of co-integration. Furthermore, Kleit (2001) reports that oil markets are more unified which is evident by the decline in transaction costs between different oil markets. In addition, Milonas and Henker (2001) indicate that oil prices are not fully integrated with reference to the oil futures markets of WTI and Brent.

In a recent study, Fattouh (2010) suggests that oil markets are not necessarily integrated in every time period and provides evidence of threshold effects in the adjustment process of crude oil price differentials to the long-run equilibrium. Along a similar vein, Reboredo (2011) finds evidence of globalisation from 1997 to mid-2010. However, his evidence of a globalised market has been undermined by increasing regionalisation in the crude oil market since late-2010. Authors such as Kaufmann and Banerjee (2014) indicate that the world oil market is not completely unified and provide support to the findings by Milonas and Henker (2001) and Fattouh (2010). More recently, Liu et al. (2015) show evidence that oil supply disruptions at Cushing, the delivery point for WTI, have significantly contributed to decreasing levels of co-integration between the WTI and Brent markets. Finally, Kuck and Schweikert (2017) report that the oil market is globalised and produce similar findings to Reboredo (2011).

2.2.4 Definition of the oil futures differential

The oil futures differential simply refers to the WTI/Brent oil futures price differential and represents the futures price differential between the two crude oil benchmarks (WTI futures price minus Brent futures price). The examination of the oil futures differential rather than other crude oil benchmarks is based on the fact that both WTI and Brent are not only crudes of similar quality but also have the most actively and highly liquid traded oil futures contracts. Since more accurate information is contained in futures prices, we expect that oil futures markets convey information that is used by traders to form expectations about future supply, demand and the equilibrium price of oil.

2.2.5 Econometric methods and data used

There are only two studies that concentrate on the research area of the determinants of the WTI/Brent oil futures differential and therefore the research is very limited. For example, the studies by Heidorn et al. (2015) and Büyükşahin et al. (2013) which both employ an autoregressive distributed lag (ARDL) model. Following Pesaran and Shin (1999), the ARDL model has the ability to test the existence of a long-run relationship between variables and further to deliver unbiased and consistent estimates of the long-run parameters under I(0) and I(1) regressors. In terms of data, Büyükşahin et al. (2013) use daily data for the nearby futures price of WTI and Brent, whereas Heidorn et al. (2015) use weekly data from various futures contracts (1, 2, 3, 4, 5, 6, 12 and 24 months).

2.2.6 Empirical findings

This channel for research involves the examination of the WTI and Brent differential (spread) by placing an emphasis on their determinants. Due to the limited research that has been conducted in this field, further investigation is required. As previously mentioned, there are few studies that concentrate on this research area. For instance, Büyükşahin et al. (2013), who show that the WTI/Brent spread is partly predicted by trading activities of commodity index traders and partly affected by macroeconomic conditions and physical market fundamental factors. More specifically, the commodity index traders represent a large group of non-commercial institutional traders in commodity markets who are offsetting the activities of other participants such as hedgers and speculators. Due to their size and specific strategies, commodity index traders are able to trigger volatility in commodities futures markets by generating disruptive price formations.

In addition, Heidorn et al. (2015) document that financial traders rather than fundamental traders are the most important drivers of the WTI/Brent spread and contribute to the integration of the two markets. The authors classify as financial traders the positions attributed to managed money and swap dealers, whereas as fundamental traders are associated with the positions attributed to producers, merchants, processors, and users. Specifically, fundamental traders refer to institutions that are involved in the production and processing of a physical commodity and use the futures markets to hedge risks related to those activities. The swap dealers act as hedge funds that are managing risk arising from their dealings in the physical commodity. Finally, managed money traders are managing futures trading on behalf of clients.

2.3 Oil price shocks and sovereign risk

2.3.1 Definition of oil price shocks

A more recent strand of the literature is related to the origin of the oil price change. Since the seminal theoretical work by Barsky and Kilian (2002, 2004) and the first structural analysis by Kilian (2009), there has been an increasing interest amongst academics to explore the link between the origin of the oil price shock and the financial market activity. In particular, Kilian (2009) classifies oil price shocks into two components: the supply-side, and the demand-side. More specifically, supply-side shocks are originate from oil supply disruptions which are caused by major geopolitical events such as the Arab Spring, whereas demand-side shocks are caused by changes in the global business cycle, such as the industrialisation of emerging economies such as China or India.

More specifically, Kilian (2009) classifies further the demand-side component into aggregate demand shocks and precautionary demand shocks. The former is attributed to movements in global aggregate demand. The latter occurs due to uncertainty about the future availability of oil. Specifically, precautionary (or oil-market specific or idiosyncratic) demand shocks are determined by market participants' expectations in response to major geopolitical unrest events and the extent to which these events will trigger oil disruption in the future. Kilian (2009) provides evidence that precautionary demand shocks have a negative effect on the economy whereas aggregate demand shocks cause positive reactions from the economy. In addition, supply-side shocks play a less important role in the economy compared with the demand-side shocks.

Adopting the same line of reasoning, Hamilton (2009a,b) classifies oil price shocks into supply–side and demand–side shocks, based on whether these shocks can be triggered by developments in world oil production or in the global business cycle. The distinction between the empirical studies of Hamilton and Kilian is related to the fact that Hamilton's study highlights the significance of supply-side shocks, whereas Kilian's study emphasises the importance of demand-side shocks to drive oil prices towards higher levels. For example, Hamilton argues that events in the oil market such as the Arab Spring in 2011 were triggered by oil supply disruptions without any impact (a reduction) on oil demand and thus this supply-side shock contributed to higher oil prices.

2.3.2 Definition of sovereign risk

Sovereign risk broadly represents an important strategic indicator for domestic and international investors. This is because sovereign risk takes into consideration a sovereign's willingness and ability to pay its commercial obligations debt. A country which has a manageable debt burden will be expected to pay back its debt which consequently leads to a stable business environment. In turn, this encourages the major ratings agencies to assign higher credit ratings. In this regard, the sovereign yield spreads can be used as a numerical representation of sovereign risk. This choice is justified by the fact that sovereign yield spreads provide substantial information regarding a country's creditworthiness (the ability to serve its debt) and they are affected by unexpected changes to the key macroeconomic indicators and unexpected developments in the financial markets. By employing the European Monetary Union (EMU) sovereign yield spreads, this is measured as the difference in 10-year sovereign bond yields between a member of the EMU and Germany.

2.3.3 The relationship between oil price shocks and sovereign risk

Higher oil prices may have a significant direct impact on government budgets. The impact of oil price changes on economic activity tends to be different when we consider the status of the country as oil-exporting or oil-importing. For instance, oil-exporting countries, due to higher income, are expected to experience improvements in their macroeconomic balances, whereas oil-importing countries are faced with uncertainty since increased oil prices could require government interventions, which could create budgetary risks. In this regard, an oil price increase is regarded as positive (negative) news for oil-exporting (oil-importing) economies through the higher (lower) government revenues. Additionally, allowance should be made for the reverse channel through which sovereign risk impacts oil prices. In particular, the widening of sovereign risk spreads signifies a greater degree of default risk, which could subsequently lead to a reduction in aggregate demand and thus lower demand for oil. In addition, higher sovereign risk might lead to lower uncertainty about future oil supply shortfalls, given the lower demand for oil.

2.3.4 Econometric methods and data used

Looking at the econometric methods employed in this line of research, we notice different methods. For example, Alexandre and de Benoist (2010) employ panel analysis, whereas Aizenman et al. (2013) employ a generalised method of moments approach. In addition, Wegener et al. (2016) employ bivariate VAR-GARCH-in-mean models, while Bouri et al. (2017) employ a Lagrange Multiplier methodology. Moreover, Lee et al. (2017) employ a SVAR model, whereas Shahzad et al. (2017) employ a time-varying approach based on the modified bootstrap rolling-window procedure. Finally, Bouri et al. (2018) employ a bivariate cross-quantilogram approach. It should be noted that the aforementioned studies employ static econometric approaches. One notable exception is the study by Shahzad et al. (2017) who use a time-varying framework.

In terms of data, sovereign Credit Default Swap (CDS) spreads are mainly used to quantify the sovereign risk in different economies to associate with developments in the oil market. For instance, Alexandre and de Benoist (2010) use the Emerging Market Bond Index Global (EMBIG) index as a measure of global risk and seventeen emerging economies. Similarly, Aizenman et al. (2013) use sovereign CDS spreads and the EU market. In a similar fashion, Wegener et al. (2016) use sovereign CDS spreads and data from nine oil-producing countries. Furthermore, Bouri et al. (2017) use sovereign CDS spreads for a sample of emerging and frontier markets. Moreover, Shahzad et al. (2017) use sovereign CDS spreads and data from oil-exporting countries. In a similar vein, Lee et al. (2017) use the International Country Risk Guide (ICRG) data for a sample of oil-exporting and oil-importing countries. Finally, Bouri et al. (2018) use sovereign CDS spreads for BRICS oil-exporting (Brazil and Russia) and oil-importing (China and India) countries and the implied volatility index of crude oil (OVX). The majority of studies prefer to use daily data and the only exceptions are the studies by Lee et al. (2017) and Aizenman et al. (2013) which prefer to use monthly frequency data.

2.3.5 Empirical findings

The existing literature within this line of research attempts to explore the channel through which oil price movements have an impact on the sovereign risk. In general, there is limited evidence on the relationship between oil price movements and sovereign risk. Some related studies which have considered this relationship include papers by Bouri et al. (2018), Bouri et al. (2017), Lee et al. (2017), Shahzad et al. (2017), Wegener et al. (2016), Aizenman et al. (2013) and Alexandre and de Benoist (2010). The picture painted by the aforementioned studies indicates that oil price changes appear to exercise a significant impact on sovereign risk and therefore oil price fluctuations can be considered as an important factor in assessing sovereign risk.

In particular, Alexandre and de Benoist (2010) examine the effect of oil prices on government bond risk premiums during the period from 1998 to 2008. They document that the risk premium of government bonds is positively and significantly affected by higher oil prices. Aizenman et al. (2013) suggest that rises in world commodity prices and oil prices lead to lower sovereign CDS spreads. By considering the period during 2004-2012, they argue that this could be explained by the fact that global economic conditions are largely strong when both prices are increasing. In the same vein, Wegener et al. (2016) investigate the relationship between oil prices and credit default swaps (CDS) spreads over the period 2011-2016. They document that positive oil price shocks lead to lower sovereign CDS spreads and therefore to reductions in sovereign risk.

Lee et al. (2017) investigate the relationship between oil price shocks and the sovereign risk over the period 1994-2015. They show that oil price shocks exert a reduction (increase) in sovereign risk for net oil-exporting (oil-importing) countries. The authors highlight the importance of supply-side (demand-side) oil price shocks to the sovereign risk of net oil-exporting (oil-importing) countries. Additionally, Bouri et al. (2017) investigate the volatility transmission from commodities markets (including oil) to sovereign CDS spreads during the period from 2010 to 2016. They report that sovereign CDS spreads are significantly affected by commodity price volatility. Moreover, Shahzad et al. (2017) examine the predictability from oil market uncertainty to the sovereign CDS spreads by considering the period, 2009-2016. They find a directional predictability from oil price volatility to sovereign CDS spreads and further conclude that higher oil price volatility contributes to increases in sovereign risk. Finally, Bouri et al. (2018) examine the dependence between oil price volatility shocks and sovereign risk for the period 2009-2017. They find that the sovereign risk of oil-exporters (importers) is more sensitive to positive (negative) shocks in oil price volatility.

2.4 The precautionary demand for oil and stock market activity

2.4.1 Nature of precautionary demand in the oil market

As previously mentioned, Kilian (2009) separates oil price shocks into two components, the supply-side and the demand-side. More specifically, supply-side shocks are originated by oil supply disruptions which are caused by major geopolitical events, whereas demand-side shocks are caused by changes in global business cycle. Kilian (2009) classifies further the demand-side component into aggregate demand shocks and precautionary (oil-market specific or idiosyncratic) demand shocks. The former is attributed to movements in global aggregate demand. The latter occurs due to uncertainty about the future availability of oil. Kilian (2009) maintains further that oil price fluctuation during geopolitical events such as the Iranian Revolution and the time-line thereafter were caused by increased uncertainty of future oil availability (precautionary demand shocks). In addition, the study by Kilian and Murphy (2014) indicates that speculative purchases may also be precautionary since they could represent increased uncertainty about future oil supply shortfalls.

2.4.2 Econometric methods and data used

Research on the nature of the precautionary demand for oil with a particular emphasis on the oil market cpnsists of only the paper by Kilian and Murphy (2014). Specifically, they employ a SVAR model and use monthly data for total US crude oil inventories scaled by the ratio of Organisation for Economic Co-operation and Development (OECD) petroleum stocks over US petroleum stocks. However, they attempt to capture the speculative demand in the oil spot market. Thus, they use global crude oil inventories to estimate speculative purchases and consequently they refer to a speculative demand shock. It should be stated that Kilian (2009) associates shifts in precautionary demand with changes in the convenience yield but he does not explicitly use it in his SVAR empirical framework.

2.4.3 Empirical findings

Kilian and Murphy (2014) examine the role of speculative (inventory demand) shocks in order to capture shifts in expectations about future oil supply and demand by considering the period during 1973-2009. They reveal that the oil price increase between 2004 and 2008 is driven by unexpected global demand shocks rather than speculative trading, whereas speculative shocks play an important role in the oil price fluctuations of 1979, 1986 and 1990.

2.4.4 Precautionary demand shocks and stock market activity

The empirical work by Kilian and Park (2009) motivates the further investigation of the impact of oil price shocks based on their origin not only on the economy but also on stock markets. They suggest that exploring the oil price change based on its origin provides a better understanding and a clear picture regarding the impact of oil price changes on stock market performance (stock market returns and stock market volatility).

2.4.5 Econometric methods and data used

Regarding the econometric methods, studies that examine the link between the origin of the oil price shock and stock markets mainly use Kilian and Park’s (2009) SVAR who use US stock market variables to test their responses to demand and supply shocks in the global crude oil market. For example, Abhyankar et al. (2013), Basher et al. (2012), Apergis and Miller (2009), among others.

Another strand of the literature investigates the relationship between oil markets and stock markets in a dynamic time-varying rather than a static environment. This is due to the fact that this relationship appears to change at different points in time. To this end, multivariate GARCH specifications such as the DCC-GARCH-GJR (Dynamic Conditional Correlation-Generalized Autoregressive Conditional Heteroskedasticity-Glosten, Jagannathan, Runkle) method or the the BEKK (Baba, Engle, Kraft and Kroner) method are used. For instance, the DCC-GARCH approach is employed by Antonakakis and Filis (2013), while Broadstock et al. (2012) adopt the BEKK method and Filis et al. (2011) employ a time-varying DCC-GARCH-GJR method.

Finally, regarding the impact of the three structural oil price shocks on stock market volatility, the research is limited and include papers by Degiannakis et al. (2014) who consider a SVAR framework and Kang et al. (2015) who use a time-varying parameter VAR model.

In terms of data, three variables are commonly used to approximate the three structural oil price shocks based on Kilian’s (2009) empirical study. More specifically, changes in the world oil production is the proxy for supply-side shocks, global economic activity index is the proxy to aggregate demand shocks which is designed to capture shifts in the global demand for industrial commodities and the real price of oil, which is based on US refiners’ acquisition cost of crude oil is the proxy to precautionary demand shocks. Furthermore, different stock market indices either in aggregate or sectoral level have been used and the US markets, the European markets and the Asian markets are commonly employed.

On a final note, the majority of studies show a preference for monthly frequency data. Since the existing literature in this field follows Kilian’s (2009) empirical framework, a plausible explanation in using monthly data can be attributed to the fact that structural shocks identification greatly depends on delay restrictions that are economically credible only at the monthly frequency.

2.4.6 Empirical findings

Kilian and Park (2009) examine the responses of industry-specific US stock returns to oil demand and oil supply shocks over the period 1973-2006. They document that US stock market returns are more influenced by demand-side oil price shocks than supply-side oil price shocks. They argue that if the demand-side oil price shock is driven by higher global economic activity (uncertainty of future availability of oil) then higher oil prices will cause a positive (negative) effect on stock market returns. Apergis and Miller (2009) investigate eight countries, namely, Australia, Canada, France, Germany, Italy, Japan, UK and the US for the period 1981-2007. They report that stock market returns do not respond significantly to aggregate demand, precautionary demand and supply-side oil price shocks. In addition, Basher et al. (2012)

provide evidence of a positive (negative) effect of aggregate (precautionary) demand shocks on emerging market stock returns, whereas supply-side shocks do not have any influence on stock market returns. Finally, Abhyankar et al. (2013) find that oil price shocks driven by changes in aggregate (precautionary) demand have a positive (negative) effect on the Japanese stock market returns, whereas the stock market returns do not react significantly to supply-side shocks.

With reference to the relationship between oil markets and stock markets in a dynamic time-varying environment, one of the early studies is by Filis et al. (2011) who examine developed and emerging economies over the period from 1987 to 2009. They show that there is a time-varying correlation between oil and stock markets and further point out that demand-driven shocks exert a stronger influence on the correlation between oil and stock market returns than supply-side shocks. Furthermore, Broadstock et al. (2012) investigate the Chinese market by covering the period 2000 to 2011. They find an increasing correlation between oil price changes and energy stock returns during the recent financial crisis of 2007-2009. Finally, Antonakakis and Filis (2013), who focus on industrialised economies and consider data from 1988 to 2011, report that the demand-side oil price shocks tend to exercise a negative effect on the oil market-stock market correlation, whereas the supply-side oil price shocks do not have any significant impact on stock market-oil market correlation.

In summary, studies in this field consider that supply-side shocks do not influence the stock market returns whereas aggregate demand shocks have a positive effect on the stock market returns and precautionary demand shocks exert a negative effect on the stock market returns. By focusing on precautionary demand shocks, this can be explained by the fact that this shock occurs due to the uncertainty about the future availability of oil. An increasing oil market uncertainty is associated with an increase in the concerns about future oil supply shortfalls. This causes a fall in economic activity. The unstable business and financial environment corresponds to a decrease in stock market activity and therefore lowers the real economic activity.

Although the research on the relationship between the origin of the oil price shocks and the stock market returns has received attention, there are only few attempts to investigate the impact of the three previously mentioned oil price shocks on stock market volatility. Namely, Kang et al. (2015) and Degiannakis et al. (2014) assess the aforementioned relationship. More specifically, Degiannakis et al. (2014) report that the stock market volatility is affected negatively by positive aggregate demand shocks whereas positive supply-side shock and precautionary demand shocks do not significantly affect the stock market volatility. Similarly, Kang et al. (2015) indicate that positive aggregate demand shocks and positive precautionary demand shocks lead to lower levels of stock market volatility, whereas unanticipated disruptions of crude oil supply do not have a statistically significantly effect on stock market volatility.

Last but not least, an important study related to the precautionary demand for oil is the paper by Anzuini et al. (2015) who examine the impact of precautionary demand shocks, approximated by changes in the futures-spot price spread, on US economic activity and inflation. They employ a two-stage identification procedure of a regression equation and a SVAR and use daily data over the period 1986-2008. They find that an unanticipated oil price increase driven by higher precautionary demand leads to a decrease in US economic activity 6 months after the impact and an immediate increase in the Consumer Price Index (CPI). In addition, they show that this shock raises oil inventories, depresses the stock market returns and increases stock market volatility.

2.5 Conclusion

Overall, the purpose of this chapter is to provide a detailed review of the literature which is associated with three empirical essays. We note that a shorter review of literature is also presented within each empirical chapter. A number of sub-sections is provided in order to clarify the terms of interest. In other words, in each sub-section we begin with the definition of the keywords, then we indicate the econometric methods and data used related to the existing literature and finally we present the empirical findings from each research study. Initially, we highlight the extent to which the oil market is globalised or regionalised, paying attention to the WTI and Brent prices, and, further, we detect potential determinants of the WTI/Brent oil futures price differential. Next, we review the link between oil price changes, based on their origin, and sovereign risk. Finally, we present the research about the exact origin of the precautionary demand shock and discuss the relationship between this shock and the stock market activity by focusing on the stock market returns and stock market volatility.

2.6 Gaps in the literature

The existing literature provides a mounting empirical evidence on the relationship between oil prices and financial markets and further to the economy. However, research in this area is still growing and expanding in various directions. In this regard, the current research focuses on three specific strands in the literature and attempts to identify gaps by filling voids, in which the literature remains silent or to explore links where the literature is limited. By reviewing the key studies in these three specific fields, we identify several avenues for further research.

Subsequently, the first respect in which the research is clearly limited refers to the investigation of the *globalisation-regionalisation hypothesis* in the oil futures market by reflecting on a set of potential determinants of the oil futures differential between the WTI and Brent crude oil benchmarks. Overall, research into the determinants of oil futures differential is very limited and the *globalisation-regionalisation hypothesis* has received limited attention in the context of oil futures prices.

The second area in which research remains limited is the examination of the correlation between sovereign yield spreads as a numerical representation of sovereign risk, and oil price shocks. In this respect, we bring together for the first time the disaggregation of the oil price, a time-varying environment and the sovereign yield spreads in the EMU, which is on aggregate the largest oil-importer in the world. Overall, research into the link between oil prices and sovereign risk does not fully consider a time-varying econometric framework, the origin of the oil price shock and the EU market by separating this into core and periphery economies.

The third respect in which we add significantly to the existing literature is the investigation of the exact nature of a precautionary demand shock by disaggregating precautionary demand into two components, namely, the shock that is based on the convenience yield and the idiosyncratic oil price shock. Subsequently, an evaluation is performed of the financial effects of both shocks on US stock market activity.

2.7 Data collection and research methods in the current study

2.7.1 Data collection

The purpose of data collection from various sources can be considered as the main input to acquire information, to make decisions and transfer information to other researchers. In this thesis, which is based on an econometric analysis, time series and therefore secondary data will be used. Time series are usually reused and do not require a lot of effort and time and hence is less costly for the researcher. Once we clearly decide about the chosen variables, the next step is the collection of those data. Since we use time series and based on the fact that there are no issues related to data availability, we have the advantage to collect these data which are available as e-resources and are free of charge since the University has bought these resources from the commercial suppliers. Examples of e-resources include: Bloomberg and Thomson-Reuters global financial markets databases. In addition, time series can be costless, downloaded by agencies and organisations such as the US Bureau of Labor Statistics (BLS) and the US Energy Information Administration (EIA).

Last but not least, the period of our study is dictated by the availability of data. This necessitates that we cover three different time periods either in respect of the beginning period or the end period. To be more specific, for the first empirical chapter, the time period spans from January 1993 to December 2016, for the second empirical chapter, the time period runs from January 1999 to January 2016, and, for the third empirical chapter, the data sample ranges from January 1986 to December 2016. Thus, the time periods in the empirical chapters are not identical and thus we do not succeed in terms of consistency regarding the time period. In addition, it must be noted that we collect and use only monthly data. A plausible explanation could be attributed to our decision to employ the SVAR methodology in two empirical chapters. According to Kilian (2009), delay restrictions are required to identify structural shocks to the real oil price which are economically credible only at a monthly frequency.

2.7.2 Research methods

In order to gain an understanding of the use of our research methods, we state our econometric approaches employed in the three empirical chapters. In particular, Chapter 3 mainly employs a single-equation multiple linear regression (static) model, Chapter 4 mainly uses a Scalar-BEKK (time-varying) model and Chapter 5 employs a SVAR (static) model. Overall, it is evident that our econometric approaches stretch from static to time-varying models. Briefly, static models offer advantages in terms of detecting and interpreting the elasticities of the independent variables, whereas time-varying models suggest that the relationship between two variables may not be constant over time. A more detailed analysis of each econometric specification is provided in the following empirical chapters and therefore this information falls beyond the scope of this chapter. Therefore, the next chapters introduce our empirical analysis.

2.7.3 The contribution of the research methods to the literature

With reference to Chapter 3, it must be noted that our econometric technique to test the *globalisation-regionalisation hypothesis,* based on the F test, originates from our multiple regression equation, which provides an innovative approach and is applied for the first time in the respecting literature. To be more specific, we follow Milonas and Henker (2001), who employ a regression analysis and reveal that factors such as the convenience yield contribute to price disparities between WTI and Brent and furthermore cause partial market segmentation. However, Milonas and Henker (2001) examine potential determinants and argue that, due to the volatility in the WTI/Brent price spread triggered by a number of predictors, oil prices are not fully integrated. Therefore, we expand further this research by using the F test which indicates a more formal analysis of the extent to which the regression equation describes a significant amount of variation in the oil futures differential.

Turning to the Chapter 4, the time-varying econometric framework, Scalar-BEKK, guarantees an investigation of the relationship between different oil price shocks and sovereign yield spreads at each point in time. Indeed, as previously mentioned, a strand of the literature demonstrates that the relationship between oil and financial markets may not be stable over time. The use of Scalar-BEKK represents an advancement in the research area of the relationship between different oil price shocks and sovereign risk as the majority of the previous studies employ static econometric approaches. Although there is a study which uses a time-varying modified bootstrap rolling-window procedure, it is worth noting that this approach suffers from the identification of the appropriate window size and from a weak expression of test statistics. In contrast, our Scalar-BEKK time-varying framework does not suffer from these limitations.

Regarding Chapter 5, in which we employ a SVAR model, it should be mentioned that all studies that focus on oil price shocks based on their origin largely follow Kilian's (2009) SVAR model, which allows the identification of the three oil price shocks. Similarly, the inclusion of the stock market block requires us to follow Kilian and Park's (2009) SVAR model. Thus, we recognise that the econometric approach that is adopted in this chapter does not contribute to further innovations in this strand of the literature in terms of econometric methods. However, we point out that the motivation behind this chapter was neither to follow a specific model nor to develop a new model but, instead, to investigate the exact nature of the precautionary demand shock in the oil market. Overall, armed with this knowledge, we are able to proceed to the empirical analysis.

Chapter 3: The WTI/Brent oil futures price differential and the globalisation-regionalisation hypothesis

3.1. Introduction

Crude oil is an important commodity and constitutes a large part of trade in global financial markets (Westgaard et al., 2011). In addition, the price of crude oil is an important factor which affects the global economy and contributes to financial stability (Chang, 2012). Since oil is traded through futures contracts, oil futures markets can play an important role in providing an efficient price discovery mechanism (Bekiros and Diks, 2008). Therefore, the analysis of crude oil futures contracts is an important tool to explain developments in the international crude oil market (Alquist and Arbatli, 2010). Furthermore, oil futures contracts are important derivative instruments for hedging the risk of unanticipated changes in future oil prices (Lean et al., 2010) and thus, traders and investors design hedging strategies using these contracts to deal with energy risk management.

Hedging strategies may vary across different crude oil benchmarks, such as; WTI (West Texas Intermediate) and Brent. Hence, the degree of co-movement between those benchmarks provides valuable information regarding the effectiveness of crude oil benchmarks as hedging instruments (Reboredo, 2011). In this regard, Adelman (1984) posits that the world oil market is “one great pool”, thus advancing the *globalisation hypothesis*. Under a globalised market, the crude oil prices will fluctuate together in both upswings and downswings of the oil market. By contrast, the *regionalisation hypothesis* implies that crude oil prices do not move in unison. Therefore, the *globalisation-regionalisation hypothesis* recognises the existence of two states of the world oil market.

In this respect, it is important to explain further these two concepts. In a globalised oil market, the prices of two similar in quality crude oil benchmarks (e.g., WTI and Brent) in two different markets should move closely together. Oil supply and oil demand shocks which have an impact on oil prices in one region are transmitted to another region and influence the oil prices there. This implies that under the globalisation hypothesis, the oil price differential does not feature any systematic component and hence cannot be predicted. Any price difference can be attributed to transportation costs. Considering a regionalised oil market, oil prices of similar qualities in the two different regions show independent reactions to oil supply and oil demand shocks. Therefore, the impact of these shocks is limited to the particular regions or markets. This could contribute to significant variations in the oil price differential. These significant variations imply the oil markets are not fully integrated since regional differences exist.

Historically, WTI trades slightly above Brent. This price advantage for WTI can be due to higher quality characteristics. Since WTI and Brent are generally considered as crude oils of similar quality, the consensus is that their prices should move in unison. However, factors such as regional logistical bottlenecks and geopolitical turmoil may have contributed to a significant divergence between WTI and Brent prices in late-2010, reducing the price of WTI below Brent (trading at a discount).[1] This is broadly indicative of regionalisation in the crude oil market since the two major benchmarks are significantly affected by local market conditions and geopolitical events.

Turning to the infrastructure logistics, WTI as a landlocked crude oil can experience bottlenecks in supply via pipelines, whereas Brent does not experience bottlenecks, as it is

[1] In summary, the main causes for the observed variation over time in the oil price differential were (i) the increasing US domestic production from shale formations (Bakken in North Dakota and Eagle Ford in Texas) and crude oil imports from Canada, and, (ii) the political instability in the Middle East, known as the Arab Spring. Reports and additional information can be found on the Energy Information Administration (EIA).

extracted at sea and transferred by ship. Regarding the geopolitical turmoil, Brent crude oil is affected mainly by geopolitical events such as political instability in Syria and Libya, pushing Brent to a higher price level.[2] This can be attributed to the fact that African and Middle Eastern oil production tends to be priced relative to the price of Brent. Regional oil market fundamental conditions (supply and demand) or world turmoil conditions (the global financial crisis of 2007-2009), as well as political tensions and instability, appear to affect to a greater magnitude separately on one market relative to the other. This can be considered a key supportive factor of decreasing levels of market integration and consequently it amplifies regionalisation.

The WTI/Brent oil futures price differential (henceforth "oil futures differential") represents the futures price differential between the two crude oil benchmarks (WTI futures price minus Brent futures price). We examine the WTI (US) and Brent (European) crude oil markets rather than the Dubai/Oman (Persian Gulf) crude oil market since globally, both WTI and Brent have the most actively and highly liquid traded oil futures contracts (see Elder et al., 2014). Our preference for the oil futures differential, as opposed to the oil spot differential, is motivated by relatively more accurate information contained in futures prices (see, Kao and Wan, 2012). Oil futures markets convey information that is used by traders to form expectations about future supply, demand and the equilibrium price of oil.

The behaviour of the oil futures differential is considered a key element in explaining changes in oil market dynamics and international oil-trade flows.[3] The examination of the oil futures differential is essential since the oil futures market's participants need to be aware of these

[2] Choi and Hammoudeh (2010) underscore the importance of the geopolitical crises on the price of Brent, which can adversely affect exports of crude oil from the Middle East and Africa. Barsky and Kilian (2004) emphasise the effect of events such as war in the Middle East on the oil markets.
[3] The EIA provides a detailed scope regarding the two crude oil futures benchmarks of WTI and Brent.
For more information, see: https://www.eia.gov/todayinenergy/detail.php?id=24692

changes in order to design effective hedging strategies and exploit arbitrage profit opportunities. Trading oil futures contracts in the oil futures market allows for hedging activities by commercial consumers and producers, and arbitrage activities by market agents.[4] Given that historically the oil futures differential exhibits a mean reverting behaviour by oscillating within fixed bounds apart from the post-2010 period, trading strategies with a particular emphasis on the oil futures differential can be employed to handle energy risk management.

Surprisingly, the *globalisation-regionalisation hypothesis* has received limited attention in the use of oil futures prices (see, for instance, Milonas and Henker, 2001) and the research into determinants of oil futures differential is very limited (see, for example, Büyükşahin et al., 2013). Our choice to focus on the spread form in the set of explanatory variables which has not been discussed previously in other literature, such as the WTI/Brent convenience yield spread, is justified by the fact that the oil futures differential is traditionally identified by the difference between the quality and freight rates (location) in the two crude oil markets. As a result, we should expect that additional differentials may possibly provide predictive power in market expectations regarding the future value in WTI and Brent benchmarks. Thus, this research aims to fill this void.

In a more detailed analysis, although our study builds upon the study of Büyükşahin et al. (2013) who provide evidence that physical-market fundamentals and financial variables have

[4] Arbitrage is the process where agents taking advantage of a price differential between two commodities (WTI and Brent) by simultaneously buying and selling the two crudes to generate profits. Hedging allows traders to protect (hedge) themselves against price risk by taking a position in the futures market which is opposite to their position in the physical market. Thus, hedging with oil futures contracts reduces the risk of price fluctuations on the physical market. When WTI and Brent crude oil trade closely together and hence move in unison, the scope for arbitrage opportunities diminish and the effectiveness of hedging strategies increases. On the other hand, if one market trades significantly above or below relative to the other, driving the oil market to operate at higher levels of price uncertainty, the arbitrageurs can take advantage of the oil futures differential and the effectiveness of hedging strategies declines.

predictive power to explain the WTI/Brent behaviour, our study differentiates from Büyükşahin et al. (2013) by considering three main differences which can be described as follows. First, we pay particular attention to the inclusion of the convenience yield, given that oil is a storable asset and unexpected changes in the demand for inventory are expected to affect movements in WTI/Brent. In contrast, Büyükşahin et al. (2013) do not employ this oil market-specific variable. Second, the Büyükşahin et al. (2013) study is based on the very short-run period concentrating only on the WTI/Brent nearby spread, while we employ the 1-month, 3-month and 6-month futures contracts between WTI and Brent in order to test the short-run period more extensively. Third, Büyükşahin et al. (2013) use data from 2003 to 2012, whereas we use a longer time period which runs from 1993 to 2016.

The contributions of the study can be described succinctly as follows. First, we consider a comprehensive set of crude oil-market specific factors and oil-futures market specific indicators, which have not been explored by the existing literature to test the *globalisation-regionalisation hypothesis*. Second, we focus on the futures oil price differentials rather than the spot oil price differentials, given that futures prices are more informative. Third, we consider the recent period which has seen a significant divergence in the oil futures differential since late-2010. Finally, we consider these effects on various futures contracts maturities (i.e. 1, 3 and 6-month contracts).

Our findings are as follows. First, the WTI/Brent convenience yield spread has a negative and significant effect on the oil futures differential for the contracts near to maturity (1-month and 3-month). Second, the WTI/Brent oil consumption spread has a negative and significant effect on the oil futures differential for the 6-month to maturity contract. Third, the WTI/Brent oil production spread has a negative and significant effect on the oil futures differential among the corresponding maturities of 1-month, 3-month and 6-month contracts. Fourth, the WTI/Brent open interest spread has a negative and significant effect on the oil futures differential for the 3-month and the 6-month to maturity contracts. Fifth, the WTI/Brent trading volume spread has a positive and significant effect on the oil futures differential for the contracts near to maturity (1-month and 3-month). Overall, we suggest that the state of the oil futures market is not stable in every time period. Specifically, we provide evidence that the market is regionalised in the short-run and globalised in the long-run.

The remainder of the chapter is organised as follows. Section 3.2 reviews the literature of the study. Section 3.3 describes the data and provides a preliminary analysis of the variables. Section 3.4 outlines the econometric models. Section 3.5 analyses the estimation results. Section 3.6 offers some concluding remarks and discusses points for further research.

3.2. Review of the related literature

Chang et al. (2010) argue that among the four international crude oil benchmarks (WTI, Brent, Tapis and Dubai/Oman), only WTI and Brent are the world references for crude oil. WTI and Brent have similar qualities as both belong to the light sweet category.[5] As previously stated, our choice to examine the WTI and Brent markets is further justified by the fact that both markets have the most actively traded oil futures contracts in the world.[6] WTI is the reference

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[5] These quality differences are due to the higher percentage of gasoline and the lower percentage of heating oil in WTI than in Brent (Milonas and Henker, 2001). They are light because of low density and sweet because of low sulphur. Using light sweet crude oil, products like gasoline can be produced easily and cheaply. More specifically, WTI has an API (American Petroleum Institute) gravity of 39.6 degrees and contains 0.20 percent of sulphur, whereas Brent API gravity is 38.3 degrees and contains 0.40 percent of sulphur. Thus, a price advantage for WTI may arise due to it being lighter and sweeter than Brent.
The interested reader can find all the necessary information about different quality characteristics of crude oils in the following link: http://www.eia.gov/tools/glossary/index.cfm?id=A#API_grav

[6] Although the Dubai/Oman futures contract is listed on the Dubai Mercantile Exchange Limited (DME), its trading volume is relatively small compared to the WTI and Brent, which are considered the most liquid traded futures contracts in the global oil market.

not only for other types of crude oil produced domestically in the US, but also for imported crude oil produced in Canada. Therefore, WTI is the dominant crude oil benchmark in the large North American market.

Although Brent accounts for 1 percent of world-wide crude oil production, it is used to set prices for crude oil produced and traded not only in the smaller European market but also in other parts of the world like North Africa, the Middle East, Australia and a number of countries in Asia.[7] Therefore, Brent represents two-thirds of the crude oil traded internationally (see, for instance, Arouri et al., 2011; Filis et al., 2011). The WTI has the most liquid futures contracts in the crude oil market compared with Brent. However, the trading volume of Brent futures contracts exceeded the trading volume of WTI futures contracts in April 2012 for the first time. This is indicative of the increasing significance of Brent as a global crude oil benchmark.[8]

While Brent is considered a global crude oil benchmark, the discussion as to whether this crude oil benchmark can be mimicked by the WTI is dominated by the *globalisation-regionalisation hypothesis*, pioneered by Adelman (1984). As aforementioned, there is a globalised market when crude oil prices move in unison and a regionalised market when crude oil prices fluctuate with different intensities. Some studies related to the aforementioned hypothesis include papers by Liu et al. (2015), Ji and Fan (2015), Wilmot (2013), Candelon et al. (2013), Reboredo (2011), Fattouh (2010), Hammoudeh et al. (2008), Kleit (2001), Milonas and Henker (2001), Gülen (1997, 1999) and Weiner (1991).

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[7] The source of the information can be found on the EIA: http://www.eia.gov/todayinenergy/detail.cfm?id=18571.
[8] Reports and additional information can be found on the EIA.

Evidence of regionalisation is endorsed by Weiner (1991) who argues that the ensuing effectiveness of energy policies, such as changes in the Strategic Petroleum Reserves in the US, depends on whether such policies pertain to the US market or are internationally transmitted. On the contrary, Gülen (1997, 1999) provides evidence that oil prices in different markets fluctuate closely together which is indicative of co-integration. In addition, Milonas and Henker (2001) indicate that oil prices are not fully integrated with reference to the oil futures markets of WTI and Brent. Along a similar vein, Fattouh (2010) suggests that oil markets are not necessarily integrated in every time period and provides evidence of threshold effects in the adjustment process of crude oil price differentials to the long-run equilibrium.

Recently, Reboredo (2011) tests the *globalisation-regionalisation hypothesis* and finds evidence of globalisation from 1997 to mid-2010. However, the *globalisation hypothesis* has been undermined by increasing regionalisation in the crude oil market since late-2010.[9] More recently, Liu et al. (2015) use high-frequency data to investigate the price discovery between WTI and Brent futures prices over the period from 2008-2011 and show evidence that oil supply disruptions at Cushing, the delivery point for WTI, have significantly contributed to decreasing levels of co-integration between the WTI and Brent markets.

[9] In late-2010, the combination of two key events in the US oil market; namely, an increasing volume of domestic production from North Dakota and Texas, as well as, growing imports from Canada, outpaced the Cushing's capacity to store and distribute excess oil supplies. The existing pipeline infrastructure in Cushing was inadequate to transport growing oil production to refineries in the Gulf Coast. This created stockpiles and bottlenecks in Cushing, reducing the price of WTI below Brent, resulting in WTI trading at a discount. However, in early 2013, improvements in oil transportation infrastructures diminished the scope for further bottlenecks between Cushing and the Gulf Coast, putting upward pressure on WTI prices. For further reading about the price differences in the WTI/Brent spread since late-2010, articles and reports on this subject may be found on the EIA. For more information, see:
http://www.eia.gov/todayinenergy/detail.cfm?id=11891,
http://www.eia.gov/forecasts/steo/special/pdf/2012_sp_02.pdf
http://www.eia.gov/todayinenergy/detail.cfm?id=12391

Considering the econometric approach, the existing literature sheds light on different methodologies that are employed to test the globalisation-regionalisation hypothesis. On general principles, cointegration tests, regression analysis, correlation analysis and copula functions have been used. It should be mentioned that studies related to the WTI/Brent price differential include only those by Liu et al. (2015), Reboredo (2011), Fattouh (2010), Hammoudeh et al. (2008) and Milonas and Henker (2001). It must be noted that our econometric technique to test the globalisation-regionalisation hypothesis is based on the F test that originates from the multiple linear regression model for the oil futures price differential. The intuition of the F test builds our previous arguments that globalised oil markets manifest in overlapping information contents. Consequently, the futures price differential under globalisation features no systematic component and thus should be unpredictable. To be more specific, we follow Milonas and Henker (2001) who employ a regression analysis and reveal that factors such as the convenience yield contribute to price disparities between WTI and Brent and further cause partial market segmentation. Therefore, the use of the F test indicates the extent to which the regression equation describes a significant amount of variance in the oil futures differential.

The debate regarding the structure of the global oil market begins with Adelman (1984) who uses the interdependence of regional oil prices in order to measure market integration. He claims that “the world oil market, like the world ocean, is one great pool”. Nevertheless, Weiner (1991) provides the first formal empirical analysis by using correlation analysis and switching regression analysis with aim to test the degree of regionalisation in global oil markets. In addition, Gülen (1997, 1999) uses bivariate and multivariate cointegration tests introduced by Johansen (1988) in order to test the degree of efficiency arguing that regionalisation gives rise to arbitrage opportunities. Furthermore, Kleit (2001) follows an arbitrage cost approach based on the theory of arbitrage as introduced by Spiller and Wood (1988a,b) to estimate transaction costs between oil regions, while the methodology of Milonas and Henker (2001) is based on various regression models.

In more recent literature, Hammoudeh et al. (2008) use the Engle-Granger method (1987) and the Momentum-Threshold Autoregressive (M-TAR) model by Enders and Siklos (2001) which allows for asymmetry in the return to equilibrium levels. Moreover, Fattouh (2010) uses standard unit root tests with the aim of identifying if oil price differentials can or cannot deviate without bounds. Furthermore, he uses a Threshold autoregressive (TAR) process proposed by Caner and Hansen (2001) to distinguish between different regimes that allows oil price differentials to follow a random walk (mean reversion) if oil price differentials are above (below) a certain threshold. Reboredo (2011) considers several copula models with time-varying and time-invariant dependence structures. Candelon et al. (2013), propose a technique which allows for testing for Granger causality in down- and upside risk for multiple risk levels across tail distributions. The authors build on Hong et al. (2009) who consider the concept of Granger causality in risk between two markets only at a particular risk level.

Wilmot (2013) employs cointegration tests that allow for endogenously determined structural breaks. These structural changes could cause the cointegrating vector to shift. To this end, the author follows the Gregory and Hansen (1996) approach which is based on augmented Dickey-Fuller and Phillips-Perron tests to account for structural breaks. Ji and Fan (2015) employ an error correction model combined with a directed acyclic graph technique in order to construct contemporaneous causal relations. Finally, Liu et al. (2015) use three econometric approaches to test for cointegration patterns. Initially, they use Johansen's (1995) test, then they employ Hasbrouck's (1995) Information Shares measure and finally they employ Gonzalo and

Granger's (1995) Permanent-Transitory Common Factor Weights to gauge the roles played by WTI and Brent in price discovery between them.

The recent developments are discordant with the notion of globalised markets, according to which crude oil of similar quality characteristics in different markets should be priced very closely to each other, resulting in a constant range of fluctuations in their price differential (Wilmot, 2013; Fattouh, 2010). Specifically, in our empirical analysis we seek to identify channels through which the oil market is globalised or regionalised, which in turn can trigger a range of responses in energy policy. Following Fattouh (2010), due to their similar quality and because they are the most liquid traded futures contracts, WTI and Brent are characterised by the absence of threshold effects in their price differential. Thus, the WTI/Brent oil futures differential is expected to be stationary within certain bounds. Through the mechanism of error correction, as indicated by the arbitrage activity, the oil futures differential adjusts to certain boundaries in case of a deviation from the long-run equilibrium. Specifically, large deviations above or below a certain threshold can be eliminated quickly through arbitrage by market participants in both futures markets, leading to a long-run equilibrium.

Against this background, our expectation is that the oil futures market is globalised in the long-run. However, the recent developments in the crude oil market since late-2010, driven by regional supply and demand imbalances, as well as geopolitical unrest (both of which caused Brent trading at a persistent premium over WTI), can be a hindrance to the adjustment process to the long-run equilibrium. Thus, while the oil futures market may be globalised in the long-run, this study seeks to advance the understanding of the short-run determinants of the oil futures differential, and hence regionalisation.

Within the limited body of research on the subject (see, among others, Hammoudeh et al., 2010; Caumon and Bower, 2004; Milonas and Henker, 2001), the importance of the fundamental factors on the oil futures differential (e.g., supply and demand) is accentuated. Specifically, Milonas and Henker (2001) underscore the importance of supply and demand conditions on the oil futures differential. Similarly, research by Caumon and Bower (2004) suggest that the oil futures differential can be affected by different supply and demand events which occur in both markets. A similar picture is painted by Hammoudeh et al. (2010) who indicate that the oil futures differential is affected by fundamental and transitory components in both the WTI and Brent crude oil benchmarks.

Recently, Büyükşahin et al. (2013) identify that physical market fundamentals, such as the North American oil production (including the oil supply in US and imports from Canada), can help explain the oil futures differential. Thus, supply and demand imbalances for WTI and Brent crude oil generate a significant short-term impact on their futures prices. For example, an unexpected increase in global demand for crude oil (triggered by the industrialisation of some emerging economies) or unexpected oil supply disruptions (due to pipeline limitations or political instability in the Middle East) can create supply and demand imbalances. These imbalances can affect WTI and Brent crude oil futures prices and thus, their oil futures differential.

Our research is conceptually similar to Duan and Lin (2010), who ascribe the WTI/Brent spot price differential to crude oil convenience yields. In addition, futures prices incorporate the investor's belief regarding the value of the convenience yield (Mellios and Six, 2011). The convenience yield reflects market expectations about the future availability of crude oil. It is highly associated with shortages and inventories of oil. According to Hull (2012), shortages in the crude oil market are reflected in a higher value of the convenience yield. If the probability of shortages in the near future is perceived to be relatively low and the holders possess relatively high inventories, the convenience yield decreases. In the case of low inventories, the convenience yield tends to be higher as shortages are more likely to occur.

Studies related to the determinants of the oil futures differential include papers by Heidorn et al. (2015), Büyükşahin et al. (2013) and Milonas and Henker (2001). Specifically, Milonas and Henker (2001), who use various regression models to examine the relation among the WTI/Brent oil futures differential, convenience yield and supply and demand for both WTI and Brent crude oil. Fundamental factors of quality discrepancies are identified as the main drivers of the differential for those contracts away from expiration. However, for contracts near to maturity, the main determinant is the convenience yield. More recently, Büyükşahin et al. (2013) employ an autoregressive distributed lag (ARDL) model on daily data to examine fundamental and financial drivers of the nearby oil futures differential between WTI and Brent. They conclude that positions from commodity index traders and physical traders in both futures markets partly help to predict the behaviour of the oil futures differential.

Furthermore, Heidorn et al. (2015) use a term structure model on weekly data to investigate the impact of fundamental and financial traders' market positions on the Brent/WTI oil futures differential for a range of different maturities. They find that financial rather than fundamental traders tend to exercise a significant influence on WTI/ Brent market integration by eliminating price differences between them. As aforementioned, the goal of this chapter is to investigate the *globalisation-regionalisation hypothesis* in the WTI/Brent oil futures price differential by assessing a broader set of crude oil-market specific factors and oil-futures market specific indicators. There is little research in the above context and thus we seek to contribute to this literature.

3.3. Data and preliminary analysis

The sample period runs from January 1993 to December 2016, including 288 monthly observations. The time period is dictated by data availability.

3.3.1 WTI/Brent oil futures differential

The present study focuses on the oil futures contracts that are traded in two international markets. For the US crude oil market, we include 1, 3 and 6 month futures contracts available from the New York Mercantile Exchange (NYMEX). For the European crude oil market, we include the Intercontinental Exchange (ICE) oil futures contracts for the same maturities. Prices of crude oil are expressed in US dollars per barrel and the size of a contract is 1,000 barrels (contract unit) with a minimum fluctuation of $0.01 per barrel. These prices are extracted from Bloomberg.

Futures prices can be obtained from various available databases, such as the Energy Information Administration, Bloomberg and Datastream. Therefore, in this study, the futures prices are readily available and not constructed. For example, the continuous futures prices are collected from Bloomberg for the purposes of this chapter. The Bloomberg terminal is a computer system that allows investors and researchers to access the Bloomberg data service, which provides real-time financial data. Overall, the key element of the Bloomberg terminal is reliability in delivering fast and accurate information about economic and financial data, news and analytics. However, there is a need to provide a brief information regarding the construction of the continuous futures price series. To elaborate further, the construction of the continuous futures price series (also known as spread-adjusted price series), is composed by adding the cumulative difference between the old and the new contracts at rollover points to the new contract series. The resulting price series would be free of the distortions due to spread difference that exist at the rollover points between contracts (see Schwager and Etzkorn, 2017).

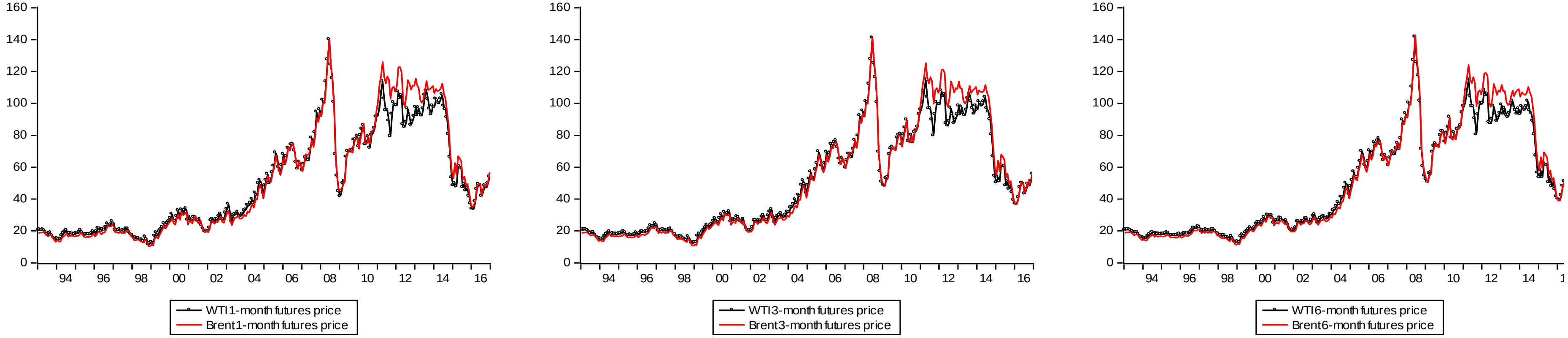
The identification of potential determinants on the oil futures differential is examined for 1, 3 and 6-month maturities of futures contracts. Firstly, the 1-month futures contract has the greatest amount of predictive information which can potentially explain future movements and volatility in the spot price (see Hammoudeh et al., 2003). Secondly, futures contracts with shorter maturities (1-month and 3-month) present higher trading volumes and thus generate greater liquidity (see Hammoudeh and Li, 2005; Hammoudeh and Yuan, 2008) compared to futures contracts for other maturities. Thirdly, the 6-month oil futures contract is the average contract where the price of risk for the far to maturity month contract does not exceed the premium received on the nearest to maturity month contract. According to Miffre (2004), hedging with longer maturity futures contracts (six to nine months) is more uncertain than hedging with shorter maturity futures contracts (three to six months). In addition, Graham-Higgs et al. (1999) find that the futures market is efficient for maturities shorter than 6 months. Therefore, the prices of such contracts reflect all available information.

Monthly futures prices and the oil futures differential (both at 1, 3 and 6 months to maturity) are displayed in Figures 3.1 and 3.2. It is clear that both markets were traded at similar prices with the WTI price trading at a small premium over Brent. Since late-2010, this relationship began to change causing in a significant divergence between WTI and Brent prices, resulting in the price for WTI trading at a discount below Brent. However, during the period 2011-2015, the substantial premium of Brent over WTI diminished gradually to a small premium and returned to prior to late-2010 levels in December 2015, which coincided with the lifting of the

US crude oil export ban. As a result, in early 2016, the oil futures differential narrowed and almost returned to parity. By the end of December 2016, the oil futures differential widened slightly again (a higher rise in Brent relative to WTI).

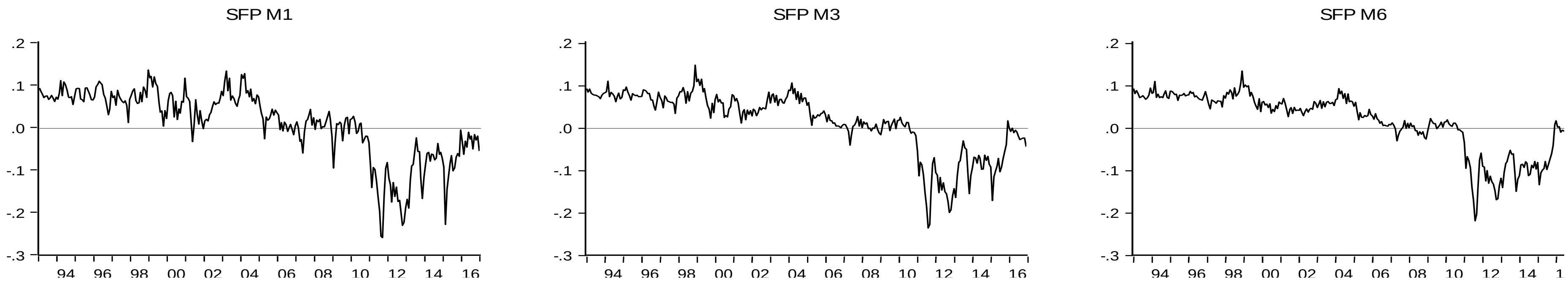
Figures 4.1 and 4.2 further show that WTI and Brent oil futures prices fluctuate similarly during the period 1993-2010 (apart from late-2010), which suggests the existence of a globalised market in the long-run. On the other hand, during the period 2011-2016 (apart from December 2015), WTI was trading at a persistent discount relative to Brent. This discount was pronounced from 2011 to 2014 when the difference between WTI and Brent widened considerably. This result suggests that at times of intense regional logistical bottlenecks and severe geopolitical unrest, which clearly emerged during 2011-2014, the globalised nature of the oil futures market appears to be challenged.

Figure 3.1: Time series plots for WTI and Brent oil futures prices



Note: This Figure depicts variation over time in the WTI and Brent futures prices. The sample period runs from January 1993 to December 2016.

Figure 3.2: Time series plots for the WTI/Brent oil futures price differential



Note: This Figure depicts variation over time in the WTI/Brent oil futures differential (SFP). M1 = one-month futures contract, M3 = three-month futures contract, M6 = six-month futures contract. The sample period runs from January 1993 to December 2016.

3.3.2. Explanatory variables

In this chapter, we use the spread of the WTI/Brent convenience yield, WTI/Brent oil consumption, WTI/Brent oil production, WTI/Brent open interest and WTI/Brent trading volume as possible explanatory variables. The Energy Information Administration (EIA) database is the source of monthly historical data for oil-market specific explanatory factors such as crude oil production[10] and petroleum consumption.[11] It is worth noting that our measure of the WTI crude oil production might in part reflect the rapid growth in US shale oil production (shale oil revolution) which was triggered by technological advances in drilling and contributed to the recent developments in US crude oil production. In particular, shale oil production experienced an increase in 2003 and a rapid expansion in 2009, which resulted in almost half of US crude oil production coming from the accumulation of US shale oil production in 2014 (see, for instance, Kilian, 2016). Open interest and trading volume represent trading activities in the oil futures market.[12] Open interest and trading volume together are employed to indicate changes in market depth and provide information in explaining futures price volatility. Market participants use these variables as indicators of price trends in the futures market. We use the open interest and the trading volume of WTI and Brent at 1, 3 and 6 month futures price contracts. Data on open interest and trading volume are collected from Bloomberg.

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[10] Although WTI is produced only in the Midwest region, it is considered as the major benchmark in the US (Speight, 2011). Crude oil production in the US and crude oil imports from Canada into the PADD 2 region is used as a proxy for WTI oil production, whereas the Brent crude oil output is given by the sum of the UK and Norway total crude oil production in the North Sea (Hamilton, 2008), insofar as both countries hold the majority of oil fields in this area.

[11] The EIA uses product supplied as a proxy for US petroleum consumption. We employ this variable as a proxy for WTI oil consumption. In the US, oil consumption is benchmarked to domestically produced WTI (Hammoudeh et al., 2010), whereas our measure of Brent oil consumption is constructed using data on petroleum consumption in France, Germany, Italy and the UK. This is due to the fact that Brent is typically refined in Europe and is consumed in large quantities in Northwest Europe (Speight, 2011). Candelon et al. (2013), argue that due to the continuous decline in production, Brent crude oil is largely consumed locally in Europe.

[12] Open interest is the number of outstanding contracts that have not been delivered on a specific day. Trading volume is the number of contracts bought and sold for a given time period.

Furthermore, we use the ICE LIBOR[13] (Intercontinental Exchange, London Interbank Offered Rate) and the US Treasury bill rate, both at 1, 3 and 6 months as risk-free interest rates to construct our measure of the convenience yield. Specifically, we employ the LIBOR (Knetsch, 2007) as the main risk-free interest rate, whereas the US Treasury bill rate (Gospodinov and Ng, 2013; Milonas and Henker, 2001) is used as an alternative measure of a risk-free interest rate in order to test the robustness of our results. Both rates are known as the most widely-used benchmarks for risk-free interest rates. Data on the ICE LIBOR interest rate are extracted from Bloomberg, whereas data on the US Treasury bill rate are collected from Datastream. In addition, for the construction of the convenience yield, we use WTI and Brent spot crude oil prices, which are obtained from EIA.

It is worth noting that the choice of the US Treasury bill rate as an alternative measure is based on the recent claims of extensive manipulation of the LIBOR which contributed to increasing concerns about the integrity of this rate (i.e. the financial crisis of 2007-2009). From a theoretical perspective, banks could gain cumulative returns by manipulating LIBOR if they indicate a less volatile rate to attract the attention of investors. As far as payments in loans by companies are based on LIBOR movements, it appears to have an impact on their borrowing costs and further reduces the reliability of the banking sector and the confidence in the financial markets. According to Duffie and Stein (2015), manipulating the LIBOR is beneficial in periods of financial stress since a lower interest rate implies that a bank is able to receive credit. Furthermore, it is also beneficial for banks, in cases of small distortions in LIBOR fixing while having large trading positions in a derivative market which are also indexed to LIBOR.

[13] Due to the fact that government bonds include liquidity premia, Alquist et al. (2014) argue that LIBOR seems to provide a good measurement of the borrowing costs experienced by companies in the oil industry.

Some related studies choose LIBOR rather than the T-bill as the main proxy for the risk-free rate of return in computing the convenience yield. These include the papers by Alquist et al. (2014) and Fontaine and Garcia (2012). By looking at the Fontaine and Garcia (2012) empirical study, they document that tight funding conditions lower substantially the risk premium on US Treasury bonds but raise the risk premium implicit in LIBOR rates, swap rates, and corporate bond yields. Similarly, Alquist et al. (2014) use LIBOR data for maturities of 1, 2, 3, 6 and 12 months rather than US Treasury bill data, because the former represent a better measure of the borrowing costs incurred by oil companies. Government bonds can embody large liquidity premia due to favourable taxation treatment, repo specials, scarcity premia and benchmark status.

Next, we present in detail the construction of the spread variables. Specifically, the oil futures differential is given by:

$$SFP_{t,n} = FW_{t,n} - FB_{t,n} \tag{1}$$

where $SFP_{t,n}$ is the difference (spread) between WTI and Brent crude oil futures prices at time *t* and maturity *n*, $FW_{t,n}$ is the futures price for WTI at time *t* and maturity *n* and $FB_{t,n}$ is the futures price for Brent at time *t* and maturity *n*.

Similarly, the convenience yield spread (*SCY*) is given as follows.

$$SCY_{t,n} = CYW_{t,n} - CYB_{t,n} \tag{2}$$

where $CYW_{t,n}$ and $CYB_{t,n}$ are the WTI and Brent convenience yields at time *t* and maturity *n*.

To calculate the convenience yield (*CY*) in crude oil markets, we adopt the recent approach proposed by Gospodinov and Ng (2013). This approach consists of calculating the net (of storage and insurance costs)[14] percentage convenience yield as follows:

$$CY_{t,n} = \frac{(1+i_{t,n})S_t - F_{t,n}}{S_t} \qquad (3)$$

where $i_{t,n}$ is the risk-free interest rate at time *t* and maturity *n*, S_t denotes the spot price of crude oil for delivery at time *t* and $F_{t,n}$ denotes the futures price of crude oil for delivery at time *t* and maturity *n*.

It is worth mentioning that the convenience yield can be associated with shifts in precautionary oil demand arising from an unexpected disruption in oil supply or an unexpected growth in oil demand (see, for example, Kilian and Park, 2009). In other words, shifts in precautionary demand may represent increasing uncertainty in the oil market. In this regard, the greater the uncertainty in the oil market, the higher the convenience yield. Furthermore, uncertainty about oil supply shortfalls could potentially be attributed to geopolitical unrest caused by political instability and wars in the Middle East such as; the Persian Gulf crisis of 1990-1991, the second Iraq war of 2003 and the Arab Spring of 2011 (see Alquist and Kilian, 2010; Kilian, 2009). Therefore, we suggest that the geopolitical turmoil is well captured by the convenience yield that we employ in this study.

Further, the oil consumption spread (*SCO*), the oil production spread (*SPR*), the open interest spread (*SOI*) and the trading volume spread (*STV*) are given as follows.

$$SCO_t = COW_t - COB_t \qquad (4)$$

$$SPR_t = PRW_t - PRB_t \qquad (5)$$

[14] Fama and French (1988) in their empirical analysis for the theory of storage assume that the relative warehouse costs of holding the commodity are roughly constant.

$$SOI_{t,n} = OIW_{t,n} - OIB_{t,n} \quad (6)$$

$$STV_{t,n} = TVW_{t,n} - TVB_{t,n} \quad (7)$$

where COW_t (COB_t) indicates the WTI (Brent) oil consumption, PRW_t (PRB_t) represents the WTI (Brent) oil production and finally, $OIW_{t,n}$ ($TVW_{t,n}$) and $OIB_{t,n}$ ($TVB_{t,n}$) are the WTI and Brent open interests (trading volumes) at time *t* and maturity *n*, respectively. The next section reports the preliminary analysis.

3.3.3 Descriptive statistics

All explanatory variables are expressed in logarithms, except for *SCY*, whereas the variables measuring oil consumption and oil production are seasonally adjusted. Descriptive statistics are presented in Table 3.1. Panel A summarises descriptive statistics of the oil futures differential (*SFP*) and the convenience yield spread (*SCY*) for 1, 3 and 6 months to maturity as well as the oil consumption spread (*SCO*). Panel B summarises the open interest spread (*SOI*) and the trading volume spread (*STV*) for 1, 3 and 6 months to maturity as well as the oil production spread (*SPR*).

In panels A and B, we indicate that the *SFP* is fairly volatile as the contract approaches maturity. Also, since the future path of oil prices is highly uncertain as we move further out into the future, the *SCY* is more volatile for longer maturity futures contracts, exhibiting greater uncertainty of the future availability of oil in the more distant future. The Jarque-Bera statistic rejects the null of normality in all of the series. The observed non-normality is also evident in the skewness and kurtosis statistics.

The Augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1981) and Philips-Perron (PP) (Phillips and Perron, 1988) unit root tests are reported in Table 3.2 (see Panels A and B).

Irregardless of the maturity of the futures contract, both tests indicate the presence of a unit root for WTI and Brent futures prices. The ADF test decisively rejects the null of a unit root for the differential form of our explanatory variables with the exception of the *SPR*. Similarly, the PP test cannot reject the null hypothesis of a unit root for the *SPR*. Because these results may be biased towards the presence of a unit root in the event of a structural break, we also perform the Zivot-Andrews (ZA) (Zivot and Andrews, 1992) unit root test that allows for the presence of structural breaks in the constant, the trend or in both the constant and trend. The results of these tests are reported in Panel C. Crucially, the ZA test rejects decisively the unit root in the *SFP*. This result resonates well with evidence of co-integration between the two benchmarks, as the difference between the WTI and Brent oil prices can be perceived as a deviation from the long-run equilibrium relation (Fattouh, 2010; Chevillon and Rifflart, 2009).

The results of the ADF and PP tests for the rest of the variables are endorsed by the ZA test. Variables such as *SFP*, *SCY, SOI, STV* (for all different maturities), and *SCO* appear to be stationary in levels and thus the null hypothesis of unit root is rejected. Also, the tests show that *SPR* features a unit root if the ADF and PP tests are used. Although the ZA test rejects the null of a unit root (in terms of the constant), since the variable shows no evidence of structural break, we establish the stationarity of *SPR* by transforming this variable into first differences. Furthermore, the ZA test is indicative of determining endogenously a structural break in the *SFP*. Figure 3.3 reveals the ZA test for the *SFP*. This vindicates the use of a dummy variable in the regression models in Section 3.4. More specifically, the structural break in the *SFP* was detected in January 2011, which is almost in line with Büyükşahin et al. (2013), who document a structural break in the middle of December 2010 by using a Chow test which roughly matches the period for which the dummy variable we construct takes on value 1. Furthermore, a structural break in the *SFP* is also evident in terms of a Bai and Perron (Bai and Perron, 1998) breakpoint test. Similarly, a structural change was detected endogenously in January 2011. In Table 3.3, we observe the Bai and Perron breakpoint test results.

Table 3.4 reports the coefficients of unconditional correlation of the series in order to identify the linear relation among the variables under investigation. Overall, the unconditional correlation between the dependent variable and the explanatory variables alters substantially. A negative and relatively weak or moderate correlation is observed between *SFP* and *DSPR*, as well as *SFP* and *SCO*, while a positive and relatively weak or moderate correlation is observed between *SFP* and the remaining explanatory variables (with the exception of the SCY for the 1-month). Further to the above diagnostic tests, we employ a multiple linear regression to proceed to the stage of the empirical analysis and the discussion of results.

Table 3.1: Descriptive statistics

Panel A: Oil futures differential, convenience yield spread at 1, 3 and 6 months to maturity and oil consumption spread.

	SFP M1	SFP M3	SFP M6	SCY M1	SCY M3	SCY M6	SCO
Mean	0.0094	0.0124	0.0126	0.0083	0.0051	0.0050	0.8867
Median	0.0243	0.0289	0.0347	0.0064	0.0042	0.0049	0.9061
Maximum	0.1348	0.1465	0.1328	0.0933	0.0913	0.1259	1.0648
Minimum	-0.2604	-0.2377	-0.2209	-0.0795	-0.1164	-0.1309	0.6853
Std. Dev.	0.0807	0.0736	0.0695	0.0253	0.0279	0.0333	0.1010
Skewness	-1.0777	-1.1212	-1.0296	0.3070	-0.0072	-0.0751	-0.2365
Kurtosis	3.7644	3.6771	3.2532	4.3852	4.5035	4.3312	1.9771
Jarque-Bera	62.7642***	65.8398***	51.6496***	27.5498***	27.1272***	21.5345***	15.2400***
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005

Panel B: Open interest spread, trading volume spread at 1, 3 and 6 months to maturity and oil production spread.

	SOI M1	SOI M3	SOI M6	STV M1	STV M3	STV M6	SPR
Mean	0.0317	0.3184	0.5954	0.4991	0.4693	0.6860	0.6116
Median	0.0708	0.3650	0.5970	0.6029	0.4397	0.6728	0.4380
Maximum	1.9522	1.9606	2.8793	1.2007	1.9519	2.6751	1.6066
Minimum	-1.0991	-1.1320	-1.0786	-0.3974	-0.6961	-1.1227	0.1333
Std. Dev.	0.3676	0.4603	0.5988	0.3758	0.5660	0.7125	0.4578
Skewness	0.1696	-0.2288	0.3401	-0.7908	0.1843	0.3079	0.9830
Kurtosis	5.3830	3.6664	3.8589	2.7997	2.3610	2.8550	2.5111
Jarque-Bera	69.5233***	7.8402**	14.4029***	30.5011***	6.5299**	4.8028*	49.2488***
Probability	0.0000	0.0198	0.0007	0.0000	0.0382	0.0906	0.0000

Note: This table summarises descriptive statistics (sample mean, median, maximum, minimum, standard deviation, skewness, kurtosis, the Jarque-Bera test statistic, and the p-value associated to the Jarque-Bera test statistic) of SFP, SCY and SCO (Panel A), SOI, STV and SPR (Panel B). SFP = WTI/Brent oil futures price differential, SCY = WTI/Brent convenience yield spread, SOI = WTI/Brent open interest spread, STV = WTI/Brent trading volume spread, SCO = WTI/Brent oil consumption spread, SPR = WTI/Brent oil production spread, M1 = one-month futures contract, M3 = three-month futures contract, M6 = six-month futures contract. Asterisk * (**, ***) denotes the 10% (5%, 1%) significance level. The sample period runs from January 1993 to December 2016.

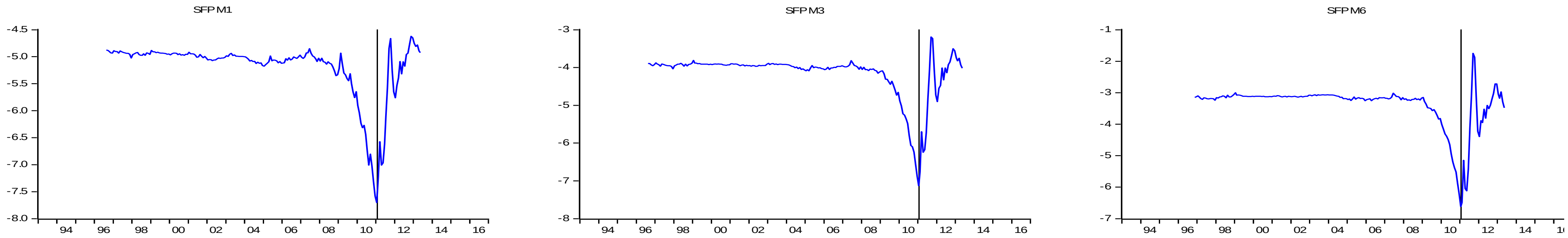
Table 3.2: Augmented Dickey-Fuller (1981), Philips-Perron (1988) and Zivot-Andrews (1992) unit root tests.

Panel A – ADF test						
	C		C&T		N	
WF M1	-1.9510		-2.6510		-0.7701	
WF M3	-1.8621		-2.5520		-0.7026	
WF M6	-1.7839		-2.4683		-0.6435	
BF M1	-1.8152		-2.4932		-0.7329	
BF M3	-1.7695		-2.4535		-0.6931	
BF M6	-1.7109		-2.3899		-0.6470	
SFP M1	-3.0148	**	-4.7496	***	-3.0364	***
SFP M3	-2.3414		-3.7757	**	-2.3820	**
SFP M6	-2.0608		-3.3973	*	-2.1153	**
SCY M1	-8.3123	***	-8.3002	***	-7.5233	***
SCY M3	-10.5766	***	-10.6720	***	-10.3510	***
SCY M6	-8.5793	***	-8.6728	***	-8.4708	***
SOI M1	-1.7973		-3.1596	*	-1.9353	*
SOI M3	-2.8536	*	-5.1762	***	-2.0198	**
SOI M6	-2.8517	*	-7.6895	***	-2.4716	**
STV M1	-2.0027		-3.8989	**	-1.6602	*
STV M3	-2.0297		-3.0431		-2.3436	**
STV M6	-2.2944		-4.3515	***	-2.2839	**
SCO	-1.4094		-5.0578	***	1.3078	
SPR	1.1749		-2.7051		2.0786	
Panel B – PP test						
	C		C&T		N	
WF M1	-1.8716		-2.3591		-0.7450	
WF M3	-1.7789		-2.2612		-0.6721	
WF M6	-1.7247		-2.2557		-0.6004	
BF M1	-1.6550		-1.5935		-0.6288	
BF M3	-1.6143		-1.8902		-0.6204	
BF M6	-1.6057		-1.8324		-0.5763	
SFP M1	-2.8952	**	-4.6700	***	-2.9166	***
SFP M3	-2.0088		-3.6271	**	-2.0685	**
SFP M6	-1.7399		-3.3107	*	-1.8219	*
SCY M1	-14.0897	***	-14.0778	***	-13.7397	***
SCY M3	-10.8059	***	-10.8335	***	-10.7392	***
SCY M6	-8.5247	***	-8.6288	***	-8.3879	***
SOI M1	-10.4297	***	-15.7848	***	-10.3767	***
SOI M3	-6.7137	***	-12.1751	***	-4.5194	***
SOI M6	-7.3565	***	-12.6282	***	-4.0774	***
STV M1	-3.2619	**	-7.0202	***	-2.3469	**
STV M3	-4.0251	***	-10.1018	***	-3.8999	***
STV M6	-6.4948	***	-13.6656	***	-4.2980	***

SCO	-1.3777		-4.8127	***	2.1368	
SPR	0.9326		-2.7937		1.7253	
			Panel C – ZA test			
	C		C&T		T	
SFP M1	-5.8693	***	-7.7013	***	-5.0190	
SFP M3	-4.8116	**	-7.1282	***	-4.0245	*
SFP M6	-4.0552	**	-6.6180	***	-3.4131	**
SCY M1	-6.1770	***	-6.3341	**	-5.9618	***
SCY M3	-11.1622	***	-11.4873	***	-11.0264	***
SCY M6	-9.1877	***	-9.5835	***	-8.9150	**
SOI M1	-6.3439	***	-6.4460	***	-5.8495	***
SOI M3	-6.8665	***	-6.8856	***	-6.1088	***
SOI M6	-6.0744	***	-6.2039	***	-5.1827	***
STV M1	-4.2999	***	-5.4440	***	-3.0423	
STV M3	-5.7855	**	-6.8295	***	-6.2879	***
STV M6	-6.7590	***	-7.3687	***	-6.7085	***
SCO	-5.6936	***	-5.6834	***	-3.9760	
SPR	-4.3066	***	-2.7964		-2.5360	

Note: For the ADF, PP and ZA unit root tests the null hypothesis is that the series features a unit root. In the ADF and PP tests, C denotes constant term, C&T denotes constant and time trend, N indicates no deterministic component in the test equation. In the ZA test equation, a constant and a linear time trend are included. C allows for a break in the constant, T allows for a break in the trend, and C&T allows for a break in both the constant and the time trend. WF = WTI futures price, BF = Brent futures price, SFP = WTI/Brent oil futures price differential, SCY = WTI/Brent convenience yield spread, SOI = WTI/Brent open interest spread, STV = WTI/Brent trading volume spread, SCO = WTI/Brent oil consumption spread, SPR = WTI/Brent oil production spread, M1 = one-month futures contract, M3 = three-month futures contract, M6 = six-month futures contract. Asterisk * (**, ***) denotes the 10% (5%, 1%) significance level. The sample period runs from January 1993 to December 2016.

Figure 3.3: Zivot-Andrews test for the WTI/Brent oil futures price differential



Note: This Figure depicts the structural break in the WTI/Brent oil futures differential (SFP), based on the Zivot-Andrews unit root test, which is detected endogenously in January 2011. M1 = one-month futures contract, M3 = three-month futures contract, M6 = six-month futures contract. The sample period runs from January 1993 to December 2016.

Table 3.3: Bai-Perron breakpoint test

Panel A – SFP M1			
Breaks	F-statistic	Weighted F-statistic	Critical value
1*	365.9492	365.9492	8.58
2*	329.5632	391.6415	7.22
3*	269.1704	387.4970	5.96
4*	220.5981	379.3050	4.99
5*	156.4944	343.4072	3.91

Break dates:
1. January 2011
2. February 2005, January 2011
3. June 1999, March 2005, January 2011
4. August 1996, April 2000, March 2005, January 2011
5. August 1996, March 2000, October 2003, May 2007, January 2011

Panel B – SFP M3			
Break Test	F-statistic	Weighted F-statistic	Critical value
1*	399.9585	399.9585	8.58
2*	472.4084	561.3940	7.22
3*	388.1757	558.8166	5.96
4*	375.7220	646.0310	4.99
5*	293.6514	644.3809	3.91

Break dates:
1. January 2011
2. March 2005, January 2011
3. August 1999, March 2005, January 2011
4. August 1996, March 2000, March 2005, January 2011
5. August 1996, March 2000, October 2003, May 2007, January 2011

Panel C – SFP M6			
Break Test	F-statistic	Weighted F-statistic	Critical value
1*	462.1309	462.1309	8.58
2*	559.0958	664.4103	7.22
3*	557.4351	802.4821	5.96
4*	501.4236	862.1673	4.99
5*	360.8139	791.7605	3.91

Break dates:
1. January 2011
2. April 2005, January 2011
3. August 1999, April 2006, January 2011
4. August 1996, March 2000, April 2006, January 2011
5. August 1996, March 2000, October 2003, May 2007, January 2011

Note: This Table shows the Bai-Perron test of Global L breaks vs. none breaks in the WTI/Brent oil futures differential (SFP), Trimming 0.15, Max. breaks 5. M1 = one-month futures contract, M3 = three-month futures contract, M6 = six-month futures contract. Asterisk * denotes the 5% level of significance. The sample period runs from January 1993 to December 2016.

Table 3.4: Coefficients of correlation

	SFP M1	SFP M3	SFP M6	SCY M1	SCY M3	SCY M6	SCO	DSPR	SOI M1	SOI M3	SOI M6	STV M1	STV M3	STV M6
SFP M1	1													
SFP M3	0.9803	1												
SFP M6	0.9564	0.9908	1											
SCY M1	-0.0056	0.0362	0.0498	1										
SCY M3	0.3038	0.2329	0.2015	0.7979	1									
SCY M6	0.4241	0.3350	0.2688	0.6659	0.9509	1								
SCO	-0.6977	-0.7266	-0.7587	-0.0082	-0.1159	-0.1229	1							
DSPR	-0.1369	-0.1340	-0.1333	-0.0076	-0.0527	-0.0597	0.1361	1						
SOI M1	0.4920	0.5020	0.5249	-0.1173	-0.0004	0.0149	-0.6890	-0.0963	1					
SOI M3	0.5294	0.5428	0.5657	-0.1185	0.0056	0.0144	-0.6922	-0.1036	0.7193	1				
SOI M6	0.5494	0.5573	0.5678	-0.1312	0.0094	0.0506	-0.7142	-0.1141	0.6437	0.7171	1			
STV M1	0.8186	0.8521	0.8700	0.0296	0.1503	0.1893	-0.7366	-0.1294	0.6419	0.6551	0.6142	1		
STV M3	0.7504	0.7816	0.8061	0.0092	0.1256	0.1467	-0.8828	-0.1597	0.7374	0.6812	0.6793	0.8663	1	
STV M6	0.6625	0.6743	0.6882	-0.1127	0.0384	0.0815	-0.7666	-0.0854	0.6701	0.6459	0.7153	0.7096	0.8278	1

Note: This table summarises the Pearson coefficients of correlation among the WTI/Brent oil futures price differential (SFP), the WTI/Brent convenience yield spread (SCY), the WTI/Brent oil consumption spread (SCO), the WTI/Brent oil production spread in first difference (DSPR), the WTI/Brent open interest spread (SOI) and the WTI/Brent trading volume spread (STV). M1 = one-month futures contract, M3 = three-month futures contract, M6 = six-month futures contract. The sample period runs from January 1993 to December 2016.

3.4. Methodology

This study builds upon a battery of single-equation multiple linear regression models. The dependent variable is the oil futures differential (*SFP*) between the WTI and Brent oil futures prices. We investigate the determinants of *SFP* by employing a set of explanatory variables, such as the convenience yield spread (*SCY*), the oil consumption spread (*SCO*), the oil production spread (*SPR*), the open interest spread (*SOI*) and the trading volume spread (*STV*). The following equation defines the general (i.e. least restrictive) model that is estimated by the ordinary least squares (OLS) method:

$$SFP_t = \alpha_0 + \alpha_1 SFP_{t-1} + \alpha_2 SCY_t + \alpha_3 SCO_t + \alpha_4 SPR_t + \alpha_5 SOI_t + \alpha_6 STV_t + \alpha_7 D_t + \varepsilon_t, \text{ where } \varepsilon_t \sim iid.N(0, \sigma^2) \quad (8)$$

It should be mentioned that our decision to employ a multiple linear regression model, rather than a cointegration framework, is based on the information extracted from the unit root tests which show that the WTI/Brent oil price differential is stationary in level, whereas the WTI and Brent oil prices feature a unit root. This is indicative of a long-run equilibrium relationship and consequently a cointegration between the two series, the WTI futures price and the Brent futures price. This suggests a globalised oil futures market in the long-run. It should be noted that authors such as Fattouh (2010) use standard unit root tests to examine the stationarity of various oil price differentials and Wilmot (2013) employs cointegration tests to investigate the long-run equilibrium relationship. In other words, there is no reason to perform a cointegration analysis since the long-run equilibrium relationship has been already addressed by these authors among others.

In principle, the unit root tests do not guarantee that the two oil futures prices move together in the short-run and hence there is no evidence of a short-run equilibrium relationship. Thus, we are seeking to examine short-run deviations from the long-run equilibrium. In this regard, we employ a multiple linear regression model which is characterised by three specifications with short-run futures contracts. Consequently, the F test allows us to ascertain whether physical oil market fundamental factors and oil futures market variables collectively drive a significant wedge between the WTI and Brent oil futures prices. If this holds, we are able to argue that there are short-run deviations from the long-run equilibrium and hence a regionalised oil futures market.

In addition to the aforementioned determinants, we further include the first lag of the dependent variable to take into account serial correlation (SFP_{t-1}). The inclusion of the lagged dependent variable captures dynamic effects in *SFP* behaviour, such as persistence, path dependencies and sluggish adjustment to a shock, and thus, contributes to an improved performance of our model. We also employ a dummy variable in order to capture the structural change in the level of the oil futures differential in the post-2010 period. It takes the value 0 from January 1993 to July 2010 and the value 1 from August 2010 to December 2016. Finally, ε_t is the random disturbance term, which is assumed to be independently and identically distributed with a normal distribution, with mean 0 and variance σ^2. In our regression models, firstly we examine individually the effects of each explanatory factor on the *SFP*. Secondly, we consider all explanatory variables collectively. This process is reiterated for maturities of 1, 3 and 6 months.

Overall, we posit the following testable hypotheses:

Hypothesis 1: *A positive change in the SCY leads to a decrease in the SFP.*

The convenience yield represents the benefits from holding a physical asset (i.e. a barrel of oil). It reflects market expectations about the future availability of crude oil. Futures prices will go down when the benefits of holding barrels of oil are high and vice versa. For example, the higher the level of inventories today, the lower the convenience yield and therefore the higher the energy trader’s expectation of scarcity to occur in the near future in the oil markets. This tends to put an upward pressure on oil futures prices. We suggest that a positive change in the *SCY* (i.e. an increase in the WTI convenience yield or a decrease in the Brent convenience yield) lowers the WTI futures price relative to the Brent futures price, leading to an overall decrease in the *SFP* and hence, $\alpha_2 < 0$.

Hypothesis 2: *A positive change in the SCO leads to an increase in the SFP.*

Crude oil consumption approximates the demand for oil. An increase in oil demand is followed by increases in oil prices. The higher the intensity of energy consumption, the higher the impact on oil prices (Maghyereh, 2004). We indicate that a positive change in the *SCO* (i.e. an increase in WTI consumption or a decrease in Brent consumption) increases the WTI futures price relative to the Brent futures price, leading to an overall increase in the *SFP* and hence, $\alpha_3 > 0$.

Hypothesis 3: *A positive change in the SPR leads to a decrease in the SFP.*

Crude oil production approximates the supply of oil. Oil supply increases lead to reductions in oil prices. Moreover, fears over capacity constraints are expected to put upwards pressure on futures prices. We consider that a positive change in the *SPR* (i.e. and increase in WTI production or a decrease in Brent production) decreases the WTI futures price relative to the Brent futures price, leading to an overall decrease in the *SFP* and hence, $\alpha_4 < 0$.

Hypothesis 4: *A positive change in the SOI affects positively (negatively) the SFP if there is excess demand for hedging from oil consumers (producers) in anticipation of higher economic activity.*

We consider the open interest as a proxy for hedging demand in the oil futures market. According to Hong and Yogo (2012), open interest will have a positive (negative) effect on the futures price, if there is excess demand for hedging from oil consumers (producers) who wish to buy long (sell short) futures contracts in anticipation of higher economic activity. The sign of the open interest effect will depend on whether hedging consumers or hedging producers prevail in the market. We recommend that a positive change in the *SOI*, leading to an increase or a decrease in the *SFP* and hence, $\alpha_5 > 0$ or $\alpha_5 < 0$.

Hypothesis 5: *A positive change in the STV leads to an increase in the SFP.*

Trading volume approximates the flow of information arriving in the futures market. Following Chordia and Swaminathan (2000), high-volume assets respond faster to market-wide information than low-volume assets. Therefore, a change in the trading volume spread should have a significant effect on the relative futures market valuation of WTI versus Brent. A positive relation between the futures price differential and changes in the volume of trading is predicted by Jennings et al. (1981) who argue that short positions are possible, but are more costly than long positions. Therefore, an increase in the volume of trading is indicative of a bull market with long positions as opposed to a bear market with short sales. We propose that a positive change in the *STV* (i.e. an increase in the WTI trading volume or a decrease in the Brent trading volume) increases the WTI futures price relative to the Brent futures price, leading to an overall increase in the *SFP* and hence, $\alpha_6 > 0$.

Hypothesis 6: *If the coefficients of the model $\alpha_2 - \alpha_6$ are collectively significant (i.e., the corresponding determinants drive a significant wedge between WTI and Brent futures prices and therefore contribute to price disparities), then futures markets are said to be regionalised.*

WTI and Brent are the most extensively traded commodities futures contracts in the worldwide oil futures market. Deviation from the parity between WTI and Brent triggered by our comprehensive set of determinants confirms oil futures market regionalisation. We use a standard F test to determine whether the selected determinants are jointly significant. If the coefficients are not significantly different from zero, then the futures markets are said to be globalised.

3.5. Empirical analysis

Section 3.5.1 provides an additional preliminary analysis based on the single-equation multiple linear regression models which are described extensively in the previous Section and associated with equation 8. Section 3.5.2 describes the estimation analysis based on the determinants of the oil futures differential. Section 3.5.3 summarises two robustness checks. For the first robustness check, we use the US Treasury bill rate as an alternative risk-free interest rate to compute the convenience yield. A data availability issue imposes a constraint on the sample period as the 1-month US Treasury bill rate is only available from August 2001. Thus, we investigate the period from August 2001 to December 2016 (185 monthly observations). However, for the 3-month and the 6-month US Treasury bill rates, we consider the main sample period of January 1993-December 2016.

For the second robustness check, we employ a Seemingly Unrelated Regression (SUR) estimation approach (Zellner, 1962), in which we jointly estimate the oil futures differential for 1-month, 3-month, and 6-month futures contracts respectively. The SUR estimation approach conveniently takes into account the possible presence of correlations among the random disturbance terms from the three equations. Finally, in Section 3.5.4, the *globalisation-regionalisation hypothesis* is tested.

3.5.1 Additional preliminary analysis

In terms of additional preliminary analysis, a number of econometric tests will be provided in order to ensure the reliability and validity of our specifications which are used in the empirical analysis. In order to measure the degree of multicollinearity among the explanatory variables in each multiple linear regression model, we employ the Variance Inflation Factor approach, which indicates the increase in variance triggered by collinearity between one explanatory variable and the other predictors. The Variance Inflation Factors are presented in Table 3.5. The general rule of thumb denotes that if a variable's Variance Inflation Factor exceeds 10, this may be considered as serious evidence of multicollinearity. Our findings show that each multiple linear regression model does not suffer from multicollinearity, since the centered Variance Inflation Factor for each variable and each specification is not greater than 10, and most of the values are lower than 5.

Overall, we need to respect that the issue of multicollinearity is only of relevance if the concern is with the individual effects of the right-hand side variables. It needs to be understood that we are testing the determinants of the oil futures differential collectively or when we investigate the globalisation-regionalisation hypothesis, this represents a joint hypothesis. In other words, the interest is in the collective effect of five explanatory variables. Multicollinearity is an important factor in the context of examining individual influences on a dependent variable. It has the effect of inflating values of standard errors and suppressing values of t statistics."

Table 3.5: Variance Inflation Factor	
Variable	Centered VIF
Panel A – Regression model – 1-month futures contract	
SCY M1	1.6301
SCO	2.7438
DSPR	1.0788
SOI M1	2.5608
STV M1	3.1062
Panel B – Regression model – 3-month futures contract	
SCY M3	1.3133
SCO	6.7419
DSPR	1.1227
SOI M3	4.1563
STV M3	7.7588
Panel C – Regression model – 6-month futures contract	
SCY M6	1.1599
SCO	5.7493
DSPR	1.2860
SOI M6	2.6528
STV M6	2.7724

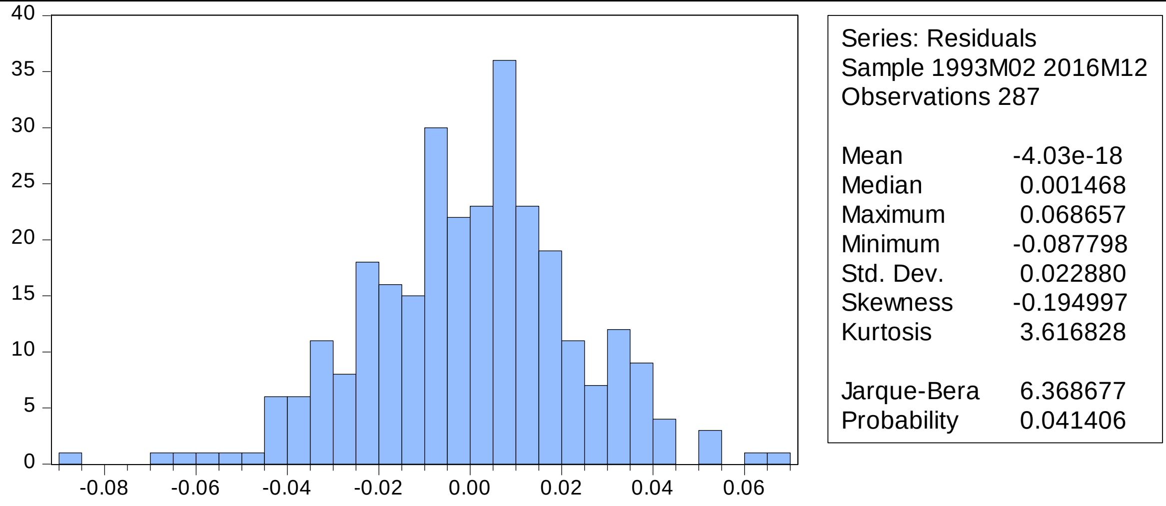
Note: This table presents the Variance Inflation Factor values among the WTI/Brent convenience yield spread (SCY), the WTI/Brent oil consumption spread (SCO), the WTI/Brent oil production spread in first difference (DSPR), the WTI/Brent open interest spread (SOI) and the WTI/Brent trading volume spread (STV). M1 = one-month futures contract, M3 = three-month futures contract, M6 = six-month futures contract. The sample period runs from January 1993 to December 2016.

We continue our preliminary tests by checking the assumption of normality of the residuals (the difference between the actual value of the dependent value and the predicted value). The null hypothesis states that the residuals follow a normal distribution. Figure 3.4 reports the results of the normality tests for the three specifications which are used to evaluate this aforementioned assumption. It is evident that the probability values associated with the Jarque-Bera statistic are lower than the significance level of five per cent. Consequently, we conclude that the residuals are not normally distributed. This could possibly suggest that at least one explanatory variable may have an incorrect functional form or may imply that at least one important explanatory variable is missing.

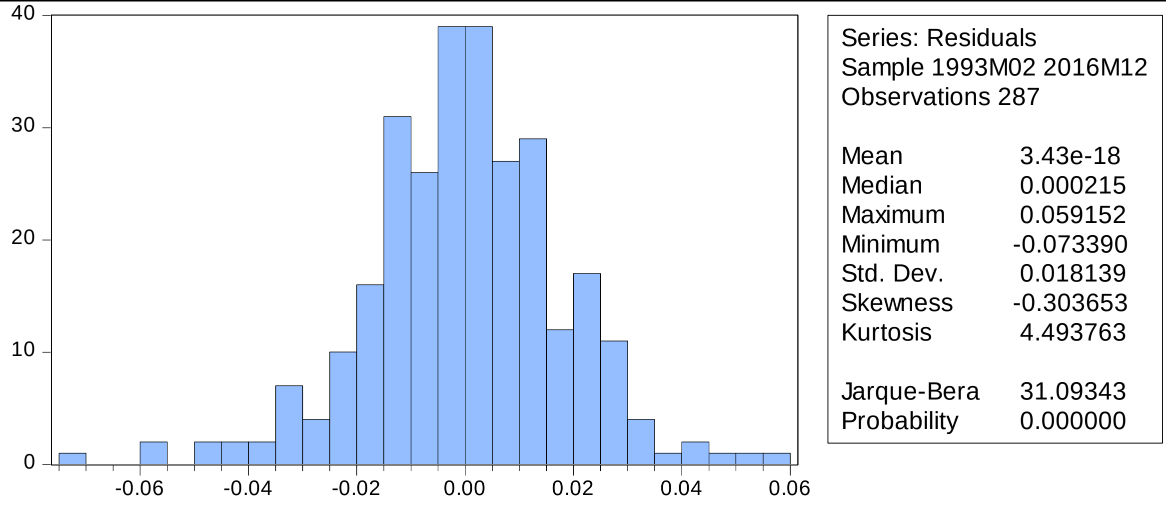
However, the case of incorrect functional form is not reinforced by the findings from the unit root tests which provide support to our chosen functional form for the variables under consideration. With reference to missing explanatory variables, this could be a case that required further investigation. Nevertheless, it was challenging to find additional differential forms as potential predictors of the oil futures differential which was purely dictated by the lack of readily available time series. Overall, even if the residuals do not have a normal distribution then the results may still be valid asymptotically.

Figure 3.4: Normality tests

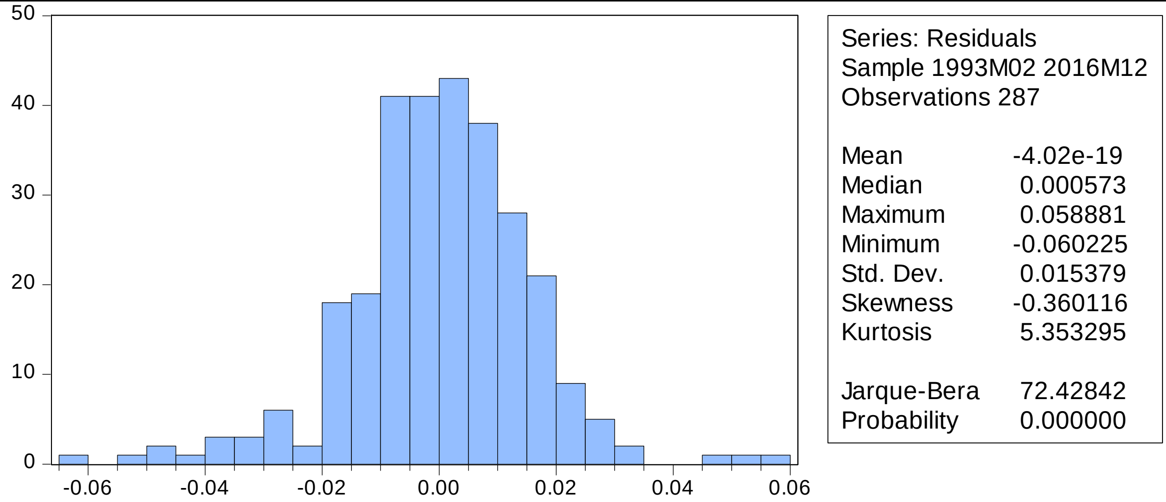
Panel A – Regression model – 1-month futures contract



Panel B – Regression model – 3-month futures contract



Panel C – Regression model – 6-month futures contract



Note: This table presents the Normality tests among the three model specifications, under the null hypothesis that the residuals are normally distributed. The sample period runs from January 1993 to December 2016.

3.5.2 Determinants of the oil futures differential

Tables 3.5 - 3.7 summarise the results for the oil futures differential for 1-month, 3-month and 6-month futures contracts, respectively. We begin our analysis with the value of the R-squared statistic which measures the goodness of fit in a multiple regression model. R-squared has the interpretation of the proportion of the total variation in the dependent variable which can be explained by the variable(s) on the right-hand side of the regression equation. Tables 3.5 – 3.7 demonstrate that the value of the R-squared is 0.9195 (0.9392, 0.9510) for the 1-month (3-month, 6-month) specification models. It is apparent that changes in the potential predictors are capable of explaining a range between 91 per cent and 95 per cent of the total variation in oil futures differential. The remaining percentage can be explained by other differentials not included in our specifications. We argue that the values of the R-squared seem to be a promising finding in respect of the quality of the three regression models. Overall, the more variance that is explained by the regression models the closer the data points will fall to the fitted regression line and hence the predicted values would equal the actual values. The increasing value of the R-squared does not represent an issue since new variables have not been added to each specification and therefore there is no need to provide interpretations for the adjusted R-squared.

We continue our preliminary analysis by concentrating on the correlation between the residuals and the explanatory variables from each specification model. It should be mentioned that the regression equation that reference is being made to has been estimated by OLS. Necessarily then there will be no correlation between the residuals and any of the right hand side variables. The findings are presented in Figure 3.5 and do not exhibit notable differences among the three regression models. Overall, the residuals are presented in a rectangular shape along the horizontal line which is indicative of a linear relationship. Data points appear to be randomly scattered and the residuals seem to be relatively small in size. There is no evidence of any systematic pattern or clustering. It should be mentioned that a non-rectangular shape implies that the linearity is violated. Thus, a curved instead of rectangular shape is evident and the residuals are no longer random. Since the Figure 3.5 demonstrates a non-curvilinear relationship we are able to argue that the variance of the residuals does not depend on the level of an independent variable and consequently there is no evidence of heteroscedasticity.

On a final note, in order to reinforce our empirical analysis, the Newey-West heteroskedasticity and autocorrelation consistent (HAC) standard errors method is used (Newey and West, 1987) in the three specifications. Specifically for the case of heteroscedasticity, although this method uses OLS inefficient estimators, at the same time computes an alternative or robust standard error that allows for the presence of heteroskedasticity. In a more detailed analysis, the coefficients in both the uncorrected OLS method and the HAC method they should be identical but the uncorrected OLS standard errors are smaller and the size of the t-statistics associated with the coefficients is smaller in HAC method. Overall, this method is carried out in the next paragraphs of this Section.

Table 3.5: Regression model estimated results – 1-month futures contract

Predictors	(1)		(2)		(3)		(4)		(5)		(6)	
C	0.0090	***	0.0430	**	0.0087	***	0.0077	***	-0.0039		0.0216	
	(0.0020)		(0.0188)		(0.0021)		(0.0023)		(0.0050)		(0.0202)	
SFP(t-1)	0.8995	***	0.7984	***	0.8140	***	0.8183	***	0.7740	***	0.8526	***
	(0.0353)		(0.0427)		(0.0334)		(0.0350)		(0.0405)		(0.0421)	
SCYt	-0.5282	***									-0.5249	***
	(0.0840)										(0.0889)	
SCOt			-0.0396	*							-0.0225	
			(0.0206)								(0.0209)	
DSPRt					-0.0862	***					-0.0771	***
					(0.0292)						(0.0258)	
SOIt							-0.0049				-0.0090	
							(0.0059)				(0.0058)	
STVt									0.0213	**	0.0149	**
									(0.0083)		(0.0074)	
Dt	-0.0155	***	-0.0238	***	-0.0270	***	-0.0247	***	-0.0188	***	-0.0123	**
	(0.0058)		(0.0055)		(0.0054)		(0.0061)		(0.0060)		(0.0061)	
R^2	0.9157		0.8916		0.8924		0.8908		0.8930		0.9195	
BG	2.4092		0.5235		0.3701		0.5651		0.7330		1.4486	

Note: This table reports estimation results for the 1-month futures contract. The dependent variable is the WTI/Brent oil futures price differential (SFP). The explanatory variables are the lagged WTI/Brent oil futures price differential (SFP(t-1)), the WTI/Brent convenience yield spread (SCYt), the WTI/Brent oil consumption spread (SCOt), the WTI/Brent oil production spread in first difference (DSPRt), the WTI/Brent open interest spread (SOIt), the WTI/Brent trading volume spread (STVt), and the dummy variable that takes on value 1 (0) after (before) August 2010 (Dt). Heteroscedasticity robust standard errors are reported in parentheses. For the Breusch-Godfrey Serial Correlation (BG) test, the Wald statistic is reported. Asterisk * (**, ***) denotes the 10% (5%, 1%) level of significance. The sample period runs from January 1993 to December 2016.

Table 3.6: Regression model estimated results – 3-month futures contract

Predictors	(1)		(2)		(3)		(4)		(5)		(6)	
C	0.0054	***	0.0302	**	0.0057	***	0.0077	***	0.0018		0.0094	
	(0.0017)		(0.0154)		(0.0017)		(0.0021)		(0.0016)		(0.0201)	
SFP(t-1)	0.9007	***	0.8606	***	0.8753	***	0.8826	***	0.8323	***	0.8359	***
	(0.0294)		(0.0399)		(0.0304)		(0.0307)		(0.0414)		(0.0338)	
SCYt	-0.1185	**									-0.1203	**
	(0.0521)										(0.0536)	
SCOt			-0.0281	*							-0.0033	
			(0.0164)								(0.0213)	
DSPRt					-0.0474	**					-0.0434	*
					(0.0222)						(0.0224)	
SOIt							-0.0046				-0.0126	***
							(0.0033)				(0.0037)	
STVt									0.0086	***	0.0120	***
									(0.0029)		(0.0041)	
Dt	-0.0152	***	-0.0150	***	-0.0170	***	-0.0195	***	-0.0159	***	-0.0214	***
	(0.0046)		(0.0047)		(0.0047)		(0.0049)		(0.0050)		(0.0044)	
R^2	0.9346		0.9334		0.9336		0.9332		0.9344		0.9392	
BG	1.4810		1.5828		1.2203		1.2977		2.2549		1.2605	

Note: This table reports estimation results for the 3-month futures contract. The dependent variable is the WTI/Brent oil futures price differential (SFP). The explanatory variables are the lagged WTI/Brent oil futures price differential (SFP(t-1)), the WTI/Brent convenience yield spread (SCYt), the WTI/Brent oil consumption spread (SCOt), the WTI/Brent oil production spread in first difference (DSPRt), the WTI/Brent open interest spread (SOIt), the WTI/Brent trading volume spread (STVt), and the dummy variable that takes on value 1 (0) after (before) August 2010 (Dt). Heteroscedasticity robust standard errors are reported in parentheses. For the Breusch-Godfrey Serial Correlation (BG) test, the Wald statistic is reported. Asterisk * (**, ***) denotes the 10% (5%, 1%) level of significance. The sample period runs from January 1993 to December 2016.

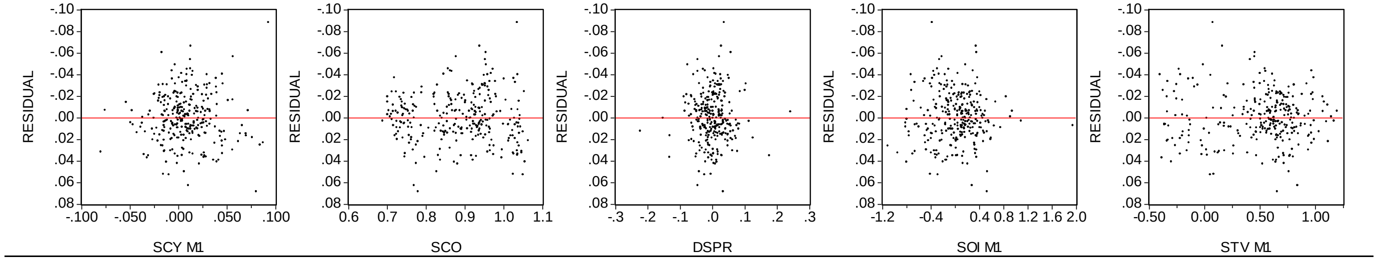
Table 3.7: Regression model estimated results – 6-month futures contract

Predictors	(1)		(2)		(3)		(4)		(5)		(6)	
C	0.0041	***	0.0275	*	0.0042	***	0.0047	***	0.0036	**	0.0408	***
	(0.0015)		(0.0145)		(0.0015)		(0.0017)		(0.0017)		(0.0148)	
SFP(t-1)	0.9088	***	0.8835	***	0.9028	***	0.9086	***	0.9030	***	0.8810	***
	(0.0268)		(0.0385)		(0.0279)		(0.0300)		(0.0328)		(0.0375)	
SCYt	-0.0169										-0.0155	
	(0.0349)										(0.0326)	
SCOt			-0.0264	*							-0.0380	**
			(0.0153)								(0.0151)	
DSPRt					-0.0327	*					-0.0315	*
					(0.0174)						(0.0179)	
SOIt							-0.0009				-0.0038	*
							(0.0021)				(0.0021)	
STVt									0.0006		0.0001	
									(0.0018)		(0.0019)	
Dt	-0.0123	***	-0.0112	**	-0.0126	***	-0.0128	***	-0.0122	***	-0.0130	***
	(0.0043)		(0.0044)		(0.0043)		(0.0041)		(0.0043)		(0.0040)	
R^2	0.9495		0.9501		0.9499		0.9495		0.9495		0.9510	
BG	1.9908		2.3453		1.8989		1.8549		2.0152		1.8586	

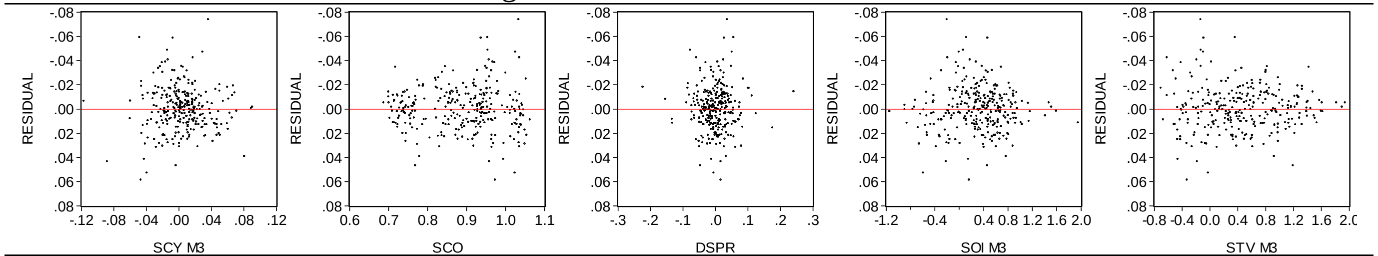
Note: This table reports estimation results for the 6-month futures contract. The dependent variable is the WTI/Brent oil futures price differential (SFP). The explanatory variables are the lagged WTI/Brent oil futures price differential (SFP(t-1)), the WTI/Brent convenience yield spread (SCYt), the WTI/Brent oil consumption spread (SCOt), the WTI/Brent oil production spread in first difference (DSPRt), the WTI/Brent open interest spread (SOIt), the WTI/Brent trading volume spread (STVt), and the dummy variable that takes on value 1 (0) after (before) August 2010 (Dt). Heteroscedasticity robust standard errors are reported in parentheses. For the Breusch-Godfrey Serial Correlation (BG) test, the Wald statistic is reported. Asterisk * (**, ***) denotes the 10% (5%, 1%) level of significance. The sample period runs from January 1993 to December 2016.

Figure 3.5: Correlation between residuals and predictors

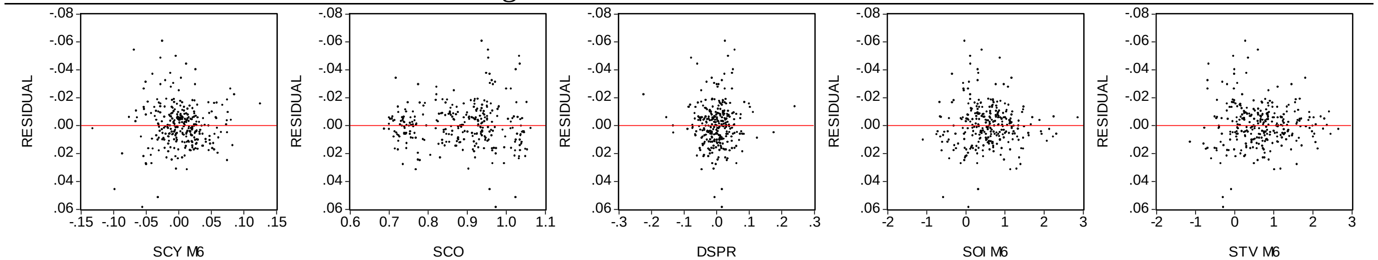
Panel A – Regression model – 1-month futures contract



Panel B – Regression model – 3-month futures contract



Panel C – Regression model – 6-month futures contract



Note: This figure shows the correlation between the residuals and the explanatory variables from each specification model. SCY = WTI/Brent convenience yield spread, SOI = WTI/Brent open interest spread, STV = WTI/Brent trading volume spread, SCO = WTI/Brent oil consumption spread, DSPR = WTI/Brent oil production spread in first difference, M1 = one-month futures contract, M3 = three-month futures contract, M6 = six-month futures contract. The sample period runs from January 1993 to December 2016.

The lagged dependent variable and the dummy variable have a statistically significant effect in all specifications. The coefficient on the lagged dependent variable (dummy variable) has the expected positive (negative) sign. More specifically, the former indicates the degree of persistence in the oil futures differential, whereas the latter indicates the existence of a structural break. In specifications from 1 to 5, predictors of the oil futures differential enter regressions individually, whereas specification 6 employs the entire set of predictors. Our analysis primarily focuses on specification 6 since we seek to determine how additional predictors simultaneously affect the dependent variable. However, we do refer to the remaining specifications when required.

Of particular interest is the relationship between the oil futures differential and the convenience yield spread. The convenience yield measures the increased gain that the trader receives from holding barrels of crude oil rather than holding futures contracts for crude oil. The results show that the convenience yield spread exerts a significant effect for the nearest to maturity month and the 3-month to maturity futures contracts, whereas the same does not hold true for the 6-month to expiration futures contract. Furthermore, consistently with Gospodinov and Ng (2013), the convenience yield spread has the expected negative sign.

This finding can be explained as follows. The convenience yield is negatively related to the inventory level in the oil spot market (Fama and French, 1998). More specifically, a decrease in the inventory level today is associated with a higher convenience yield and an increase in the spot price of oil. A higher convenience yield, net of storage cost, implies that traders are more willing to hold physical assets and are less willing to buy futures contracts of crude oil. As a result, traders will benefit from increasing the demand for barrels of oil in the spot market (which contributes to increases in spot prices) and selling short oil futures contracts (which results in decreases in futures prices).

Next, we focus on the empirical relationship between the oil futures differential and oil-market specific fundamental variables. The results show that the coefficient of the oil production spread is consistent with the initial expectation of a negative sign and also significant for all corresponding maturities of 1-month, 3-month and 6-month contracts. Moreover, the oil consumption spread has a negative and significant effect on the oil futures differential for the 6-month contract, which disagrees with our initial expectation of a positive sign. The findings suggest weak evidence that the oil futures differential is influenced by the oil consumption spread and stronger evidence that the predictability of the oil futures differential can be ascribed to the oil production spread.

A plausible explanation for the negative and significant effect of the oil consumption spread on the oil futures differential in the 6-month contract can be explained as follows. An increase in consumption today triggers an upward movement in oil spot prices. However, energy traders in the futures market would expect a commensurate increase in oil production in the future, which would subsequently drive spot oil prices to lower levels. Thus, even though today's spot prices and possibly 1-month and 3-month futures prices may increase due to an increase in oil consumption, this effect is the reverse for the far maturity contracts months. This framework can potentially explain the significant findings for the 6-month contract and more precisely the unexpected negative sign.

Turning our attention to the importance of the oil production spread on the oil futures differential, the effect is significant for all corresponding maturities. Hence, in light of the events which took place and caused changes in the crude oil market, the analysis of the oil production effects is warranted. As aforementioned, the mismatch between US oil production and the existing infrastructure capacity that led to a disruption of oil supply provides a plausible explanation for the observed time-variation in the oil futures differential. Before this supply disruption, WTI traded at a small premium over Brent. The supply disruption in Cushing triggered WTI to trade lower than Brent. In addition, Brent oil production experienced a constant decline with no visible repercussion on the oil futures differential.

Our findings further indicate that the open interest spread exerts a negative and significant effect on the oil futures differential for both 3-month and 6-month contracts. As aforementioned, the open interest measures hedging demand activity in the futures market (Hong and Yogo, 2012). This finding can be attributed to the excess hedging demand from producers in anticipation of higher economic activity. These producers sell short contracts and drive the open interest upwards, causing a lower number of contracts for hedging. This reduces the futures price since there is a limited arbitrage by speculators.

Finally, the trading volume spread has a positive sign and appears as a statistically significant predictor of the oil futures differential for the 1-month and 3-month contracts. We consider that the trading volume measures the trading activity which reflects all market relevant information and exerts a positive impact on the futures price for maturities shorter than 6 months. A plausible explanation is that the contracts with shorter maturities (1-month and 3-month) are characterised by a greater amount of information, higher trading volume, greater liquidity and therefore a higher price movement. The nearby or front month contract is the most liquid contract. Furthermore, the 3-month oil futures contract of WTI trading on the NYMEX, has the largest market share in the world (see Hammoudeh and Li, 2005).

Overall, the above findings show that the oil futures differential is driven by the convenience yield, the fundamental factors of supply and demand and the financial indicators of open interest and trading volume. Our results suggest that the convenience yield spread provides a strongly significant predictive power for the nearby month contract and a moderately significant predictive power for the 3-month to maturity contract. In this regard, our results are in accordance with those reported by Milonas and Henker (2001). Specifically, Milonas and Henker (2001) find that for futures contracts with longer maturity, the oil futures differential is less responsive to the convenience yield than for shorter maturity futures contracts.

With reference to the oil production spread, our findings suggest that the oil futures differential is strongly (weakly) and significantly affected by the oil production spread for the 1-month (3-month and 6-month) contracts and therefore can be driven by supply imbalances. This is in agreement with the findings of Büyükşahin et al. (2013). They conclude that the North American oil supply variables trigger a statistically significant long-run relationship between the WTI/Brent crude oil nearby futures prices spread and the physical market fundamental variables, with a particular emphasis on the increasing supply of oil which depressed the WTI oil futures price.

In addition, the oil consumption spread exhibits a significant and moderate effect on oil futures differential only for the 6-month futures contract. This evidence broadly shows the decreasing importance of the fundamental factor of demand as a driver of the oil futures differential. On general principles, petroleum consumption accounts for a 36 percent of all energy consumed in the US. However, petroleum consumption in North America and Europe shows a declining trend over the last decade, which can be attributed to the use of more environment-friendly resources and the recent economic recession of 2007-2009.[15] We suggest that the above discussion can be interpreted as a supplemental explanation regarding the aforementioned trading activity by energy traders concerning the relationship between the oil consumption spread and the oil futures differential.

Concerning the open interest spread and the trading volume spread, we are able to document the importance of financial trading in the oil futures market by traders and investors who consider the oil futures differential as a financial asset. They invest in the oil futures market in order to hedge themselves or to make profits. Thus, we conclude that financial activity is important in explaining movements in the oil futures differential. Our results agree with Büyükşahin et al. (2013), who illustrate that the predictability of the WTI/Brent oil futures differential arises from both financial and physical traders' activity. In addition, our findings partly agree with Heidorn et al. (2015), who emphasise the relative importance of financial traders relative to fundamental traders in predicting the oil futures differential.

Finally, our results could support to some extent the importance of the US shale oil revolution and geopolitical turmoil to the oil futures differential. Although our empirical analysis does not explicitly focus on these two concepts and our attempt to capture their impact is not pronounced in targeting both concepts, we are able to provide a plausible explanation regarding the consideration to approximate the role of these two major events in the world crude oil market. In this regard, the former could be captured by the oil production spread, whereas the latter may be approximated by the convenience yield spread.

[15] Information can be found on the EIA:
https://www.eia.gov/energyexplained/index.cfm?page=oil_use
https://www.eia.gov/todayinenergy/detail.php?id=12691

As previously stated, the variation in the oil futures differential can be attributed to these dynamics during the period 2011 onwards. Rising crude oil flows from tight (shale) oil formations (Bakken in North Dakota and Eagle Ford in Texas) played a key role in explaining transportation bottlenecks in Cushing, the storage hub for WTI which caused the price of WTI to trade at a significant discount relative to Brent.

Furthermore, the continuous political instability in the Middle East plausibly caused an increased uncertainty about future oil supply shortfalls. This is considered a precautionary oil demand shock and signifies the convenience yield, which incorporates the need of insurance against unexpected disruptions of oil supply. Due to the fact that the Middle Eastern oil production is priced relative to Brent, the geopolitical tensions could have potentially contributed to the higher price level of Brent crude oil relative to WTI.

3.5.3 Robustness checks

To evaluate the stability of our findings, firstly we estimate our regression models using the US Treasury bill rate in the construction of the convenience yield instead of the LIBOR rate. It should be mentioned that a shorter period sample that runs from August 2001 to December 2016 is employed only for the nearby month futures contract. The choice of this sample period is motivated by the data availability. However, the time period for the 3-month and 6-month futures contracts is similar to the main regression models (i.e., January 1993 – December 2016). Overall, the results are qualitatively similar to the study's main findings for the 1-month, 3-month and 6-month futures contracts. Robustness check results are summarised in Tables 3.8 - 3.10.

In a more detailed analysis, the only noticeable difference is detected in the estimated findings for the nearby month futures contract and focused on the oil-futures market specific determinants of open interest and trading volume. Indeed, although open interest is not a significant determinant in the main findings, this has changed in the robustness check in which it appears to be strongly significant. Similarly, although trading volume contributes to significant variations in the oil future differential in the main model, this does not hold in the robustness check in which it seems to lose its significance power.

Secondly, we employ the SUR approach proposed by Zellner (1962) in order to capture the contemporaneous correlation of the error terms among the three linear regression equations. Thus, we estimate a set of simultaneous equation coefficients by combining information among them. Our results in Table 3.11 generally appear to validate the single-equation approach, particularly for contracts near to maturity (1-month and 3-month). Importantly, the signs of the estimated coefficients remain unchanged.

In addition, it seems that the oil futures differential is not affected by the aforementioned determinants to the same extent within different lengths to maturity. Indeed, our results in Table 3.12 show that the effect of the convenience yield spread is statistically different across the 1-month, 3-month and 6-month contracts. Notably, the convenience yield spread has a larger effect for shorter contracts. A plausible explanation is that oil inventories in the shorter-run can be regarded as more important by oil users (e.g. refineries) than in the longer-run. On the other hand, the effects of *SCO*, *DSPR*, *SOI* and *STV* do not seem to be significantly different across the three maturities.

The next step is to consider the difference between contemporaneous and dynamic models. In this regard, when we estimate a regression equation, we assume that the explanatory variables on the right-hand side of the regression equation may have a dynamic impact on the dependent variable and consequently a lagged relationship is estimated at time t-1. Turning to the estimated results, Table 3.13 illustrates the findings for each futures contract regression specification. By comparing the findings with those in Tables 3.5 – 3.7 related to the contemporaneous models at time t we are able to get some interesting empirical findings. Overall, it is evident that variables such as the WTI/Brent convenience yield spread appears to be insignificant, although it seems to have an instantaneous significant effect on the WTI/Brent oil futures price differential. However, this does not necessarily imply that this variable has no effect on the WTI/Brent oil futures price differential. Simply, the findings on the dynamic models indicate that this variable has a contemporaneous rather than a lagged effect.

Finally, in order to examine if the previously documented coefficient estimates are not correlated with the effects of any omitted variables, we include a number of control variables as "other" additional explanatory variables which might affect the dependent variable and might be correlated with our set of potential determinants. Then, we conduct the regression analysis by running the regression employing all explanatory variables. More specifically, when we are able to "control" for these additional factors, we can get a more complete picture related to the effect of our potential determinants by holding the impact of the control variables constant. Nevertheless, by omitting the control variables, the empirical findings from the model could possibly provide misleading estimates regarding the causal effects of each potential determinant on the dependent variable. In general, on the one hand, the inclusion of control variables can be regarded as a beneficial tool to capture the omitted variable bias issue. On the other hand, the control variables can be used incorrectly if they act as a channel through which the key potential determinants cause changes in the dependent variable.

Overall, this process attempts to capture and remove the effect of the control variables from the model. The biggest issue in this process is the challenge of gathering and measuring information on targeted control variables. Indeed, our potential determinants have been constructed in differential form, which makes the collection of the control variables in differential form to be a challenging work. Thus, we decided to include information on three control variables, in order to assess the sensitivity of the results, namely, changes in US crude oil inventory (associated with the convenience yield), global economic activity index (related to the demand for oil) and changes in world oil production (linked with the supply of oil) which are all crude oil-market specific variables. Regarding the choice of these control variables, since WTI and Brent are the world references for crude oil, world oil production is used to evaluate unexpected changes in global oil supply (Kilian, 2009). Furthermore, global economic activity index is used to record shifts in the global demand for industrial commodities including oil (Kilian, 2009). Finally, the convenience yield summarises the information contained in changes in crude oil inventories (Alquist et al., 2014). Table 3.14 summarises the results for all futures contracts regression specifications. It is evident that there are no significant changes in the responses to our potential determinants in terms of sign and level of significance. Thus, we argue that the results remain qualitatively similar.

Table 3.8: Robustness model estimated results – 1-month futures contract

Predictors	(1)		(2)		(3)		(4)		(5)		(6)	
C	0.0057	***	0.0430	**	0.0087	***	0.0077	***	0.0039		-0.0526	
	(0.0020)		(0.0188)		(0.0021)		(0.0023)		(0.0050)		(0.0503)	
SFP(t-1)	0.9130	***	0.7984	***	0.8140	***	0.8183	***	0.7740	***	0.8780	***
	(0.0464)		(0.0427)		(0.0334)		(0.0350)		(0.0405)		(0.0450)	
SCYt	-0.6719	***									-0.7056	***
	(0.0800)										(0.0856)	
SCOt			-0.0396	*							0.0613	
			(0.0206)								(0.0548)	
DSPRt					-0.0862	***					-0.0715	**
					(0.0282)						(0.0294)	
SOIt							0.0049				-0.0197	***
							(0.0059)				(0.0072)	
STVt									0.0213	**	0.0089	
									(0.0083)		(0.0087)	
Dt	-0.0097		-0.0238	***	-0.0270	***	-0.0247	***	-0.0188	***	-0.0216	**
	(0.0064)		(0.0055)		(0.0054)		(0.0061)		(0.0060)		(0.0088)	
R^2	0.9138		0.8916		0.8928		0.8908		0.8930		0.9208	
BG	2.0718		0.5235		0.3701		0.5651		0.7330		0.3617	

Note: This table reports estimation results for the 1-month futures contract. The dependent variable is the WTI/Brent oil futures price differential (SFP). The explanatory variables are the lagged WTI/Brent oil futures price differential (SFP(t-1)), the WTI/Brent convenience yield spread (SCYt), the WTI/Brent oil consumption spread (SCOt), the WTI/Brent oil production spread in first difference (DSPRt), the WTI/Brent open interest spread (SOIt), the WTI/Brent trading volume spread (STVt), and the dummy variable that takes on value 1 (0) after (before) August 2010 (Dt). Heteroscedasticity robust standard errors are reported in parentheses. For the Breusch-Godfrey Serial Correlation (BG) test, the Wald statistic is reported. Asterisk * (**, ***) denotes the 10% (5%, 1%) level of significance. The sample period runs from August 2001 to December 2016.

Table 3.9: Robustness model estimated results – 3-month futures contract

Predictors	(1)		(2)		(3)		(4)		(5)		(6)	
C	0.0055	***	0.0302	*	0.0057	***	0.0077	***	0.0018		0.0099	
	(0.0017)		(0.0154)		(0.0017)		(0.0021)		(0.0016)		(0.0201)	
SFP(t-1)	0.8995	***	0.8606	***	0.8753	***	0.8826	***	0.8323	***	0.8348	***
	(0.0293)		(0.0399)		(0.0304)		(0.0307)		(0.0414)		(0.0336)	
SCYt	-0.1150	**									-0.1185	**
	(0.0512)										(0.0527)	
SCOt			-0.0281	*							-0.0037	
			(0.0164)								(0.0214)	
DSPRt					-0.0474	**					-0.0432	*
					(0.0222)						(0.0222)	
SOIt							-0.0046				-0.0128	***
							(0.0033)				(0.0037)	
STVt									0.0086	***	0.0120	***
									(0.0029)		(0.0041)	
Dt	-0.0153	***	-0.0150	***	-0.0170	***	-0.0195	***	-0.0159	***	-0.0216	***
	(0.0046)		(0.0047)		(0.0047)		(0.0049)		(0.0050)		(0.0044)	
R^2	0.9345		0.9334		0.9336		0.9332		0.9344		0.9391	
BG	1.4778		1.5828		1.2203		1.2977		2.2549		1.2303	

Note: This table reports estimation results for the 3-month futures contract. The dependent variable is the WTI/Brent oil futures price differential (SFP). The explanatory variables are the lagged WTI/Brent oil futures price differential (SFP(t-1)), the WTI/Brent convenience yield spread (SCYt), the WTI/Brent oil consumption spread (SCOt), the WTI/Brent oil production spread in first difference (DSPRt), the WTI/Brent open interest spread (SOIt), the WTI/Brent trading volume spread (STVt), and the dummy variable that takes on value 1 (0) after (before) August 2010 (Dt). Heteroscedasticity robust standard errors are reported in parentheses. For the Breusch-Godfrey Serial Correlation (BG) test, the Wald statistic is reported. Asterisk * (**, ***) denotes the 10% (5%, 1%) level of significance. The sample period runs from January 1993 to December 2016.

Table 3.10: Robustness model estimated results – 6-month futures contract

Predictors	(1)		(2)		(3)		(4)		(5)		(6)	
C	0.0041	***	0.0275	*	0.0042	***	0.0047	***	0.0036	**	0.0408	***
	(0.0015)		(0.0145)		(0.0015)		(0.0017)		(0.0017)		(0.0148)	
SFP(t-1)	0.9088	***	0.8835	***	0.9028	***	0.9086	***	0.9030	***	0.8810	***
	(0.0268)		(0.0385)		(0.0279)		(0.0300)		(0.0328)		(0.0375)	
SCYt	-0.0169										-0.0155	
	(0.0349)										(0.0326)	
SCOt			-0.0264	*							-0.0380	**
			(0.0153)								(0.0151)	
DSPRt					-0.0327	*					-0.0315	*
					(0.0174)						(0.0179)	
SOIt							-0.0009				-0.0038	*
							(0.0021)				(0.0021)	
STVt									0.0006		0.0001	
									(0.0018)		(0.0019)	
Dt	-0.0123	***	-0.0112	**	-0.0126	***	-0.0128	***	-0.0122	***	-0.0130	***
	(0.0043)		(0.0044)		(0.0043)		(0.0041)		(0.0043)		(0.0040)	
R^2	0.9495		0.9501		0.9499		0.9495		0.9495		0.9510	
BG	1.9908		2.3453		1.8989		1.8549		2.0152		1.8586	

Note: This table reports estimation results for the 6-month futures contract. The dependent variable is the WTI/Brent oil futures price differential (SFP). The explanatory variables are the lagged WTI/Brent oil futures price differential (SFP(t-1)), the WTI/Brent convenience yield spread (SCYt), the WTI/Brent oil consumption spread (SCOt), the WTI/Brent oil production spread in first difference (DSPRt), the WTI/Brent open interest spread (SOIt), the WTI/Brent trading volume spread (STVt), and the dummy variable that takes on value 1 (0) after (before) August 2010 (Dt). Heteroscedasticity robust standard errors are reported in parentheses. For the Breusch-Godfrey Serial Correlation (BG) test, the Wald statistic is reported. Asterisk * (**, ***) denotes the 10% (5%, 1%) level of significance. The sample period runs from January 1993 to December 2016.

Table 3.11: SUR model estimated results

Predictor	Coefficient estimate	Significance	Standard error
1-Month Futures Contract			
C	0.0487	**	(0.0191)
SFP(t-1)	0.7119	***	(0.0281)
SCYt	-0.4877	***	(0.0400)
SCOt	-0.0440	**	(0.0210)
DSPRt	-0.0812	***	(0.0301)
SOIt	-0.0013		(0.0033)
STVt	0.0096	**	(0.0049)
Dt	-0.0295	***	(0.0055)
R^2		0.9117	
3-Month Futures Contract			
C	0.0427	***	(0.0157)
SFP(t-1)	0.7640	***	(0.0236)
SCYt	-0.2915	***	(0.0272)
SCOt	-0.0357	**	(0.0174)
DSPRt	-0.0535	**	(0.0239)
SOIt	-0.0024	*	(0.0012)
STVt	0.0033	*	(0.0018)
Dt	-0.0286	***	(0.0041)
R^2		0.9274	
6-Month Futures Contract			
C	0.0450	***	(0.0130)
SFP(t-1)	0.8128	***	(0.0222)
SCYt	-0.2033	***	(0.0212)
SCOt	-0.0396	***	(0.0144)
DSPRt	-0.0404	**	(0.0203)
SOIt	-0.0016		(0.0010)
STVt	0.0003		(0.0010)
Dt	-0.0226	***	(0.0036)
R^2		0.9405	

Note: This table reports estimation results for the Seemingly Unrelated Regression (SUR). The dependent variable is the WTI/Brent oil futures price differential (SFP). The explanatory variables are the lagged WTI/Brent oil futures price differential (SFP(t-1)), the WTI/Brent convenience yield spread (SCYt), the WTI/Brent oil consumption spread (SCOt), the WTI/Brent oil production spread in first difference (DSPRt), the WTI/Brent open interest spread (SOIt), the WTI/Brent trading volume spread (STVt), and the dummy variable that takes on value 1 (0) after (before) August 2010 (Dt). Asterisk * (**, ***) denotes the 10% (5%, 1%) level of significance. The sample period runs from January 1993 to December 2016.

Table 3.12: SUR model for coefficient differences

	SCY	SCO	DSPR	SOI	STV
Chi-sq	71.1255	0.4653	3.9663	0.4254	5.1287
df	2	2	2	2	2
Prob(Chi-sq)	0.0000***	0.7924	0.1376	0.8084	0.0770*

Note: This table reports the coefficients differences among the determinants of WTI/Brent convenience yield spread (SCY), WTI/Brent oil consumption spread (SCO), WTI/Brent oil production spread in first difference (DSPR), WTI/Brent open interest spread (SOI), and WTI/Brent trading volume spread (STV) under the null hypothesis of no significant difference among the coefficients. This test is measured by the Chi-square goodness-of-fit. Each variable (SCY, SCO, DSPR, SOI and STV) represents the equality of coefficients among the corresponding maturities of 1-month, 3-month, and 6-month contracts. For example, SCY denotes: SCY M1 = SCY M3 = SCY M6. M1 = one-month futures contract, M3 = three-month futures contract, M6 = six-month futures contract. Because we test for a significant difference among three coefficients, we impose two restrictions and therefore the degrees of freedom (df) equal to 2. The p-value is associated to the Chi-square. Asterisk * (**, ***) denotes the 10% (5%, 1%) significance level. The sample period runs from January 1993 to December 2016.

Table 3.13: Dynamic regression

Panel A – Regression model – 1-month futures contract		
Predictors	Parameter value	Probability
C	0.0424	0.0821*
SFP_{t-1}	0.7323	0.0000***
SCY_{t-1}	-0.1124	0.2076
SCO_{t-1}	-0.0527	0.0357**
$DSPR_{t-1}$	-0.0269	0.3603
SOI_{t-1}	-0.0177	0.0029***
STV_{t-1}	0.0274	0.0128**
D_t	-0.0212	0.0005***
R^2	0.8975	
Panel B – Regression model – 3-month futures contract		
Predictors	Parameter value	Probability
C	-0.0035	0.8760
SFP_{t-1}	0.8262	0.0000***
SCY_{t-1}	-0.0014	0.9805
SCO_{t-1}	0.0002	0.9992
$DSPR_{t-1}$	-0.0266	0.2507
SOI_{t-1}	-0.0038	0.2575
STV_{t-1}	0.0094	0.0153**
D_t	-0.0184	0.0002***
R^2	0.9344	
Panel C – Regression model – 6-month futures contract		
Predictors	Parameter value	Probability
C	0.0364	0.0223**
SFP_{t-1}	0.8689	0.0000***
SCY_{t-1}	0.0088	0.8157
SCO_{t-1}	-0.0341	0.0328**
$DSPR_{t-1}$	-0.0261	0.1716
SOI_{t-1}	-0.0050	0.0548*
STV_{t-1}	0.0023	0.1771
D_t	-0.0133	0.0021***

R^2	0.9509

Note: This table reports the dynamic estimation results for the 1-month, the 3-month and the 6-month futures contracts. The dependent variable is the WTI/Brent oil futures price differential (SFP). The explanatory variables are the lagged WTI/Brent oil futures price differential SFP(t-1), the lagged WTI/Brent convenience yield spread (SCYt-1), the lagged WTI/Brent oil consumption spread (SCOt-1), the lagged WTI/Brent oil production spread in first difference (DSPRt-1), the lagged WTI/Brent open interest spread (SOIt-1), the lagged WTI/Brent trading volume spread (STVt-1), and the dummy variable that takes on value 1 (0) after (before) August 2010 (Dt). Heteroscedasticity robust standard errors are employed. Asterisk * (**, ***) denotes the 10% (5%, 1%) level of significance. The sample period runs from January 1993 to December 2016.

Table 3.14: Control variables – contemporaneous regression

Predictors	Parameter value	Probability
Panel A – Regression model – 1-month futures contract		
Predictors	Parameter value	Probability
C	-0.0116	0.5993
SFP_{t-1}	0.8553	0.0000***
SCY_t	-0.5437	0.0000***
SCO_t	0.0191	0.4889
$DSPR_t$	-0.0712	0.0042***
SOI_t	-0.0058	0.3047
STV_t	0.0145	0.0370
$DINV_t$	-0.1764	0.2094
GEA_t	-0.0082	0.0047***
$DWOP_t$	0.1663	0.3753
D_t	-0.0231	0.0004***
R^2	0.9224	
Panel B – Regression model – 3-month futures contract		
Predictors	Parameter value	Probability
C	-0.0056	0.7942
SFP_{t-1}	0.8389	0.0000***
SCY_t	-0.1197	0.0222**
SCO_t	0.0010	0.9652
$DSPR_t$	-0.0342	0.0977*
SOI_t	-0.0125	0.0008***
STV_t	0.0118	0.0045***
$DINV_t$	-0.0796	0.4857
GEA_t	-0.0010	0.5962
$DWOP_t$	0.3026	0.0489**
D_t	-0.0226	0.0000***
R^2	0.9403	
Panel C – Regression model – 6-month futures contract		
Predictors	Parameter value	Probability
C	0.0338	0.0466**
SFP_{t-1}	0.8772	0.0000***

SCY_t	-0.0180	0.5705
SCO_t	-0.0299	0.0951*
$DSPR_t$	-0.0250	0.1174
SOI_t	-0.0035	0.0789*
STV_t	0.0001	0.9362
$DINV_t$	0.0317	0.7585
GEA_t	-0.0018	0.2966
$DWOP_t$	0.2757	0.0122
D_t	-0.0156	0.0001***
R^2	0.9521	

Note: This table reports the contemporaneous estimation results for the 1-month, the 3-month and the 6-month futures contracts, having included three selected control variables. The dependent variable is the WTI/Brent oil futures price differential (SFP). The explanatory variables are the lagged WTI/Brent oil futures price differential SFP(t-1), the WTI/Brent convenience yield spread (SCYt), the US crude oil inventories in first difference (DINVt), the WTI/Brent oil consumption spread (SCOt), the global economic activity index (GEAt), the WTI/Brent oil production spread in first difference (DSPRt), the world oil production in first difference (DWOPt), the WTI/Brent open interest spread (SOIt), the WTI/Brent trading volume spread (STVt), and the dummy variable that takes on value 1 (0) after (before) August 2010 (Dt). Heteroscedasticity robust standard errors are employed. Asterisk * (**, ***) denotes the 10% (5%, 1%) level of significance. The sample period runs from January 1993 to December 2016.

3.5.4. The Globalisation-regionalisation hypothesis

Based on the aforementioned preliminary results, we report that the oil futures differential is stationary in level. It is evident that the oil futures prices of WTI and Brent are linked closely together with a structural break. This result is supported by Wilmot (2013) who finds that regional crude oil markets of different or similar grades are linked with a structural break. Since the two oil futures markets move together, the oil futures market is globalised in the long-run. Although evidence suggests that the two oil futures prices move together in the long-run, there is no evidence that the oil futures market is globalised in the short-run. In this respect, we employ a standard F test in order to test for joint significance of the determinants of the oil futures differentials for the 1-month, 3-month and 6-month contracts, which can be considered to belong in the short-run period. Specifically, we seek to ascertain to what extent oil market fundamentals and financial variables contribute to price disparities between WTI and Brent futures prices in the short-run.

In order to test the *globalisation-regionalisation hypothesis* in the oil futures market, a standard F test has been employed.[16] The choice of this test is justified by the fact that we seek to determine the extent to which the set of our oil-market specific and oil-futures market specific determinants have predictive power to explain joint variations in the oil futures differential. The F test examines the null $\alpha_2 = \cdots = \alpha_6 = 0$. Failure to reject the null endorses the *globalisation hypothesis* in the world oil futures market. If the null is rejected, the world oil futures market is then regionalised or segmented.

[16] Technical details for the use of the standard F test are available in econometric analysis text books (see, for example, Brooks, 2014).

The F statistic reported in Table 3.15 always falls in the critical region of the null and therefore, the null is rejected regardless the maturity of the futures contract. Indeed, collectively the corresponding determinants can be regarded as significant predictors since they result in explaining a significant amount of variation between WTI and Brent futures prices, and consequently, they exercise a significant impact on the oil futures differential.

Table 3.15: F test

	1-Month Futures Contract	3-Month Futures Contract	6-Month Futures Contract
F-stat	13.5533	4.6238	2.4399
Chi-sq	67.7667	23.1193	12.1995
df	5	5	5
Prob(F-stat)	0.0000***	0.0005***	0.0347**
Prob(Chi-sq)	0.0000***	0.0003***	0.0322**

Note: This table reports the finite sample F-statistic and the asymptotic Chi-square statistic with associated p-values regarding the 1-month, 3-month and 6-month futures contracts under the null hypothesis of $\alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = 0$. WTI/Brent convenience yield spread = α_2 = SCY. WTI/Brent oil consumption spread = α_3 = SCO. WTI/Brent oil production spread in first difference = α_4 = DSPR. WTI/Brent open interest spread = α_5 = SOI. WTI/Brent trading volume spread = α_6 = STV. The degrees of freedom (df) associated equal to 5 (number of regressors estimated). Asterisk * (**, ***) denotes the 10% (5%, 1%) significance level. The sample period runs from January 1993 to December 2016.

Therefore, our results are in line with Milonas and Henker (2001) who indicate that WTI and Brent oil futures prices are not fully integrated. Our results are also similar to Liu et al. (2015) who report a decreasing level of co-integration between Brent and WTI futures markets and Fattouh (2010) who reveals that oil markets are not necessarily integrated in every time period. We provide evidence supporting the hypothesis that the world oil futures market can be influenced by regional logistical bottlenecks, geopolitical turmoil and financial activity in the short-run which reduces the degree of integration and suggests that the oil futures market does not appear to be globalised in the short-run. However, these factors exhibit a relatively short-lived effect since the oil futures market adjusts and absorbs the temporary imbalances, reduces the uncertainty about unexpected oil supply shortfalls and drives volatility between WTI and Bent oil futures prices at the lowest levels.

3.6. Conclusion

In this chapter, we investigate the role of potential determinants of the WTI/Brent oil futures price differential for the two major benchmarks of crude oil (WTI and Brent). Subsequently, we also examine the *globalisation-regionalisation hypothesis* in the oil futures market based on the WTI/Brent oil futures price differential. A limited number of studies focus on macroeconomic indicators, oil market fundamentals and financial market variables (see Büyükşahin et al., 2013). Our research extends this strand of literature by investigating the effects of additional factors such as the spread of the WTI/Brent convenience yield, the spread of WTI/Brent oil consumption, the spread of WTI/Brent oil production, the spread of WTI/Brent open interest and the spread of WTI/Brent trading volume on the WTI/Brent oil futures price differential. The choice of WTI and Brent benchmarks is based on the fact that both are global dominants of crude oil futures trading markets. Moreover, we focus on the oil futures differential since futures prices are more informative than spot prices. We use monthly data covering the period from January 1993 to December 2016.

Our findings are briefly summarised as follows. First, the convenience yield spread explains the variability in the oil futures differential for the nearest and the 3-month to maturity contracts. Second, the oil production spread affects the oil futures differential for the nearby month, 3-month and 6-month to maturity contracts, whereas the oil consumption spread acts as a driver of the oil futures differential only for the 6-month contract. Third, the open interest spread influences the oil futures differential for the 3-

month and 6-month to maturity contracts. Fourth, the trading volume spread exercises a significant impact on the oil futures differential for the nearest to expiration and the 3-month to maturity contracts. We conclude that the oil convenience yield, the physical oil market fundamental factors (oil production and oil consumption) and the oil futures market variables (open interest and trading volume) all drive a significant wedge between the WTI and Brent oil futures prices, which is indicative of a regionalised oil futures market in the short-run. These variables are significant determinants of the oil futures differential.

As far as the *globalisation-regionalisation hypothesis* between WTI and Brent in the oil futures market is concerned, any deviation of WTI or Brent from the long-run co-integration relationship would be interpreted as evidence of a regionalised oil futures market. Although WTI and Brent represent the two leading references for oil futures markets globally, the recent developments in crude oil market since late-2010, in particular the regional logistical bottlenecks, seem to have a significant impact on WTI as a leading global benchmark of the crude oil futures market. As a result, this makes WTI a less reliable indicator for pricing crude oil internationally.

However, WTI futures contracts are the most liquid and actively traded contracts in the world oil futures market which clearly explains the adoption of WTI as a valuable financial asset by energy traders in financial markets. Thus, we consider the importance of WTI and suggest that any asymmetry on the part of WTI, which contributes to a significant divergence between the two benchmarks, signifies that the world oil futures market is indeed regionalised. The extent to which the international oil futures market is integrated and the deviation of WTI futures prices does not imply regionalisation but simply reflect the deviation of the US oil futures market from the rest of the world would be an avenue for further research as it falls beyond the scope of this study.

In the same line of reasoning, Brent is considered a leading crude oil benchmark because it serves as a reference for two-thirds of the world's internationally traded crude oil. This can be attributed to the fact that it is a waterborne crude oil and does not affected by pipeline bottlenecks. This dynamic can be further endorsed by the increasing importance that Brent appears to play in the oil futures market during recent years. However, this potential dominance does not appear to be permanent. Indeed, oil production in the North Sea, (the field for Brent) continues to decline. Furthermore, the extent to which Brent could be replaced by an Asian based oil benchmark due to the growing demand for oil in Asian markets, raises concerns about Brent's ability to serve as a leading benchmark. This provides evidence to support the argument that regionalisation in the international oil futures market will likely occur from Brent.

In this regard, an interesting question that the future study might address is the consideration of additional crude oil benchmarks other than WTI and Brent, such as, the Dubai/Oman. This would suggest a more complete picture of the degree in which the state of the international oil futures market is globalised or regionalised. Since we examine WTI and Brent, we cannot argue that any significant divergence in their differential should be indicative of WTI or Brent's separation from the rest of the world. Furthermore, it would be interesting for future research to employ time-varying parameter models in order to examine whether the oil futures differential is affected by physical market and financial market factors (for example, oil consumption, oil production, open interest) at different time periods. In addition, based on the findings of this research, another interesting direction for future study is to test the ability of our significant determinants to forecast the deviations between the two crude oil benchmarks and consequently to evaluate the future state of the oil futures market (globalised or regionalised).

In addition, it would be interesting to examine the impact of renewable energy sources in production and consumption (with a particular reference to the US and the European Union energy markets) on the total energy sources, including petroleum and therefore oil production and oil consumption. The increasing use of renewable energy sources could influence the use of fossil fuels and consequently lead to reduced levels of oil production and oil consumption and further affect the convenience yield. These factors are regarded as significant determinants of the oil futures differential. In addition, legislation, regulations and the political environment are likely to have significant implications regarding the subject field.

By following recent or earlier studies such as Wang et al. (2017) and Nomikos and Pouliasis (2011), an interesting avenue for future research is to examine forecast combinations over single predictor regressions (one fundamental variable together with the intercept) with time-varying parameters in order to identify the predictability of oil prices. This is due to the fact that the impact of each oil price predictor is not of similar importance at each point in time due to different market developments. Indeed, time-varying parameters have the effectiveness to capture such developments, which is not the case when models with constant parameters are employed. Overall, the use of oil price forecasts, instead of the readily available futures prices, in the convenience yield equation appears to offer an avenue for further study.

Overall, in this study we offer a better understanding of the *globalisation-regionalisation hypothesis* in the oil futures market by examining the relationship between the oil futures differential, convenience yields and potential crude oil (fundamental and financial) predictors. Our findings are important for investors and traders in both WTI and Brent crude oil futures markets who are trading oil futures contracts, seeking to manage asset portfolios and protect themselves against adverse future price movements. In addition, our findings should be utilised by market participants when they are attempting to identify to what extent the oil futures market is affected by the physical oil market factors of supply and demand.

Chapter 4: Oil price shocks and EMU sovereign yield spreads

4.1. Introduction

The oil market is of fundamental importance for the global economy. It is thus unsurprising that developments in the oil market are monitored and reported by the media[17] and they are at the core of debate among businesses, economists, governments, and financial market participants.[18]

Since the seminal paper by Hamilton (1983), there is a wealth of literature on the effects of oil price changes on economic activity. Indeed, developments in the oil market and consequently oil price fluctuations generate responses from macroeconomic indicators since oil is an important input in industrial production. Specifically, an increase in oil prices results in higher production costs or higher income (depending on the status of the economy as oil-importer or oil-exporter), which drives inflation towards higher levels.[19] Additionally, higher oil prices may have a significant direct impact on government budgets.[20] For instance, oil-exporting countries, due to higher income, are expected to experience improvements in their macroeconomic balances, whereas oil-

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[17] See, for instance, (i) Iyengar (2018) in CNN who highlights the impact of recent increases in oil prices in the Indian economy, (ii) the report by Mackenzie, Blitz and Scaggs (2018) in Financial Times which asks whether oil rises point to a tipping point for bond yields, or (iii) the report by Liesman (2018) in CNBC which shows both the positive and negatives effects of rising oil prices in the US economy.

[18] See, for example, IMF's report by Arezki et al. (2017), IMF's (2016) World Economic Outlook, ECB's (2016) Economic Bulletin, the report by the UK's Office of Budget Responsibility (2015) or the report by the Joint Research Centre of the European Commission (2015).

[19] In this regard, we argue that inflation is generated regardless of the status of the economy as oil-importing or oil-exporting. For example, oil-importing countries experience cost-push inflation caused by rises in costs of production originated by higher oil prices. Similarly, oil-exporting countries also face increased inflation due to the higher income transferred from oil-importing countries. In this regard, the higher income allows the oil-exporting government to finance expansionary fiscal policies which stimulates aggregate demand and may lead to inflation.

[20] The impact of oil price changes on economic activity tends to be different when we consider the status of the country as oil-exporting or oil-importing. In this regard, economic activity of oil-exporting economies responds positively to higher oil prices. Specifically, an oil price increase is regarded as positive news through the higher government revenues (see, *inter alia*, Filis and Chatziantoniou, 2014; Wang et al., 2013; Arouri and Rault, 2012; Mohanty and Nandha, 2011).

importing countries are faced with uncertainty since increased oil prices could require government interventions, which could create budgetary risks.

In recent years, empirical works by Hamilton (2009a,b), Kilian (2009) and Kilian and Park (2009) have recognised the importance of exploring the origin of oil price shocks[21] and consequently the reactions of financial markets to these shocks. In this regard, a growing number of studies have analysed how the stock market performance responds to different oil price shocks.[22] In short, the existing literature shows that positive aggregate demand shocks are associated with increases in economic activity and can be regarded as positive news for stock markets, driving their prices towards higher levels. In contrast, positive precautionary demand shocks are associated with increasing concerns about future oil supply shortfalls and a fall in economic activity, which is transmitted to stock markets, pushing them to bearish territories. Finally, stock markets do not seem to be significantly impacted by supply-side shocks.

Despite this wealth of evidence on the relationship between oil prices (and shocks) and the wider economy or financial markets, the literature has remained relatively distant from the effects of the former on the sovereign risk of a country. The interest in this relationship stems from the fact that oil prices and their shocks can be considered as

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[21] Since the seminal theoretical work by Barsky and Kilian (2002, 2004), the first structural analysis can be found to Kilian (2009), who argue that a supply-side shock is originated by changes in world oil production, an aggregate demand shock is attributed to changes in global demand for industrial commodities, and a precautionary demand shock is generated by concerns about the future availability of oil, arising from geopolitical unrest.

[22] Empirical evidence includes additional papers by Antonakakis et al. (2017), Kang et al. (2017), Angelidis et al. (2015), Kang et al. (2015), Antonakakis et al. (2014), Degiannakis et al. (2014), Filis (2014), Sadorsky (2014), Abhyankar et al. (2013), Antonakakis and Filis (2013), Baumeister and Peersman (2013), Chang et al. (2013), Gupta and Modise (2013), Wang et al. (2013), Basher et al. (2012), Broadstock et al. (2012), Filis et al. (2011), Kilian and Lewis (2011), Choi and Hammoudeh (2010), Apergis and Miller (2009), Kilian and Park (2009) and Hamilton (2009a,b).

sources of macroeconomic and financial uncertainty, given their aforementioned effects.

We further argue that it is not only the oil price shocks that might exert an impact on sovereign risk. Additionally, allowance should be made for the reverse channel, through which sovereign risk impacts oil prices, which appears to hold as well. In particular, the widening of sovereign risk spreads signifies a greater degree of default risk, which could subsequently lead to a reduction in aggregate demand and thus lower demand for oil. In addition, higher sovereign risk might lead to lower uncertainty about future oil supply shortfalls, given the lower demand for oil. Finally, higher sovereign risk could lead oil producers to limit oil supply and therefore a decrease in oil production is somewhat expected. However, unexpected changes in oil supply (disruptions) could be also considered as exogenous, driven by political events in oil-producing countries (see Kilian and Murphy, 2014). Overall, oil prices are expected to decline in response to an economic downturn.

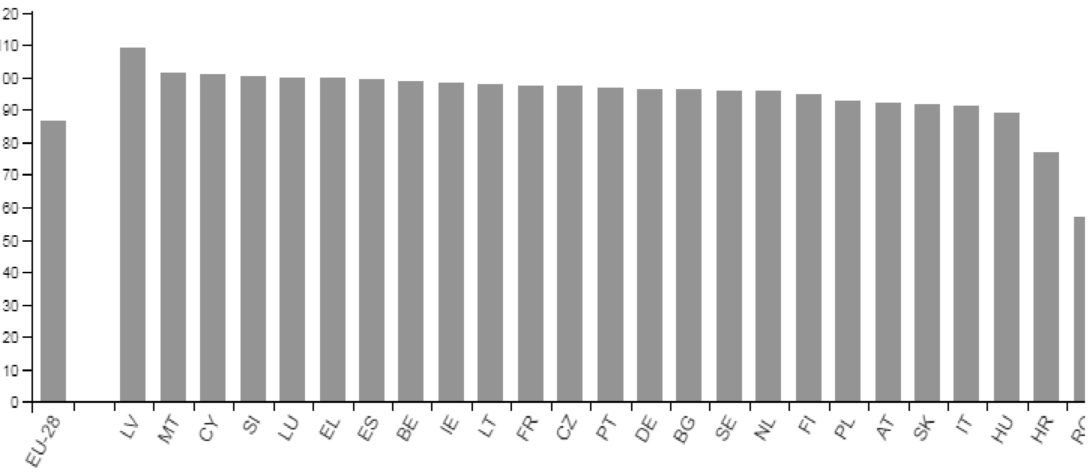
The motivation for investigating the correlation between oil price shocks and sovereign yield spreads stems not only from the limited empirical research and the theoretical arguments, mentioned above, but also from reports by financial institutions[23] and the anecdotal evidence presented in the financial press, which place emphasis on the relationship between oil prices (or their shocks) and sovereign yield spreads.[24] Similarly, it is no coincidence that the media suggest that lower oil prices present a serious challenge to US government debt and they are associated with a lower demand

[23] See, for instance the report by KfW (2017) titled “Oil prices and bond yields – hand-in-hand again”.
[24] See for instance, the CNBC (2018) article titled “Treasury yields rise as surge in oil prices boost inflation outlook; jobs report misses expectations”.

for US government bonds (CNBC, 2014) and that lower oil prices trigger a reduction in euro zone sovereign bond yields for both core and periphery countries, given their beneficial effects on inflation (Oxford Economics, 2014).

Nevertheless, the importance of the present study is also motivated by the EU's dependency on imported crude oil. Figure 4.1 depicts the oil import dependency for all 28 EU member states, revealing that European countries import more than 80%, on average, of their oil needs. Such a figure indicates the potential impact of oil price fluctuations on the import costs of these countries, exerting pressure on their trade balance and hence their economic performance.

Figure 4.1: EU's oil import dependency



Note: The figure shows the import dependency of crude oil in EU-28 during 2016. Values over 100 percent denote a stock build. Source: Eurostat

To this end, the aim of this study is to contribute towards the limited investigation of the link between oil prices (or their shocks) and sovereign yield spreads. We attempt to satisfy this objective by assessing the relationship between sovereign risk and oil prices shocks using a time-varying framework. More specifically, this study employs the sovereign yield spreads as a numerical representation of sovereign risk. This choice is justified by the fact that sovereign yield spreads provide substantial information regarding a country's creditworthiness (the ability to serve its debt) and they are affected by unexpected changes to the key macroeconomic indicators and unexpected developments in the financial markets.

To date, there are only few studies that focus on this relationship, (see, for instance, Bouri et al., 2018, Bouri et al., 2017, Lee et al., 2017, Shahzad et al., 2017, Wegener et al., 2016, Aizenman et al., 2013, Alexandre and de Benoist, 2010). For example, Wegener et al. (2016) point out that higher oil prices contribute to reductions in the sovereign risk of oil-producing countries. Shahzad et al. (2017), on the other hand, show that higher oil price volatility triggers an increase in the sovereign risk of oil-exporting countries. By distinguishing between oil-exporting and oil-importing countries, Lee et al. (2017) document that increasing oil prices cause a reduction (increase) in the sovereign risk of oil-exporters (importers). In a similar fashion, Bouri et al. (2018) show that the sovereign risk of oil-exporters (importers) is more sensitive to positive (negative) shocks in oil volatility. Nevertheless, the existing literature: i) provides limited evidence on the relationship between oil price movements and sovereign risk; ii) does not fully consider the heterogeneous effects of the different oil price shocks; and iii) is mainly based on a static rather than a dynamic environment.

Specifically, our contribution to the existing literature is threefold. First, this study sheds new light on the relation between unanticipated changes in the oil price and sovereign yield spreads, measured as the difference in 10-year sovereign bond yields between a member of the European Monetary Union and Germany. Second, this study examines the role of the origin of the oil price shocks in the aforementioned relation. To this end, we disentangle three structural oil price shocks: i) shocks to world oil supply; ii) oil price shocks arising from changes in aggregate demand; and iii) precautionary (or oil-market specific) demand shocks. We then study the extent to which the relation between oil price shocks and sovereign yield spreads is driven by the origin of oil price shocks. Third, this study complements the existing literature by examining the relationship between oil price shocks and EMU sovereign yield spreads in a time-varying framework.[25] To this end, we employ a set of core and periphery oil-importing members of the Economic and Monetary Union (EMU). It is worth noting that EMU is on aggregate the largest oil-importer in the world.

The distinction between core and periphery countries can be justified by the view that weaker periphery economies are expected to be more responsive to oil price fluctuations compared to stronger core economies (see Aizenman et al., 2013). Indeed, this could be the case for the periphery countries due to their: i) differences in terms of trade, compared to core countries (i.e. they run current account deficits); ii) slower adjustment to external shocks (see Celi et al., 2017); and iii) high dependence on imported energy (see Gibson et al., 2012).

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[25] We should notice that there is a recent evidence on the existing literature which indicates that the effect of oil prices on the economy and the stock market is likely time-varying (Boldanov et al., 2016; Broadstock and Filis, 2014; Filis, 2014; Antonakakis and Filis, 2013; Degiannakis et al., 2013; Filis et al., 2011; Bhar and Nikolova, 2010; Choi and Hammoudeh, 2010).

The empirical methodology proceeds in two steps. In the first step, we estimate a structural VAR model, which helps us uncover the three structural oil price shocks, as in Kilian (2009). In the second step, we interplay the structural oil price shocks with sovereign yield spreads in a multivariate GARCH (MGARCH) model. By way of the MGARCH model, we estimate the time-varying correlations among oil price shocks and sovereign yield spreads.

Our main findings reveal the following empirical regularities. First, correlations between sovereign yield spreads and different oil price shocks show a time-varying behaviour, which alternates between positive and negative values and exhibit heterogeneous patterns among the three shocks. Second, although correlations appear to fluctuate at relatively low values in the pre-2008 period, this pattern changes to relatively moderate and more volatile correlations in after 2008. Third, we do not produce noticeable evidence of differentiation in the correlation patterns of the sovereign yield spreads and different oil price shocks between core and periphery countries.

The rest of this paper is structured as follows. Section 4.2 discusses the existing literature in the field and presents the hypotheses under investigation. Section 4.3 describes the data used and provides a preliminary analysis. Section 4.4 presents the econometric model employed in this study. The empirical findings are reported and analysed in Section 4.5. Finally, Section 4.6 concludes the study.

4.2. Brief review of the literature and hypotheses development

As was mentioned in the introduction, oil price changes exert a significant impact on the economy and trigger responses from macroeconomic indicators. Indeed, Hamilton (1983) was among the first to concentrate the attention of researchers on the important role that oil prices play in determining economic activity. Furthermore, since the seminal paper by Jones and Kaul (1996), there has been a growing interest amongst researchers to investigate the link between oil markets and financial markets. Concerning the impact of oil price changes on stock market activity, the existing literature indicates that oil price increases cause firms' profits and expected cash flows to decline. Therefore, oil price increases are associated with decreased stock market returns. Overall, there is a wealth of literature which provides empirical evidence that oil prices have significant effects on the economy and stock market activity.[26] An in-depth review of the related literature can be found in Degiannakis et al. (2018).

In addition, since unexpected oil price changes appear to exert a significant impact on the economy and stock markets, it is reasonable to ask whether oil price fluctuations affect the risk level of the economy. The existing literature along this line of research attempts to explore the channel which suggests that oil price movements are of consequence for sovereign risk. Some related studies which have considered this relationship include papers by Bouri et al. (2018), Bouri et al. (2017), Lee et al. (2017),

[26] Recent and earliest studies that confirm the important role of oil price changes on the economy and stock market returns include papers by Du and Zhao (2017), Li et al. (2017), Silvapulle et al. (2017), Wang and Ngene (2017), Basher et al. (2016), Reboredo and Ugolini (2016), Narayan and Gupta (2015), Phan et al. (2015), Filis and Chatziantoniou (2014), Baumeister and Peersman (2013), Lippi and Nobili (2012), Filis (2010), Tang et al. (2010), Miller and Ratti (2009), Cologni and Manera (2008), Driesprong et al. (2008), Lescaroux and Mignon (2008), Nandha and Faff (2008), O' Neill et al. (2008), Park and Ratti (2008), Ciner (2001), Papapetrou (2001), Gjerde and Saettem (1999), Sadorsky (1999), Ferderer (1996), Hooker (1996), Lee et al. (1995), Mork (1989), Gisser and Goodwin (1986), Burbridge and Harrison (1984).

Shahzad et al. (2017), Wegener et al. (2016), Aizenman et al. (2013) and Alexandre and de Benoist (2010).

In particular, Alexandre and de Benoist (2010) examine the effect of changes in oil prices on government bond risk premiums of emerging countries. They use the Emerging Market Bond Index Global (EMBIG) index as a measure of global risk. They employ a panel analysis and argue that the risk premium of government bonds is positively and significantly affected by higher oil prices. Concerning the EU market, Aizenman et al. (2013) employ a generalised method of moment approach and suggest that rises in world commodity prices and oil prices lead to lower sovereign CDS spreads. They argue that this could be explained by the fact that global economic conditions are largely strong when both prices are increasing. Furthermore, Wegener et al. (2016) use data from nine oil-producing countries to investigate the relationship between oil prices and sovereign CDS spreads. They employ bivariate VAR-GARCH-in-mean models and document that positive oil price shocks lead to lower sovereign CDS spreads.

Additionally, Bouri et al. (2017) investigate the volatility transmission from commodities markets (including oil) to sovereign CDS spreads for a sample of emerging and frontier markets. They employ a Lagrange Multiplier methodology and report that sovereign CDS spreads are significantly affected by commodity price volatility. Moreover, Shahzad et al. (2017) examine the predictability from oil market uncertainty to the sovereign CDS spreads by using data from oil-exporting countries. They employ a modified bootstrap-rolling window approach and find a directional predictability from oil price volatility to sovereign CDS spreads. They conclude that higher oil price volatility contributes to increases in sovereign risk.

In a similar vein, Lee et al. (2017) investigate the relationship between oil price shocks and sovereign risk using the International Country Risk Guide (ICRG) data. They employ a Structural Vector Autoregressive model for a sample of oil-exporting and oil-importing countries. Specifically, they indicate that oil price shocks exert a reduction (increase) in sovereign risk for oil-exporting (oil-importing) countries. The authors highlight the importance of supply-side (demand-side) oil price shocks to the sovereign risk of net oil-exporting (oil-importing) countries. Finally, Bouri et al. (2018) examine the connection between oil price volatility shocks and sovereign risk for BRICS oil-exporting (Brazil and Russia) and oil-importing (China and India) countries. They employ a bivariate cross-quantilogram approach to measure the directional predictability and document that low (high) oil price volatility predicts low (high) sovereign risk.

In general, there is limited evidence on the relationship between oil price movements and sovereign risk. It should be noted that the aforementioned studies employ static econometric approaches. One notable exception is the study by Shahzad et al. (2017) who employ a time-varying approach based on the modified bootstrap rolling-window procedure. However, rolling-window approaches suffer from the identification of the appropriate window size and from weak expression of test statistics. Indeed, the shorter (longer) the rolling-window, the higher (lower) the irregular trends regarding the estimation of the model parameters and therefore the less (more) accurate parameter estimation would be. Furthermore, adding (deleting) one observation at the end (beginning) of the sample entails a loss of observations. In this regard, our time-varying framework does not suffer from these limitations.

Overall, we examine the time-varying correlation between different oil price shocks based on their origin and the 10-year sovereign yield spread as a proxy of sovereign risk. We seek to expand the existing literature not only in terms of disaggregating the oil price shock impact on sovereign yield spreads but also in terms of investigating this relationship in a time-varying rather than a static econometric framework across EMU members.

Given the aforementioned literature, we focus on the anticipated time-varying correlation between sovereign yield spreads of core and periphery countries and oil price shocks. Thus, we posit the following hypotheses:

Hypothesis 1: *Negative correlations are anticipated between sovereign yield spreads and positive supply-side shocks.*

Since both EMU core and periphery countries are oil-importing, we argue that an oil price decrease, due to increased oil production, promotes a drop in the cost of imported oil, which improves the current account balance. As a consequence of a reduction in the current account deficit there is reduced concern for the country to raise funds in order to service the external debt. In the case of such developments, spreads are expected to decrease since countries are expected to be more responsive relative to the benchmark country (e.g. Germany for the EMU member states), given that the yield of the latter has narrower variability margins.

Hypothesis 2: *Negative correlations are anticipated between sovereign yield spreads and positive aggregate demand shocks.*

A positive aggregate demand shock is associated with increases in economic activity and thus oil prices also increase. The higher economic activity, despite increased oil prices, contributes to a stable business and financial environment and reduces the uncertainty in the economy. Such developments are expected to have a greater positive impact on the least strong economies as opposed to the anchor country (e.g. Germany), leading to a decline in sovereign yield spreads.

Hypothesis 3: *Positive correlations are anticipated between sovereign yield spreads and positive precautionary demand shocks.*

More specifically, a positive precautionary demand shock represents fears about future oil supply shortfalls and therefore stimulates an increase in the oil price. This creates a weak business and financial environment, with a resultant fall in economic activity. This is expected to have negative impact to the least strong economies, with the consequence that the sovereign yield spread is expected to widen between the least strong economy and the benchmark country.

4.3. Data description and preliminary analysis

In this study, we use monthly data, from January 1999 to January 2016, on world oil production, a global economic activity index and the crude oil spot price for the purpose of estimating the three oil price shocks, as suggested by Kilian (2009), related to the supply of oil, aggregate demand and precautionary demand. The data for the world oil production are obtained from Energy Information Administration (EIA). Following Kilian (2009), we employ the global economic activity index with the aim of representing the global business cycle. Kilian provides a thorough explanation on his personal website of how this index is constructed.[27] In addition, we choose the Brent crude oil price to serve as the spot price, considering that the Brent price is a global crude oil benchmark. Specifically, Brent is used to price crude oil that is produced and traded in different parts of the world such as Europe, the Mediterranean, Africa, as well as Australia and some Asian countries.[28] Our decision to employ the Brent oil price is strongly motivated by the fact that this type of crude oil is extracted from the North Sea and mainly used locally in Europe. Data for the Brent crude oil price are collected from Datastream and are expressed in dollar terms. The oil (nominal) spot price is deflated by the US Consumer Price Index (CPI) in order to get the real oil price. The data on the CPI are available from the Bureau of Labor Statistics (BLS) of the United States.

In addition, we collect monthly data for the 10-year benchmark bond yields for eleven European countries, namely, Austria, Belgium, Finland, France, Germany, Greece,

[27] The data for the global economic activity index are retrieved from Lutz Kilian's personal website: http://www-personal.umich.edu/~lkilian/

[28] The source of the information can be found on the EIA: https://www.eia.gov/todayinenergy/detail.php?id=18571

Ireland, Italy, Netherlands, Portugal and Spain.[29,30] The data are retrieved from Datastream. We construct the 10-year sovereign yield spreads as the difference between the 10-year government bond yield issued by an EMU member-country and the German (Bund) 10-year bond yield (both yields of equal maturity). This choice is attributed to the fact that Germany's 10-year government bonds are considered to have the highest credit quality and liquidity (see Ejsing and Sihvonen, 2009).

We use the 10-year sovereign yield spread due to data availability obtained by Datastream. Specifically, our study is motivated by the fact that all of the countries have been part of the EMU since January 1999. Therefore, it is essential to use this date as the beginning period of our sample. The existing literature under this line of research employs international country risk indices and CDS spreads. With reference to the international country risk indices, Lee et al. (2017) use the ICRG index which is constructed by the PRS Group, a private company and requires the purchase of the data. Furthermore, Alexandre and de Benoist (2010) use the EMBIG index published by JP Morgan. However, this index of the spread of government bonds is related to emerging countries, whereas our study use EMU countries.

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[29] In this study, we consider the countries joined the EMU since 1999 and 2001 (the case of Greece). We do not include Luxembourg given that the government bond market of this country is relatively small (see Afonso et al., 2015) and the lack of data (see Maltritz, 2012). Furthermore, we exclude countries that joined EMU since 2007 (Slovenia (2007), Cyprus (2008), Malta (2008), Slovakia (2009), Estonia (2011), Latvia (2014) and Lithuania (2015)) due to short sovereign yield spreads data period. Finally, Germany is also excluded because is used as a reference country to construct the sovereign yield spreads for the rest countries.

[30] It should be mentioned that CDS spreads are commonly used in the existing literature to measure the sovereign risk. Nevertheless, our decision to use the 10-year sovereign yield spread as a proxy for sovereign risk is justified by the fact that it allows us to use a longer study period. In particular, the CDS data are available from 2009, whereas the data on the 10-year government bond yields for our selected countries are available since the creation of the EMU in 1999 (with the exception of Greece, which joined EMU in 2001). It should also be mentioned that, due to fiscal imbalances and fragilities among the EMU economies, and the need for the European Central Bank (ECB) to provide rescue packages to reduce the sovereign risk pressure, the 10-year sovereign yield spread may better approximate different fiscal fundamentals and could well capture uncertainty levels in the EMU economies.

As far as the use of CDS spread is concerned, Bouri et al. (2018), Bouri et al. (2017), Shahzad et al. (2017), Wegener et al. (2016) use CDS spreads gathered from Datastream. Nevertheless, they employ the 5-year contract CDS spreads, since the CDS spreads for the 10-year maturity contracts are not available. This limits the time period in the above studies to begin from 2009. An exception is the study by Aizenman et al. (2013) who use the 5-year CDS spreads from 2005. However the data are purchased by Markit, a private company.

Further to this information, there are disadvantages of using CDS spreads that the authors in the above studies do not mention. For example, the article by Carrick Mollenkamp and Serena Ng, which is published in Wall Street Journal (September 28, 2011), with the title: "A Fear Gauge Comes Up Short – Analysis Shows Credit-Default Swaps, a Popular Indicator of Market Health, Are Thinly Traded". The authors report that concerns are raised about the accuracy of the CDS spreads as a barometer for the financial health of sovereign entities due to the fact that CDS contracts are sparsely traded. Specifically, they claim that the price of a CDS may emerge from such thin trading that it does not represent a market judgment. Moreover, the Bank for International Settlements, 2010 (page 38), states that "the same CDS spread in numerical terms may not necessarily imply the same risk". Finally, Tang and Yan (2017) indicate that the large trading loss at J.P. Morgan revealed in May 2012 also illustrates liquidity problems in the CDS market.

The choice of the 10-year (long-term) sovereign yield spread is further justified by the fact that the longer the time to maturity, the larger the yield fluctuation (risk) and, consequently, the greater the uncertainty in the market. Overall, the convergence of sovereign yield spreads is considered as a factor which reduces the uncertainty of allowing an immediate and less stressful access to debt financing by market participants in financial markets and motivates investment within converging countries (see Côté and Graham, 2004). This promotes the integration of the European bond markets and consequently endorses financial stability.

In addition, in order to address a potential omitted variable bias[31], we collect data on the European economic policy uncertainty index, the European monetary policy uncertainty index, the European stock market volatility index and the realised oil price volatility, which impact on both the bond yields and oil prices (see, for instance, Arora and Cerisola, 2001, Barsky and Kilian, 2002, Anzuini et al., 2012, Antonakakis et al., 2014, Afonso et al., 2015, Bernal et al., 2016, Husted et al., 2017, Shahzad et al., 2017). Monthly data for the European economic policy uncertainty index and the European stock market volatility index[32] have been extracted from Datastream, whereas monthly data for the European monetary policy uncertainty index have been retrieved from the Federal Reserve database.[33] Furthermore, the monthly oil price realised volatility is constructed using the daily data on the Brent crude oil price during the study period, which are obtained from Datastream. Section 4.4.2 describes the method employed for the construction of the monthly oil price realised volatility.

The issue of the omitted variable bias refers to any variable not incorporated as an explanatory variable in the econometric model that might affect the dependent variable and gives rise to bias findings. In order to gain a clearer perception of the time-varying

[31] We thank an anonymous reviewer for pointing out to this important issue.
[32] The European stock market volatility index (VSTOXX) represents the implied volatility of the EURO STOXX 50.
[33] Specifically, this index has been constructed by Husted et al. (2016b) for the ECB.

correlation between oil price shocks and sovereign yield spreads in the EMU, we proceed our analysis by including additional factors that potentially affect both oil price shocks and sovereign yield spreads. This analysis guarantees to circumvent the omitted variable bias issue and helps to trace and attain more in-depth information about their actual relationship at each point in time. In this regard, we employ the European economic policy uncertainty index, the European monetary policy uncertainty index, the European stock market volatility index and the realised oil price volatility. First, we need to explain how the additional variables are associated with changes in oil price shocks and sovereign yield spreads.

Starting with the economic policy uncertainty, Pastor and Veronesi (2012) state that economic policy uncertainty refers to government actions that affect the economic environment. They claim that there are two types of such uncertainty, namely, the political uncertainty and the impact uncertainty. The former is associated with potential changes in the current government policy. The latter reflects concerns about the impact of a new government policy on the profitability of the private sector.

Recent evidence shows that economic policy uncertainty influences oil price shocks and sovereign yield spreads. To this end, Antonakakis et al. (2014) examine spillover effects from economic policy uncertainty to oil price shocks by considering a sample of European oil-importing economies. They find that changes in economic policy uncertainty trigger negative responses from all oil price shocks. This can be attributed to the fact that uncertainty about economic policy decisions has a direct negative impact on a company’s investment and production decisions, negatively affecting the demand for oil and consequently lowering the price of oil.

The importance of economic policy uncertainty in the Eurozone has been reported by Bernal et al. (2016). They provide evidence that economic policy uncertainty from the main core and periphery countries contributes to increasing risk transmission within the Eurozone's sovereign bond market. The authors argue that this risk transmission is generated by abnormal developments of sovereign yield spreads and plays a key role in weakening the Eurozone sovereign bond market.

By concentrating on the monetary policy uncertainty, Husted et al. (2017) claim that monetary policy uncertainty is associated with the perceptions that households and firms consider about Central Bank’s policy actions and consequences. They find that positive monetary policy uncertainty shocks contribute to weaker economic activity, lower output and increased borrowing costs. The earlier study by Arora and Cerisola (2001) examines the impact of the US monetary policy changes on sovereign yield spreads in emerging countries such as Latin America, Asia, and Eastern Europe. They indicate that changes in the US monetary policy trigger a direct positive effect on sovereign yield spreads.

Pertaining to the monetary policy effect on oil prices, Barsky and Kilian (2002) suggest that changes in US monetary policy regimes caused the 1970s oil price increases. In addition, Anzuini et al. (2012) argue that US monetary policy shocks contributed to the oil price increase prior to the Great Recession and the effect reduced significantly in early-2008 and during the peak stage of the oil price increase. On the other hand, Kilian and Lewis (2011), document that there is no empirical evidence to support the role of the US monetary policy in reinforcing the influence of oil price shocks on the US economy after 1987. Overall, it should be mentioned that, regardless of the fact that the uncertainty has originated from fiscal or monetary policy decisions, a negative impact on the financial markets and the macroeconomic activity is anticipated.

Turning to the stock market volatility, the VIX index represents a measure of expected future volatility and is broadly used to capture international financial risk perceptions. As regards the impact of stock market volatility on sovereign yield spreads, Afonso et al. (2015), use the VIX volatility index to approximate the international risk factor for a panel of ten euro area countries, similar to our study. They claim that a higher value for the international risk factor causes a rise in sovereign yield spreads. They find that a positive and significant relationship has been indicated since the onset of the Great Recession. Nevertheless, our study is based on EMU countries and therefore we use the implied volatility in European Eurostoxx-50 index (VSTOXX) rather than the US Standard and Poor's 500 implied volatility VIX index to measure financial market uncertainty in the EMU.

Turning to the association between oil price shocks and the European stock market volatility, a pioneering study has been presented by Degiannakis et al. (2014) who report that supply-side shocks and precautionary demand shocks do not affect stock market volatility, while aggregate demand shocks have a significant impact by reducing stock market volatility. Although this study does not mention the influence on stock market volatility of different oil price shocks, it is indicative that the link between oil price shocks and the stock market volatility has been well established.

Finally, we highlight the impact of oil price volatility on the performance of sovereign yield spreads. Surprisingly, the literature remains silent regarding this relationship. An interesting study is by Shahzad et al. (2017), who use the implied oil volatility OVX index to test the responses from sovereign CDS spreads of oil-exporting countries. They conclude that higher oil price volatility caused increases in the credit risk of these countries during 2010–2011 and 2014–2015. However, we maintain that our study employs sovereign yield spreads, rather than sovereign CDS spreads or sovereign ratings, to measure sovereign risk. In addition to this, OVX data are only available from May 2007 and therefore to include this variable in our dataset not only reduces considerably our sample period but also makes us unable to capture the early period of the transition to the EMU.

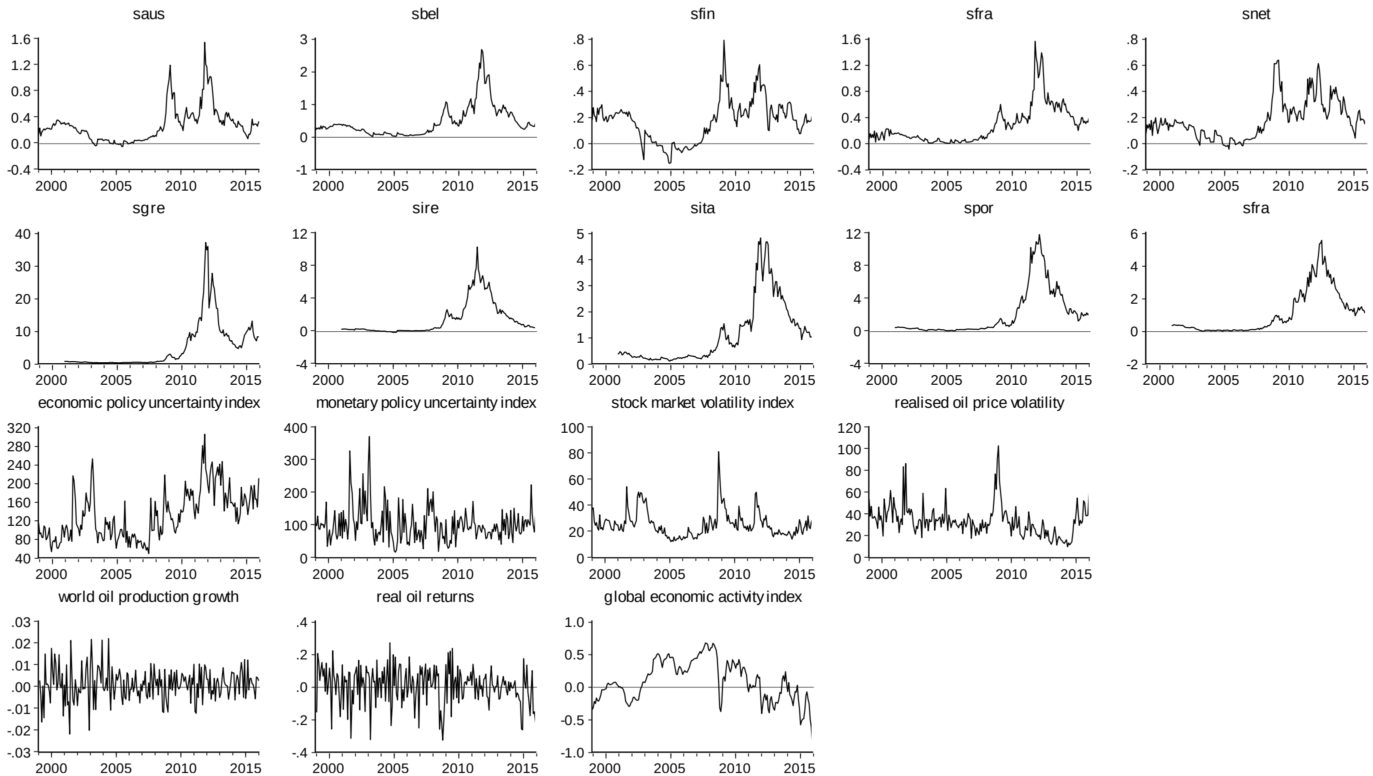
Thus, our sample consists of five EMU core countries (Austria, Belgium, Finland, France and Netherlands) and five EMU periphery countries (Greece, Ireland, Italy, Portugal and Spain). Considering the EMU core countries, our sample ranges from January 1999 to January 2016. The choice of the data period is motivated by the fact that all countries have belonged to the EMU since January 1999. It is worth noting that the data for Greece extend from January 2001, onwards, as the country joined the Eurozone in that year. Thus, a shorter period from January 2001 to January 2016 is under consideration for the EMU periphery countries. The period of analysis runs until January 2016 due to data availability for the European monetary policy uncertainty index that was devised by Husted et al. (2016b).

Figures 4.2 and 4.3 exhibit the evolution of the series under consideration and show some interesting regularities. With reference to oil-related variables, the global economic activity index shows a tendency to increase during the period 2004-2007, which is influenced by the rising global demand for industrial commodities from emerging countries. Following this episode, we observe that it suffers a significant drop during the peak months of the Great Recession (i.e. late-2008), yet again reflecting the (negative) global economic conditions of this period. In addition, a significant trough is also observed during the period of 2014-2015, corresponding to the global economic slowdown. Furthermore, the graph of the real oil return features significant troughs and relatively high volatility within the years, 2001 (the terrorist attack of September 2001), 2003 (the second Iraq war), 2007-09 (the Great Recession) and 2014-2015. World oil production growth does not seem to show similar patterns and exhibits a relatively low and stable volatility (with the exception of the period 1999-2004, which is characterised by abrupt changes). The latter can be attributed to several decisions by OPEC to cut or raise production quotas, which were associated with the early-2000 recession, the terrorist attack of 9/11 (2001), the political unrest in Nigeria and Venezuela (both in 2003) and the second Iraq war (2003).

Turning to the evolution of sovereign yield spreads, we observe a convergence in performance, which is similar for all core and periphery countries, until the early stages of the Great Recession. Since 2008, though, we observe an increasing trend in all spreads, signifying the effects of the financial crisis since the collapse of the Lehman Brothers. This increasing pattern becomes more prevalent in the post-2010 period, which reflects the start of the European debt crisis, when Greece requested financial aid from the International Monetary Fund. In most cases, the spreads tend to exhibit a declining pattern in the post-2012 period. This could be explained by the effectiveness of fiscal stimulus policies that were undertaken by European governments in order to promote economic and financial stability in response to the debt crisis. In addition, the decreasing divergence can be further explained by the ECB announcement in 2015 to implement a quantitative easing (QE) programme, known as the Expanded Asset Purchase Programme (EAPP).[34]

[34] The aim of the EAPP by the ECB was to purchase sovereign bonds by issuing new reserves and providing liquidity in the distressed countries and therefore to generate a reduction in long-term interest rates in order to control the recession and promote stability.

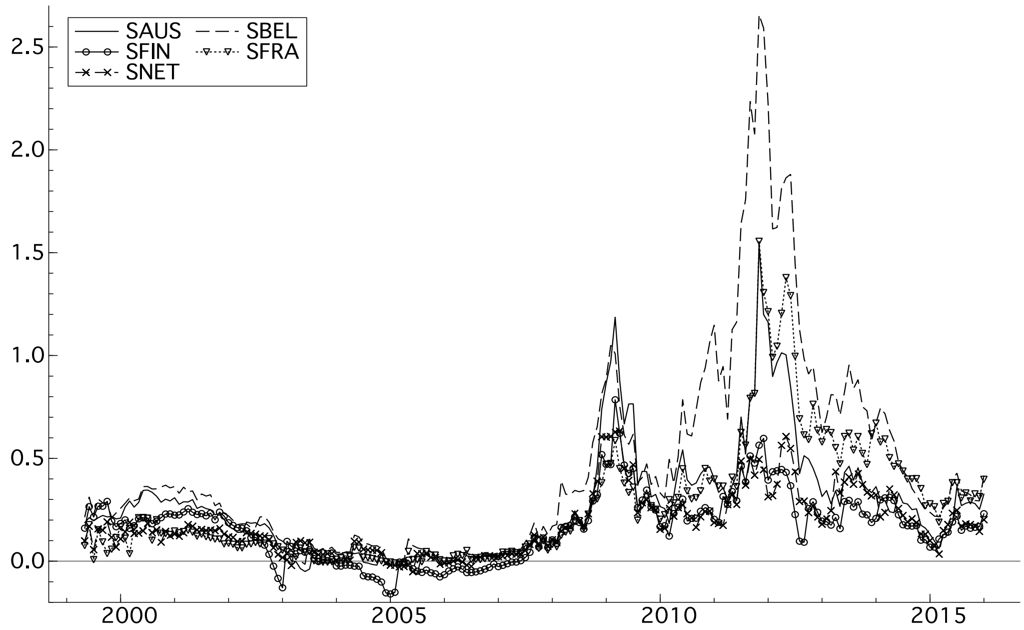
Figure 4.2: Time series employed in the study



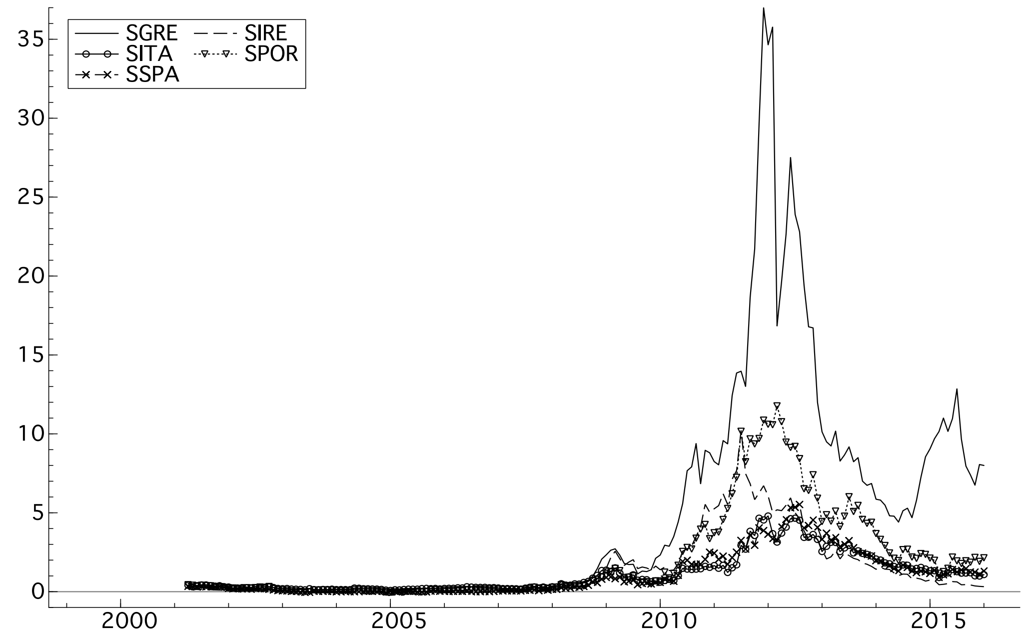
Note: This Figure exhibits the evolution of the series during the sample period. In the first row, 10-year sovereign yield spreads over Germany of the core countries (Austria (saus), Belgium (sbel), Finland (sfin), France (sfra) and the Netherlands (snet)) are represented. In the second row, 10-year sovereign yield spreads over Germany of the periphery countries (Greece (sgre), Ireland (sire), Italy (sita), Portugal (spor) and Spain (sspa)) are depicted. In the third row, the European economic policy uncertainty index, the European monetary policy uncertainty index, the European stock market volatility index and the realised oil price volatility are shown. In the fourth row, world oil production growth, real oil returns and global economic activity index are depicted. For the core countries, the time period spans from January 1999 to January 2016. For the periphery countries, the time period spans from January 2001 to January 2016.

Figure 4.3: Spreads of 10-year sovereign yields relative to Germany

Panel A – Core countries



Panel B – Periphery countries



Note: This Figure depicts variation over time of 10-year sovereign yield spreads over Germany. For the core countries (Austria (saus), Belgium (sbel), Finland (sfin), France (sfra) and the Netherlands (snet)), the time period spans from January 1999 to January 2016. For the periphery countries (Greece (sgre), Ireland (sire), Italy (sita), Portugal (spor) and Spain (sspa)), the time period runs from January 2001 to January 2016.

More specifically, the collapse of Lehman Brothers and especially the European debt crisis in post-2010 revealed the actual differences among the EMU countries that were not previously evident. In fact, differences in credit and liquidity risks influenced the government bond yields of the EMU countries and caused sovereign yield spreads to widen (see Dewachter et al., 2015). This confirms the argument that bonds that were issued by EMU countries should have never been considered as substitutes (see Favero, 2013). Overall, the period after the Great Recession indicated the vulnerability of the Eurozone and raised concerns about the macroeconomic and financial stability of core and periphery countries.

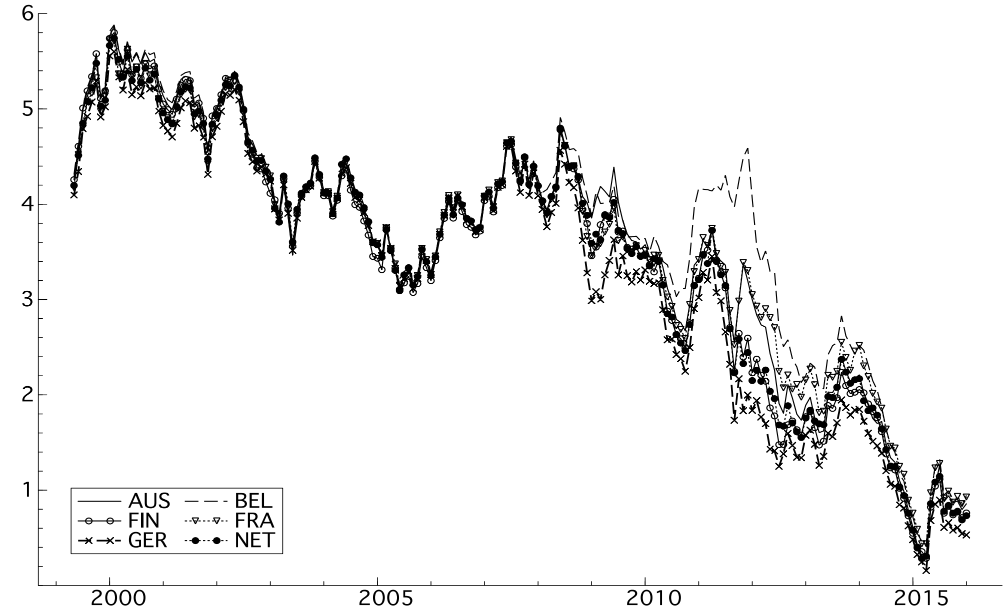
In this study, sovereign yield spreads reflect the differences between government bonds yields that were issued by EMU countries and the German Bund yield. The fact that sovereign yield spreads widened substantially during the peak months of the Great Recession emphasises the key role of Germany as the anchor country. Indeed, during this period of tightening financial conditions, the German Bund appeared to act as a 'flight-to-quality' government security for the market participants who traded in the European government bond markets. Specifically, German government bonds are characterised by safety and liquidity which explains why the German yield experienced a decreasing trend.[35]

[35] Ejsing and Sihvonen (2009) examine differences between German and French government bonds based on the fact that both bond markets are identical in terms of credit rating. They indicate that German bonds exhibited higher liquidity and a larger price premium which was more intense during the Great Recession. This can be explained by the fact that German bonds are deliverable into futures contracts in the very liquid German futures market, whereas French bonds are not delivered into futures contracts. Thus, significant liquidity spillovers from the German futures market to the German cash market could help to determine the differences between the two government bonds.

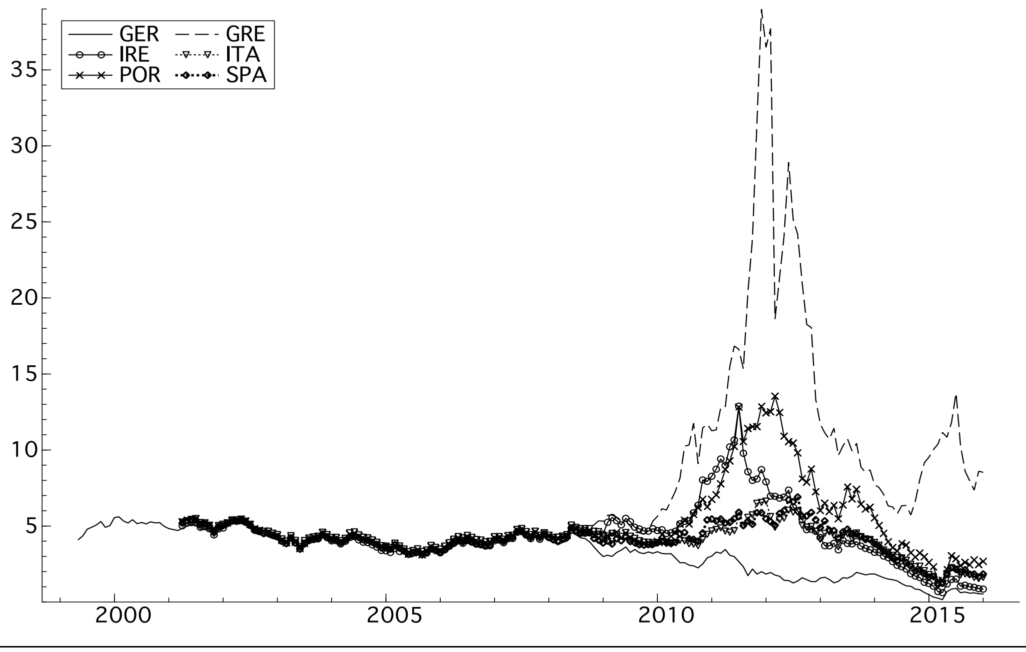
It should be mentioned that government bond yields of core countries experienced a similar decreasing trend, but to a lesser extent, compared with the German Bund. This can be attributed to the fact that the government bonds of core countries were also regarded as relatively safe and liquid assets, although not comparable to the German Bund. However, the yields for the periphery countries exhibited increasing trends and appeared to be more unstable. A plausible explanation is that these bonds are perceived to be of lower quality compared with those bonds issued by core countries. Therefore, differences in the quality possibly provide a plausible explanation for these unique asymmetric patterns of bond yields of core and periphery countries against the German Bund during the financial turmoil in the second half of 2008 and the European debt crisis in the post-2010 period. Figure 4.4 exhibits the differences in the evolution of sovereign bond yields in the EMU.

Figure 4.4: Evolution of 10-year sovereign bond yields

Panel A – Core countries and Germany



Panel B – Periphery countries and Germany



Note: This Figure depicts variation over time of 10-year sovereign bond yields. For the core countries (Austria (aus), Belgium (bel), Finland (fin), France (fra) and the Netherlands (net)), the time period spans from January 1999 to January 2016. For the periphery countries (Greece (gre), Ireland (ire), Italy (ita), Portugal (por) and Spain (spa)), the time period runs from January 2001 to January 2016. Germany (ger) represents the anchor country.

Table 4.1 reports the descriptive statistics of the series. As expected, sovereign yield spreads of the periphery countries exhibit the highest volatility compared with those sovereign yield spreads of the core countries. This is indicated by their standard deviations. In addition, none of the series are normally distributed (with the exception of world oil production and the global economic activity index). This is clearly shown by values of the Jarque-Bera statistic, and standardised measures of skewness and kurtosis.

Table 4.1: Descriptive statistics

	Mean	Median	Max.	Min.	St.Dev.	Skewness	Kurtosis	J-B	Prob.
Panel A – Core countries									
saus	0.2666	0.2226	1.5390	-0.0589	0.2675	1.7477	6.8298	229.6466***	0.0000
sbel	0.4469	0.3065	2.6570	-0.0156	0.4961	2.1033	7.9199	357.8997***	0.0000
sfin	0.1639	0.1739	0.7845	-0.1593	0.1612	0.4830	3.6371	11.4377***	0.0032
sfra	0.2601	0.1462	1.5550	-0.0132	0.2901	1.8523	7.0080	254.4446***	0.0000
snet	0.1755	0.1483	0.6322	-0.0512	0.1498	1.0489	3.8293	43.4613***	0.0000
Panel B – Periphery countries									
	Mean	Median	Max.	Min.	St.Dev.	Skewness	Kurtosis	J-B	Prob.
sgre	4.8634	0.6355	36.9890	0.0799	7.2359	2.1980	8.3443	361.1355***	0.0000
sire	1.3456	0.3180	10.2210	-0.2368	2.0364	1.8000	5.7016	152.7883***	0.0000
sita	1.0925	0.4991	4.7950	0.0805	1.1815	1.4621	4.3509	78.2523***	0.0000
spor	2.0178	0.4370	11.7670	-0.0355	2.8724	1.7381	5.1430	125.7706***	0.0000
sspa	1.0599	0.3406	5.5220	-0.0518	1.3362	1.3832	4.0842	66.5812***	0.0000
Panel C – Oil-market specific variables and control variables									
	Mean	Median	Max.	Min.	St.Dev.	Skewness	Kurtosis	J-B	Prob.
PRO	72938.22	73448.49	81205.06	64798.05	3901.09	-0.1050	2.4700	2.7762	0.2495
GEA	0.0811	0.0600	0.6636	-0.9557	0.3087	-0.1050	2.5183	2.7993	0.2467
ROP	29.6913	27.5764	65.4427	6.0534	14.0001	0.3122	1.8856	13.9384***	0.0009
EPU	130.2943	119.9992	304.6002	47.6923	52.4946	0.6777	2.8061	16.0122***	0.0003
MPU	100.1870	92.9904	370.4282	15.2935	52.4935	1.6620	7.8087	291.8889***	0.0000
VOL	25.2468	23.1200	81.0300	11.9900	9.9416	1.8443	8.3227	358.2069***	0.0000
ROV	33.3037	32.1759	102.6001	9.3144	14.2368	1.5768	7.4579	254.6974***	0.0000

Note: This table summarises descriptive statistics (sample mean, median, maximum, minimum, standard deviation, skewness, kurtosis, the Jarque-Bera test statistic, and the p-value associated to the Jarque-Bera test statistic). Panel A shows 10-year sovereign yield spreads over Germany of core countries (Austria (saus), Belgium (sbel), Finland (sfin), France (sfra) and the Netherlands (snet)). Panel B displays 10-year sovereign yield spreads over Germany of periphery countries (Greece (sgre), Ireland (sire), Italy (sita), Portugal (spor) and Spain (sspa)). Panel C demonstrates the variables used for the estimation of the oil price shocks, world oil production (PRO), global economic activity index (GEA) and real oil price (ROP), as well as, the control variables European economic policy uncertainty index (EPU), the European monetary policy uncertainty index (MPU), the European stock market volatility index

(VOL) and the realised oil price volatility (ROV). Asterisk * (**, ***) denotes the 10% (5%, 1%) significance level. For the core countries, the time period spans from January 1999 to January 2016. For the periphery countries, the time period spans from January 2001 to January 2016.

Table 4.2 summarises the results of the Augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1981) and Phillips-Perron (PP) (Phillips and Perron, 1988) unit root tests. According to Panels A and B, there is present a unit root for all core and periphery countries' sovereign yield spreads. Applying a first-difference transformation, we achieve stationarity in these series. Similarly, world oil production and the oil spot price do not appear to be stationary in levels and thus the null hypothesis of unit root cannot be rejected. Thus, we proceed with the first difference transformation of these two variables. In contrast, the series on the global economic activity index is stationary by construction, since it reflects the global business cycle (Kilian and Murphy, 2014). Finally, the series on the control variables (European economic policy uncertainty index, the European monetary policy uncertainty index, the European stock market volatility index and the realised oil price volatility) are stationary, according to the results of the unit root tests.

Table 4.2: Augmented Dickey-Fuller (1981) and Phillips-Perron (1988) unit root tests.

Panel A – ADF test						
	C		C&T		N	
saus	-2.7088	*	-2.8710		-1.7652	*
dsaus	-8.9493	***	-8.9279	***	-8.9704	***
sbel	-2.1969		-2.3790		-1.2960	
dsbel	-8.7319	***	-8.7124	***	-8.7533	***
sfin	-2.8028	*	-3.0270		-1.8239	*
dsfin	-16.2675	***	-16.2329	***	-16.3079	***
sfra	-1.6310		-2.2344		-0.8773	
dsfra	-10.6033	***	-10.5759	***	-10.6243	***
snet	-2.9372	**	-3.2860	*	-1.6924	*
dsnet	-16.3071	***	-16.2648	***	-16.3470	***
sgre	-1.7686		-2.0855		-1.2711	
dsgre	-9.1172	***	-9.0916	***	-9.1355	***
sire	-1.7243		-1.6850		-1.3778	
dsire	-6.2504	***	-9.1809	***	-6.26856	***
sita	-1.5794		-2.0051		-0.8458	

dsita	-6.0029	***	-6.0014	***	-6.0154	***
spor	-2.0920		-2.6250		-1.4610	
dspor	-3.2814	**	-3.2767	*	-3.2856	***
sspa	-1.2199		-1.5896		-0.7525	
dsspa	-15.9153	***	-15.8773	***	-15.9523	***
PRO	-0.5032		-2.6831		1.8974	
DPRO	-14.9021	***	-14.8802	***	-14.6785	***
GEA	-2.7226	*	-3.0175		-2.6725	***
ROP	-1.8713		-1.5807		-0.5179	
DROP	-14.7486	***	-15.1536	***	-14.7706	***
EPU	-4.2458	***	-5.4768	***	-0.9633	
MPU	-9.7248	***	-9.7814	***	-1.9544	**
VOL	-5.1159	***	-5.1084	***	-1.2408	
ROV	-4.1911	***	-4.3059	***	-1.0974	
Panel B – PP test						
	C		C&T		N	
saus	-2.9032	**	-3.1092		-1.8194	*
dsaus	-15.9998		-15.9623		-16.0356	
sbel	-2.0776		-2.2072		-1.4210	
dsbel	-13.1257	***	-13.0958	***	-13.1562	***
sfin	-2.6528	*	-2.8500		-1.5929	
dsfin	-16.3711	***	-16.3363	***	-16.4130	***
sfra	-2.0494		-2.9174		-1.1646	
dsfra	-15.8530	***	-15.8108	***	-15.8879	***
snet	-2.8441	*	-3.2584	*	-1.4514	
dsnet	-16.4247	***	-16.3806	***	-16.4662	***
sgre	-2.0743		-2.5055		-1.5425	
dsgre	-12.6532	***	-12.6151	***	-12.6850	***
sire	-1.4466		-1.3400		-1.1536	
dsire	-14.0574	***	-14.0594	***	-14.0968	***
sita	-1.5039		-1.9350		-0.7856	
dsita	-14.3449	***	-14.3188	***	-14.3801	***
spor	-1.5697		-1.8957		-1.0399	
dspor	-14.5391	***	-14.5143	***	-14.5668	***
sspa	-1.3098		-1.4360		-0.8224	
dsspa	-15.8201	***	-15.7841	***	-15.9001	***
PRO	-0.4121		-2.6459		2.0521	
DPRO	-14.9939	***	-14.9702	***	-14.7027	***
GEA	-2.6226	*	-2.8973		-2.5606	**
ROP	-2.0333		-1.9215		-0.6215	
DROP	-14.7709	***	-15.1262	***	-14.7922	***
EPU	-4.0246	***	-5.3311	***	-0.5459	
MPU	-9.9827	***	-10.0272	***	-3.2933	***
VOL	-4.9211	***	-4.9160	***	-1.3640	
ROV	-7.0334	***	-7.4156	***	-1.6434	*

Note: The table reports the unit root tests of 10-year sovereign yield spreads over Germany of core and periphery countries (Austria (saus), Belgium (sbel), Finland (sfin), France (sfra), Netherlands (snet), Greece (sgre), Ireland (sire), Italy (sita), Portugal (spor) and Spain (sspa)). In addition, it reports the unit root tests of 10-year sovereign yield spreads over Germany of core and periphery countries in first differences (Austria (dsaus), Belgium (dsbel), Finland (dsfin), France (dsfra), Netherlands (dsnet), Greece (dsgre), Ireland (dsire), Italy (dsita), Portugal (dspor) and Spain (dsspa)). Furthermore, it shows the unit root tests of oil-market related variables of world oil production in levels (PRO) and first difference (DPRO), global economic activity index (GEA) and real oil price in level (ROP) and first difference (DROP), as well as, of the control variables European economic policy uncertainty index (EPU), the European monetary policy uncertainty index (MPU), the European stock market volatility index (VOL) and the realised oil price volatility (ROV) in levels. For the ADF and PP unit root tests the null hypothesis is that the series features a unit root. In both tests, C denotes constant term, C&T denotes constant and time trend, N indicates no deterministic component in the test equation. Asterisk * (**, ***) denotes the 10% (5%, 1%) significance level. For the core countries, the time period spans from January 1999 to January 2016. For the periphery countries, the time period spans from January 2001 to January 2016.

Table 4.3 reports the unconditional correlations among sovereign yield spreads (in first differences) and the three oil price shocks, based on a linear relationship. We notice that negative unconditional correlations are estimated between sovereign yield spreads and supply-side shocks (with the exception of Greece), as expected. In addition, contrary to our initial hypothesis, we observe positive unconditional correlations between sovereign yield spreads and aggregate demand shocks (with the exception of the Netherlands). It is also evident that the unconditional correlations between sovereign yield spreads and precautionary demand shocks are negative (with the exception of Ireland), which is also not anticipated. It should be noted that the findings from Table 4.3 hold for the whole period either for core or periphery countries.

Furthermore, in Table 4.4 we report the unconditional correlations during the pre- and post-Great Recession periods, which clearly show a change in relationships, especially for the aggregate and precautionary demand shocks. These preliminary results motivate the use of a time-varying framework. Thus, in order to acquire a thorough picture about the time-varying correlations of the said relationships, a more in-depth analysis is carried out in Section 5.[36]

Table 4.3: Unconditional correlations between sovereign yield spreads and oil price shocks – whole sample

	Supply-side shock	Aggregate demand shock	Precautionary demand shock
saus	-0.0676	0.0982	-0.1294
sbel	-0.0721	0.1678	-0.1417
sfin	-0.0922	0.0454	-0.1135
sfra	-0.0596	0.1084	-0.1229
snet	-0.0243	-0.0162	-0.1475
sgre	0.0110	0.0002	-0.1066
sire	-0.1486	0.0459	0.0803
sita	-0.0770	0.0684	-0.1189
spor	-0.0994	0.1071	-0.0002
sspa	-0.0105	0.0275	-0.0681

Note: Unconditional correlations between 10-year sovereign yield spreads over Germany of core and periphery countries in first differences and different oil price shocks. Core countries: Austria (saus), Belgium (sbel), Finland (sfin), France (sfra) and the Netherlands (snet). Periphery countries: Greece (sgre), Ireland (sire), Italy (sita), Portugal (spor) and Spain (sspa). For the core countries, the time period spans from January 1999 to January 2016. For the periphery countries, the time period spans from January 2001 to January 2016.

[36] The Granger-causality test also confirms the relationship (either bidirectional or unidirectional) between oil price shocks and the 10-year government bond yield spreads. For brevity we do not show the results here, but they are available upon request.

Table 4.4: Unconditional correlations among sovereign yield spreads and oil price shocks – divided sample

	Supply-side shock	Aggregate demand shock	Precautionary demand shock
Panel A – Pre-Great Recession			
saus	-0.1971	-0.0886	0.1777
sbel	-0.0549	-0.0703	0.1240
sfin	-0.1921	-0.0387	0.1701
sfra	-0.0708	-0.0742	-0.0162
snet	0.0296	-0.1111	0.0597
sgre	0.1030	0.0374	0.1347
sire	0.0857	-0.0700	0.0119
sita	0.0771	-0.0630	0.0444
spor	0.1414	0.0416	0.1389
sspa	0.0823	0.0919	0.0441
Panel B – Post-Great Recession			
saus	-0.0689	0.1220	-0.2616
sbel	-0.1289	0.2018	-0.2778
sfin	-0.0284	0.0698	-0.3257
sfra	0.0853	0.1428	-0.2032
snet	-0.0826	0.0059	-0.3069
sgre	0.0130	0.0046	-0.1617
sire	-0.2318	0.0538	-0.1234
sita	0.1289	0.0829	-0.1872
spor	-0.1616	0.1240	-0.0069
sspa	-0.0250	0.0324	-0.1049

Note: Unconditional correlations between 10-year sovereign yield spreads over Germany of core and periphery countries in first differences and different oil price shocks. Core countries: Austria (saus), Belgium (sbel), Finland (sfin), France (sfra) and the Netherlands (snet). Periphery countries: Greece (sgre), Ireland (sire), Italy (sita), Portugal (spor) and Spain (sspa). For the core countries, the time period spans from January 1999 to January 2016. For the periphery countries, the time period spans from January 2001 to January 2016. The pre-Great Recession extends until August 2008, whereas the post-Great Recession begins in September 2008.

4.4. Methodology

4.4.1 Structural VAR model and historical decomposition

To disaggregate different oil price shocks based on their origin, a SVAR model inspired by Kilian (2009) is employed. As previously mentioned, we decompose the oil price into supply-side shocks identified by changes in world oil production ($DPRO_t$), aggregate demand shocks approximated by the global economic activity index (GEA_t) and precautionary demand shocks represented by changes in the Brent real oil price ($DROP_t$). We highlight that D represents the first difference between the values in month *t* and month *t*-i.

The use of the SVAR requires imposing restrictions on the parameters which are indicating the contemporaneous relationships among the endogenous variables. These restrictions are used to identify the structural innovations of the model and are dictated by the economic theory. Moreover, the impulse response analysis helps us ascertain the impact of an unexpected innovation in one endogenous variable on the other variables in the system. Expressed differently, we examine the response of an endogenous variable to a one standard deviation shock, to either itself or another variable entering the system.

The representation of the SVAR model of order k (where the order k denotes the maximum number of lag length reflected in the model) takes the following form:

$$A_0\, Z_t = \alpha_0 + \sum_{i=1}^{k} A_i\, Z_{t-i} + \varepsilon_t, \qquad (1)$$

where Z_t is the (3x1) vector of the three aforementioned endogenous variables, i.e. Z_t= ($DPRO_t, GEA_t, DROP_t$,), A_0 represents the (3x3) matrix which includes the contemporaneous relations among the variables, α_0 is the (3x1) vector of intercept (constant) terms, A_i is the (3x3) matrix of coefficient parameters which need to be estimated for *í = 1,2,3....k* , Z_{t-i} is the vector of lagged endogenous variables and ε_t is a (3x1) vector of serially and mutually uncorrelated structural shocks (disturbances) which are assumed to have zero covariance.

Our decision to select the AIC is justified by the formal analysis about the lag order selection for VAR models provided by Ivanov and Kilian (2005). They document that the AIC tends to produce the most accurate impulse response estimates for all realistic sample sizes for structural and semi-structural impulse responses in monthly VAR models. In a more detailed analysis, they employ six information criteria, namely, the Schwarz Information Criterion (SIC), the Hannan-Quinn Criterion (HQC), the Akaike Information Criterion (AIC), the general-to-specific sequential Likelihood Ratio test (LR), a small-sample correction to that test (SLR) proposed by Sims (1980), and the specific-to-general sequential Portmanteau test interpreted as a Lagrange Multiplier (LM) test of a given VAR model for zero coefficient restrictions at higher-order lags (see, for example, Lütkepohl, 1993). The authors argue about the accuracy of the AIC whose average reduction in mean-squared error can be as high as 27% relative to the SIC and 6% relative to the HQC.

In addition, the variance covariance matrix of the structural shocks can be illustrated as follows:

$$\mathrm{E}\,(\varepsilon_t \varepsilon_t') \;=D\; = \begin{bmatrix} \sigma_{SS}^2 & 0 & 0 \\ 0 & \sigma_{AD}^2 & 0 \\ 0 & 0 & \sigma_{PD}^2 \end{bmatrix}. \qquad (2)$$

We emphasise that the variance covariance matrix of the structural shocks is diagonal, given that the structural shocks are assumed to be orthogonal and therefore mutually uncorrelated. In Equation 2, *E* is the unconditional expectations operation, σ^2 is the variance of a random disturbance term and *D* is a diagonal matrix.

To estimate the SVAR model, a reduced form representation is required to be implemented. Therefore, a reduced form representation of the SVAR model is indicated as:

$$Z_t = \beta_0 + \sum_{i=1}^{k} B_i Z_{t-i} + e_t. \quad (3)$$

This process implies that we multiply all parts of the equation (1) by A_0^{-1}. This process implies that $\beta_0 = A_0^{-1}\alpha_0$, $B_i = A_0^{-1}A_i$, and $e_t = A_0^{-1}\varepsilon_t$. We notice that the reduced form errors (disturbance terms) e_t are linear combinations of the structural shocks ε_t . In line with the previous analysis, the variance covariance matrix of the reduced form errors can be represented as:

$$E(e_t e_t') = E[(A_0^{-1}\varepsilon_t)(A_0^{-1}\varepsilon_t)'] = E(A_0^{-1}\varepsilon_t \varepsilon_t' A_0^{-1\prime}) = A_0^{-1}E(\varepsilon_t \varepsilon_t')A_0^{-1\prime} = A_0^{-1}DA_0^{-1\prime} = \Omega. \quad (4)$$

It is worth noting that the reduced form errors are correlated across equations, which is in contrast with the structural shocks, and are assumed to be orthogonal and therefore mutually uncorrelated. A symmetric positive definite matrix *Ω* denotes that the entries above or below the principal diagonal are non-zero. In this regard, it is necessary to orthogonalise the reduced form errors by imposing a structural decomposition. Equation (5) shows how the vector of reduced form errors (e_t) can be decomposed into structural disturbances (ε_t):

$$e_t = \begin{bmatrix} e_{DPRO,t} \\ e_{GEA,t} \\ e_{DROP,t} \end{bmatrix} = A_0^{-1}\varepsilon_t = \begin{bmatrix} \alpha_{11} & 0 & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix} \times \begin{bmatrix} \varepsilon_{SS,t} \\ \varepsilon_{AD,t} \\ \varepsilon_{PD,t} \end{bmatrix}, \quad (5)$$

where, $\varepsilon_{SS,t}$ denotes the supply-side shocks originated from the world oil production, $\varepsilon_{AD,t}$ represents the aggregate demand shocks related to the global economic activity and $\varepsilon_{PD,t}$ indicates the precautionary demand shocks associated with the real oil price. Following Kilian (2009), we impose short-run restrictions on the lower triangular matrix A_0^{-1} with the aim of detecting the structural shocks of the model. These short-run restrictions allow us to set all entries located above the principal diagonal to zero. It must be mentioned that these short-run restrictions have been well demonstrated, explained and verified in Kilian's (2009) structural analysis.

The short-run restrictions which are imposed in Equation (5) are rationalised as follows. First, world oil production may not react contemporaneously to changes in global demand for industrial commodities and changes in oil prices. For this reason it takes time for the world oil production to adjust to these changes and consequently involves high adjustment costs. Nevertheless, world oil production responds contemporaneously to supply-side shocks. These short-run restrictions are observed in the first row as: $\alpha_{12} = 0$, $\alpha_{13} = 0$, and a non-zero α_{11}.

Second, global economic activity is not instantaneously influenced by changes in oil prices due to the sluggishness of global real economy to react to these changes. However, global economic activity is contemporaneously affected by supply-side shocks and aggregate demand shocks. Similarly, we observe these short-run restrictions in the second row as: $\alpha_{23} = 0$, and a non-zero α_{21} and α_{22}. Third, changes in oil prices are affected within the same month by supply-side shocks, aggregate demand shocks and its own innovations. We summarise that all types of shocks are allowed to contemporaneously impact oil prices. This is demonstrated by non-zero coefficients in the third row.

The ordering of the endogenous variables in the SVAR model is based on the empirical study by Kilian (2009). More specifically, Kilian uses three types of oil price shocks within the SVAR framework. The recursive identification scheme based on the Cholesky decomposition of the oil price shocks requires us to set the correct order which entails the first variable in the system to be the least endogenous, and the last variable to be the most endogenous. This process guarantees that the first variable is not influenced by the remaining two variables and responds only to its own innovations. The second variable is responsive to its own changes and innovations originating from the first variable but is not affected by shocks generated by the last variable. Finally, innovation to the last variable could be triggered by its own changes and events related to the first and the second variables.

In a more detailed analysis, Kilian considers the world oil production at the top of the system due to high adjustment costs which prevent it from responding contemporaneously to changes in oil demand. Then, the global economic activity index is placed as the second variable due to its immediate response to oil production changes and its own shocks. The oil price as the third variable could be affected by shocks generated by the supply-side, the aggregate demand and the oil-specific demand innovations. Overall, this process indicates that an innovation to the higher ordering variable exercises an instantaneous impact on the lower ordering variable. However, an innovation to the lower ordering variable has a lagged instead of an instantaneous effect on the higher ordering variable. Since the Cholesky identification scheme imposes causal assumptions, the ordering of the variables matters. According to Kilian (2009), the interpretation of SVAR models related to the contemporaneous restrictions of different oil price shocks is predetermined by the economic theory. Therefore, any alternative identification scheme, such as to allow a delay in responses or a scheme unrelated to the Cholesky identification would not be compatible with the economic theory and hence we do not consider any other ordering in the set of our variables in the SVAR framework.

Next, we proceed to the historical decomposition in order to test the effects of the three oil price shocks on real oil price returns at each point in time. Given that the SVAR is already estimated, we follow Burbidge and Harrison (1985) who indicate that this technique involves three stages. Initially, a SVAR model is utilised to allow the identification of the three oil price shocks. Next, we forecast the endogenous variables. Finally, we decompose the forecast errors into the cumulative contributions of the structural oil price shocks. Thus, the cumulative effects from the three structural oil price shocks on the real oil returns are used as explanatory variables and allow identifying the importance of each shock at each point in time. To this end, Kilian and Park (2009) suggest that the computation of the historical decomposition is important in order to gain a clearer understanding of the cumulative effect of these shocks on the real oil returns.

4.4.2 Scalar-BEKK model

In order to investigate the dynamic correlation between different oil price shocks and the 10-year sovereign yield spread, a time-varying framework is adopted. The Baba-

Engle-Kraft-Kroner (BEKK) model described in Engle and Kroner (1995) and the dynamic conditional correlation (DCC) model introduced by Engle (2002) can be viewed as the most commonly used time-varying frameworks that successfully estimate dynamic conditional correlations between time series. Both models are considered as multivariate generalised autoregressive conditional heteroscedasticity (MGARCH) specifications. However, empirical evidence that has been supplied by Caporin and McAleer (2008, 2012) indicates the superiority of BEKK for estimating conditional correlations. Filis (2014) and Broadstock and Filis (2013) show respect for the empirical findings of Caporin and McAleer (2008, 2012) in their research regarding the use of time-varying models and underline the advantages of employing a BEKK model. Thus, we adopt a BEKK framework instead of using the DCC framework.

Turning our attention to the BEKK framework, we should not lose sight of the fact that a standard (general) BEKK contains a large number of parameters and computational problems. For example, a standard BEKK requires the estimation of $(n(n + 1) / 2) + 2n^2$ parameters. These issues are improved with the use of a scalar-BEKK in which the number of estimated parameters is significantly smaller as $(n(n + 1) / 2) + 2$ parameters require estimation.

The structure of the scalar-BEKK can be presented as:

$$\begin{gathered}
\boldsymbol{y}_t = \boldsymbol{\mu} + \boldsymbol{\delta}\,\boldsymbol{X}_{t-1} + \boldsymbol{\varepsilon}_t \\
\boldsymbol{\varepsilon}_t = \boldsymbol{H}_t^{1/2}\boldsymbol{z}_t \\
\boldsymbol{z}_t \sim NID(\boldsymbol{0}, \boldsymbol{I}_N) \\
\boldsymbol{H}_t = \boldsymbol{H}_t^{1/2}(\boldsymbol{H}_t^{1/2})'
\end{gathered} \tag{6}$$

In this context, the *(n x 1)* vector y_t relates to the multivariate stochastic process to be predicted and contains the variables of interest. Specifically, $\boldsymbol{y}_t = (y_{1,t}, y_{2,t})'$, where $y_{1,t}$ denotes each one of the oil price shocks and $y_{2,t}$ represents the 10-year sovereign yield spread, at time *t*. Similarly, $\boldsymbol{\varepsilon}_t = (\varepsilon_{1,t}, \varepsilon_{2,t})'$ is the vector of unexpected random shocks (errors) and reflects the innovations (news) for each variable at time *t*. Thus, the innovations are shocks to the variables of interest. Furthermore, the vector $\boldsymbol{\mu}$ represents the constant vector of means, $\boldsymbol{H}_t^{1/2}$ is a *(n x n)* matrix, which is obtained by a Cholesky decomposition, $\boldsymbol{z}_t$ is a *(n x 1)* vector process which is assumed to follow a standard normal distribution such that $E(\boldsymbol{z}_t) = \boldsymbol{0}$ and $Var(\boldsymbol{z}_t) = E(\boldsymbol{z}_t\boldsymbol{z}_t') = \boldsymbol{I}_N$ with the latter ($\boldsymbol{I}_N$) to express an *(n x n)* identity matrix.[37] [38]

In the spirit of Degiannakis et al. (2016), a set of control variables (***X***) are also included in the mean equation, in order to accommodate any omitted variable bias. In particular, vector ***X*** includes the European Economic Policy Uncertainty (EPU), European Monetary Policy Uncertainty (MPU), as well as stock market and oil price volatilities (VOL and ROV, respectively). Their use is motivated by the fact that previous research has convincingly shown their impact on both bond yields and oil prices (see, for instance, Arora and Cerisola, 2001, Barsky and Kilian, 2002, Anzuini et al., 2012,

[37] In this study, our empirical analysis based on the equation $\mathbf{y}_t = (y_{1,t}, y_{2,t})'$, where $y_{1,t}$ denotes each one of the oil price shocks and $y_{2,t}$ represents the 10-year sovereign yield spread, at time t. However, an alternative approach implies the modelling of all oil shock components and sovereign risk spread component as a complete system. In this regard, the equation has been changes and presented as: $\mathbf{y}_t = (y_{1,t}, y_{2,t}, y_{3,t}, y_{4,t})'$, where $y_{1,t}$ denotes the supply-side shock, $y_{2,t}$ denotes the aggregate demand shock, $y_{3,t}$ denotes the precautionary demand shock and $y_{4,t}$ represents the 10-year sovereign yield spread, at time t. Overall, our results appear to be qualitatively similar for both approaches.

[38] In the analysis of our scalar-BEKK, the error term is allowed to follow a t distribution. Hence, allowance is made for the error term in order to follow a t distribution which has fatter tails than the normal. In this regard, we expect a greater chance to obtain extreme patterns that fall far from their mean. By modelling all oil shock components and sovereign risk spread components as a complete system and further having allowed a t distribution with fatter tails within this system, we document that our results appear to be qualitatively similar.

Antonakakis et al., 2014, Afonso et al., 2015, Bernal et al., 2016, Husted et al., 2017, Shahzad et al., 2017). Hence, their inclusion allows us to separate any impact of the aforementioned variables on the time-varying relationship between oil price shocks and bond yield spreads.[39] Finally, $\boldsymbol{\delta}$ denotes vector of coefficients to be estimated for each control variable. We also estimate the scalar-BEKK model excluding the vector of the control variables ($\boldsymbol{X}$) from the mean equation so to allow relevant comparisons.

The variance-covariance matrix, $\boldsymbol{H}_t$, is estimated assuming a first-order GARCH process, such as that:

$$\boldsymbol{H}_t = \boldsymbol{C}\boldsymbol{C}' + \boldsymbol{A}\boldsymbol{\varepsilon}_{t-1}\boldsymbol{\varepsilon}'_{t-1}\boldsymbol{A}' + \boldsymbol{B}\boldsymbol{H}_{t-1}\boldsymbol{B}', \quad (7)$$

where $\boldsymbol{C}$ is an *(n x n)* lower triangular matrix, whereas the $\boldsymbol{A}$ and $\boldsymbol{B}$ are *(n x n)* square parameter matrices. Specifically, matrix $\boldsymbol{A}$ reflects the news shock and matrix $\boldsymbol{B}$ represents the persistence in conditional volatility.

In addition, as proposed by Ding and Engle (2001) the scalar-BEKK representation implies that $\boldsymbol{A} = \alpha \boldsymbol{I}_N$ and $\boldsymbol{B} = \beta \boldsymbol{I}_N$, where α and β are positive scalars. Hence, $\boldsymbol{A}$ and $\boldsymbol{B}$ are matrices of ones and proportional to the I_N and the scalar-BEKK can be written as:

$$\boldsymbol{H}_t = \boldsymbol{C}\boldsymbol{C}' + \alpha^2(\boldsymbol{\varepsilon}_{t-1}\boldsymbol{\varepsilon}'_{t-1}) + \beta^2\boldsymbol{H}_{t-1} \quad (8)$$

which in turn indicates a single parameter in each of the two matrices and consequently suggests the scalar-BEKK as the most restricted version of BEKK models. The matrix

[39] Despite the fact that the EPU, MPU and VOL are readily available, the ROV is constructed as follows: $ROV_t = 100\sqrt{12\sum_{k=1}^{\tau}\left(logROP_{t_k} - logROP_{t_{k-1}}\right)^2}$, where ROP_{t_k} denotes the real oil prices of day *k* at month *t*.

of constants is decomposed into two triangular matrices, $\boldsymbol{C}$ and $\boldsymbol{C}'$, to ensure that $\boldsymbol{CC}'$ is a positive definite matrix. Consequently, $\boldsymbol{H}_t$ is also positive definite.

Finally, the time-varying correlation at time *t* (ρ_t) between two series *i* (10-year sovereign yield spread) and *j* (each of the oil price shocks) is expressed as:

$$\rho_{ij,t} = \frac{h_{ij,t}}{\sqrt{h_{ii,t}}\sqrt{h_{jj,t}}} \tag{9}$$

where the numerator expresses the non-diagonal element of $\boldsymbol{H}_t$ (the time-varying conditional covariance term between *i* and *j*) and the denominator states the square roots of the diagonal elements of $\boldsymbol{H}_t$ (the time-varying conditional volatilities of *i* and *j*). Overall, technical details for the estimation process of the scalar-BEKK[40] are available in Xekalaki and Degiannakis (2010). Having explained the empirical framework, we further proceed to investigate the time-varying correlation between the variables under consideration.

In considering the differences between the BEKK and the DCC models, we make reference to the empirical analysis by Caporin and McAleer (2008, 2010) who examine the suitability of the two models. They document a number of similarities, such as the ability to forecast conditional correlations, conditional variances, covariances and consequently VAR thresholds. The authors indicate that the asymptotic properties of

[40] The asymmetric BEKK has been proposed by Kroner and Ng (1998) and represents an extension of the BEKK in which the variance-covariance matrix is not only dependent on the magnitude of past squared return innovations but also on the sign of the past squared return innovations. To this end, the BEKK model includes the elements of an additional matrix which reflects the potential asymmetric volatility transmission between oil price shock and sovereign yield spreads. The results show that the asymmetric coefficient (denoted as D1 is significant at the five per cent significance level only in the cases of Greece and Portugal. Although there is some evidence of asymmetry, this does not change the overall findings of this chapter. This supports our decision to employ a scalar-BEKK than the asymmetric BEKK."

BEKK have been specified under a set of untestable moment conditions while DCC possessed asymptotic properties under a set of untestable regularity conditions. More specifically, they argue that the scalar BEKK restricted specification is the model in which the number of parameters can be reduced considerably. This is because in the unrestricted version of both models, the number of parameters increases quite rapidly with the model dimensionality which is associated with the number of financial assets in a portfolio. Therefore, the authors consider the superiority of BEKK model for estimating either conditional correlations or conditional covariances. In turn, this reinforces our decision to employ a scalar BEKK rather than a DCC econometric framework.

On the other hand, turning to the differences between the BEKK and the Copula models, Lee and Long (2009) attempt to model MGARCH for non-normal multivariate distributions. They propose an innovative model named a Copula-based Multivariate GARCH model which allows modelling conditional correlation (by DCC, BEKK and varying correlation (VC)) as well as dependence structure (by a Copula) separately and simultaneously. By employing three foreign exchange rates, their empirical analysis provide evidence that the Copula is the optimal model in terms of out-of-sample multivariate density forecast and in-sample model selection compared with DCC, BEKK and VC. Overall, they claim that the choice of Copula functions instead of volatility models is preferable when correlation and dependence are employed at the same time. Thus, Copula functions can be a tool regarding avenues for future study in terms of multivariate modelling in order to designate the dependence between two or more random variables.

On a final note, it should be mentioned that the scalar-BEKK model is regarded as a more parsimonious model among complex MGARCH specifications. This is due to the fewer number of parameters to be estimated which makes the scalar-BEKK as the MGARCH with lowest complexity. This warrants that parsimonious models are more persuasive and provide more reasonable interpretations.

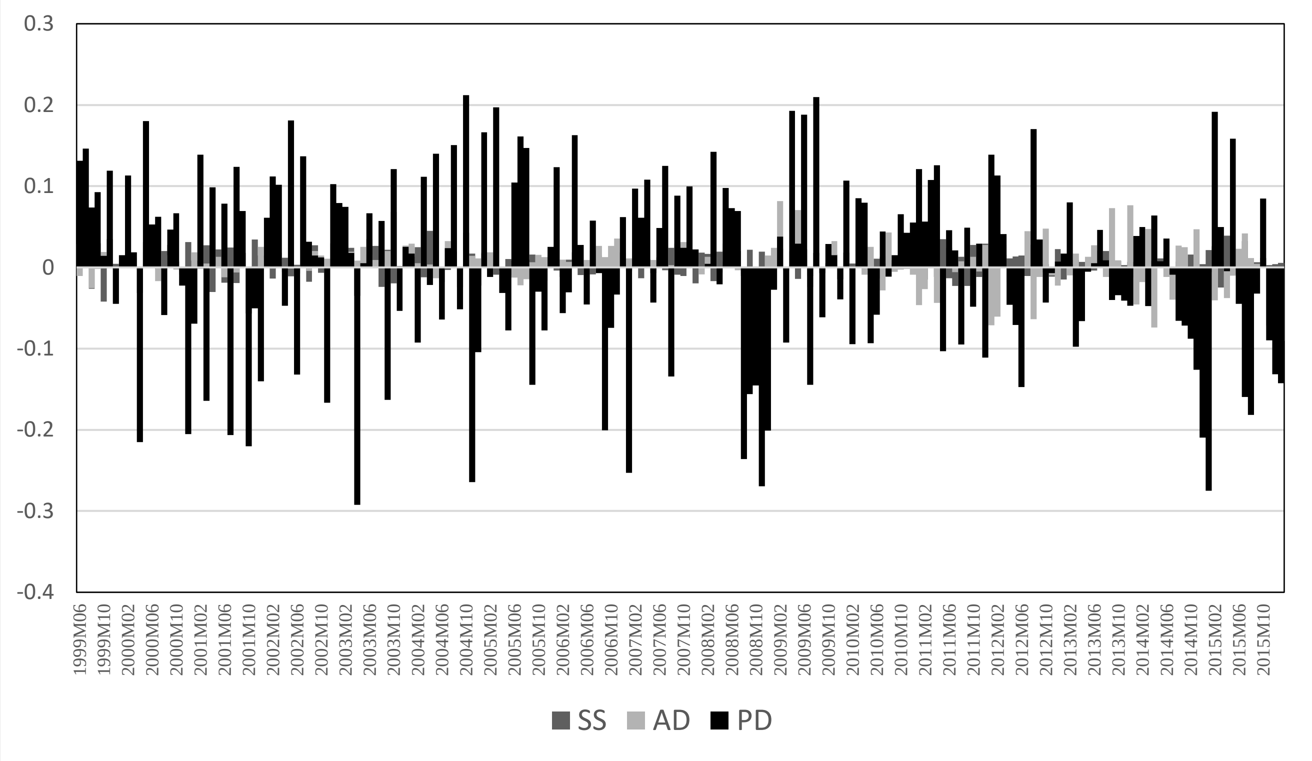
4.5. Empirical analysis

4.5.1 Historical decomposition of oil price shocks and the time-line of major events

The historical decomposition of the real oil returns and consequently the cumulative effect of supply-side shocks, aggregate demand shocks and precautionary demand shocks on the real oil returns are presented in Figure 4.5. It is evident that precautionary demand shocks have a higher historical contribution, followed by aggregate demand shocks and then supply-side shocks. It is worth noting that the historical contribution of precautionary demand shocks has mainly fluctuated between -20% and 20%. Similarly, the percentage level of aggregate demand shocks has mostly ranged between -5% and 5%. Finally, the percentage contribution of supply-side shocks has not exceeded the level of ±0.5%. Overall, real oil returns appear to be more responsive to geopolitical events and generally fears about the future availability of oil.

The higher magnitude of precautionary demand shocks at each point in time can be explained by the fact that geopolitical risk includes a broad range of interrelated events, such as political instability, military conflicts, terrorist attacks, civil wars, embargos, financial and macroeconomic uncertainty, supply constraints on commodities and other globally trade assets. On the other hand, aggregate demand shocks do not seem to influence significantly real oil returns until the onset of the Great Recession. These shocks appear to have a greater impact on the sharp fall in oil price during the period 2007-2009 and the period 2014-2015. Finally, supply-side shocks do not seem to contribute significantly to real oil returns since the magnitude is very small.

Figure 4.5: Historical decomposition of real oil price returns



Note: This Figure exhibits the historical decomposition of the real oil price returns at each point in time based on the origin of the oil price shock. SS denotes the supply-side shock, AD represents the aggregate demand shock and PD reflects the precautionary demand shock. The sample period runs from January 1999 to January 2016.

Next, we concentrate on specific events during which significant oil price movements (peaks and troughs) took place and generated either supply-side or demand-side oil price shocks.[41] Through a time-line, we pay particular attention to the early-2000

[41] Previous studies based on a time-line of major events in the oil market that investigate time-varying correlations between oil markets and stock markets include papers by Antonakakis et al. (2017), Boldanov et al. (2016), Broadstock and Filis (2014), Antonakakis and Filis (2013), Degiannakis et al. (2013) and Filis et al. (2011). A common feature of the aforementioned studies reveals that the correlations are time-varying, and the magnitude of the correlations differs at different events.

recession, the terrorist attack of 9/11 (2001), the second Iraq war (2003), the Atlantic hurricanes (late-2005), the increased demand for oil from emerging market countries such as China (2006-2007), the Great Recession (2007-2009), the European debt crisis (2010-2013), the Arab Spring together with continuing geopolitical turmoil in the Middle East (2011-2014) and finally the oil price crash (mid-2014 - early-2015).

Linking these episodes with the oil price shocks, we note that supply-side shocks are typically associated with OPEC's decisions to cut or increase production quotas and natural disasters which cause a physical disruption in oil supply. On the other hand, aggregate demand shocks originate during turbulent economic periods, whereas precautionary demand shocks are linked with episodes of geopolitical uncertainty.

4.5.2 Time-varying correlation between oil price shocks and sovereign yield spreads

4.5.2.1 Key research findings

Figures 4.6 – 4.10 exhibit the time-varying correlations between each of the three oil price shocks and the 10-year sovereign yield spread of each core country, while Figures 4.11 – 4.15 display the time-varying correlations between each of the three oil price shocks and the 10-year sovereign yield spread of each periphery country. It should be mentioned that we observe the time-varying correlations having included the control variables to capture the omitted variable bias issue (solid line). Also, we provide the time-varying correlations having excluded the control variables (dashed line).[42]

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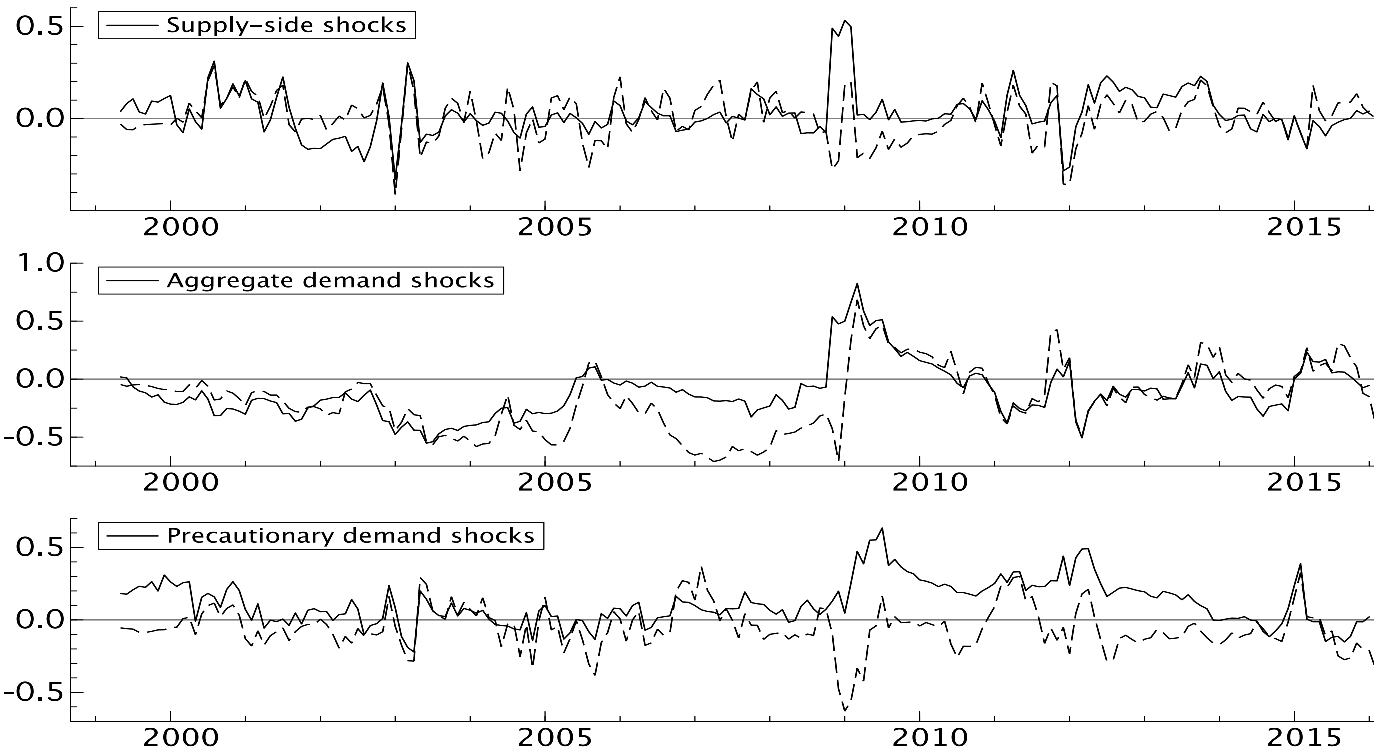
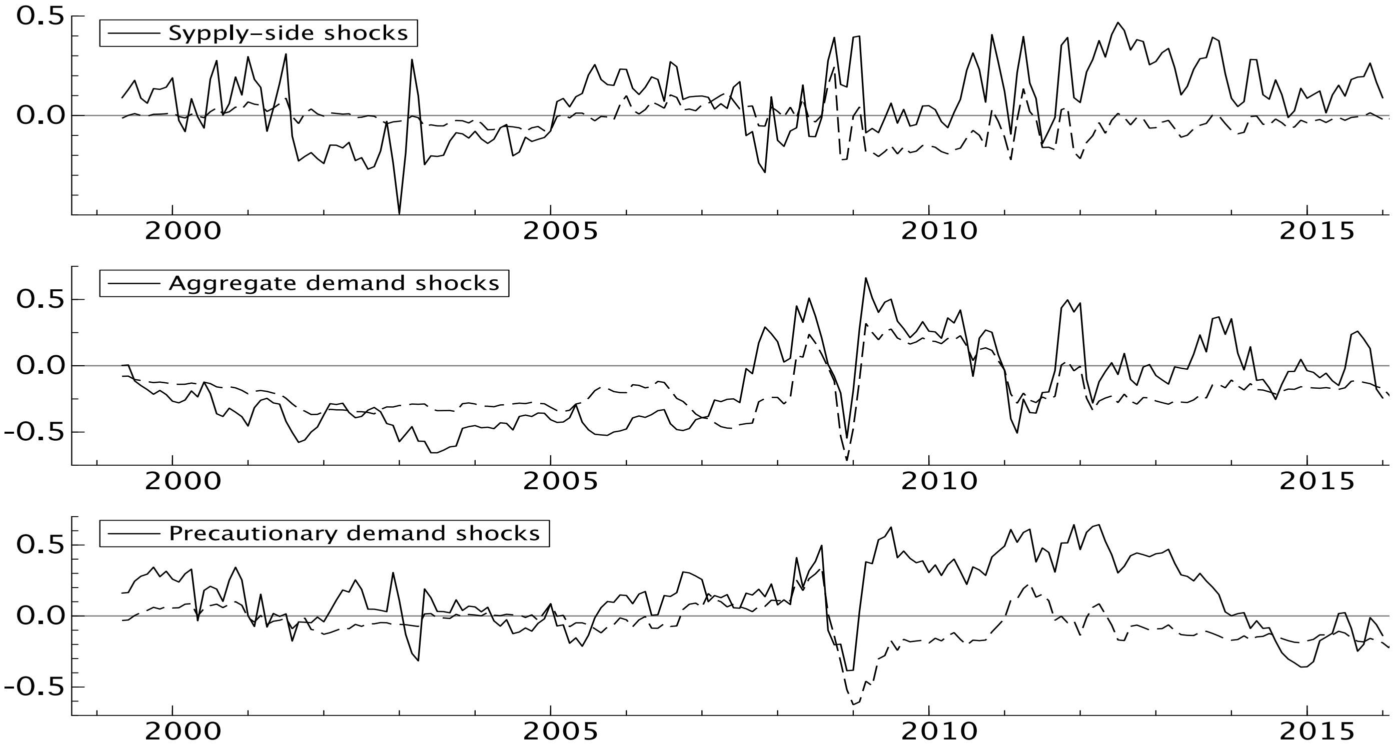
[42] Although our analysis is mainly relies upon visual illustrations about the correlation patterns between different oil shocks and sovereign yield spreads, an additional analysis provides lower and upper bounds in order to test the significance of the correlation patterns within a time-line of major events in the oil market. The diagrams that are been provided show clearly the fluctuations which occur in the correlation coefficients and the extent to which these are distributed about the mean. Overall, it is evident that the correlation patterns show a significant response to events that played a significant role and affected the oil market.

Figure 4.6: Time-varying correlations between oil price shocks and the 10-year sovereign yield spread of Austria



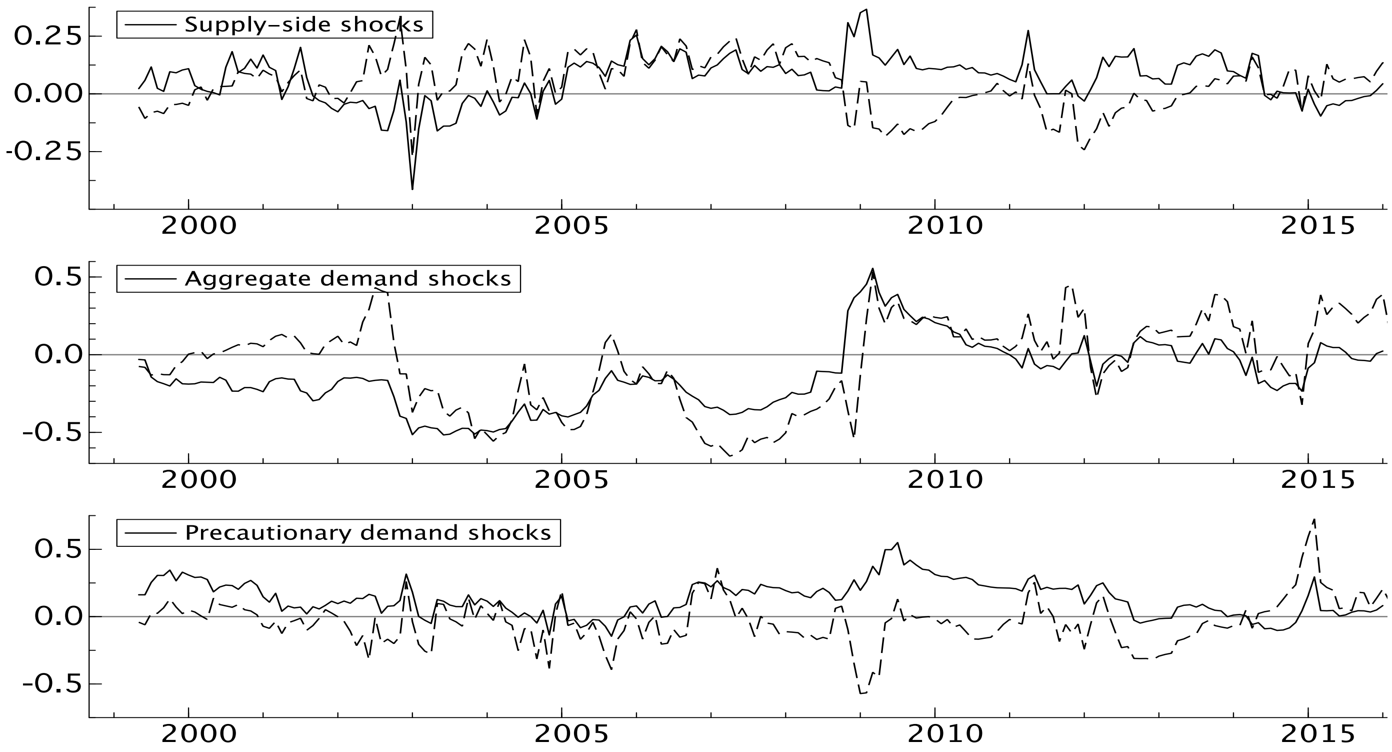
Note: This Figure depicts the time-varying correlation between supply-side shocks, aggregate demand shocks, precautionary demand shocks and the 10-year Austrian sovereign yield spread (the difference between the Austrian sovereign bond yield and the yield on the German Bund). The solid line (dashed line) shows the correlation that includes (excludes) the control variables related to the omitted variable bias issue. The time period spans from January 1999 to January 2016.

Figure 4.7: Time-varying correlations between oil price shocks and the 10-year sovereign yield spread of Belgium



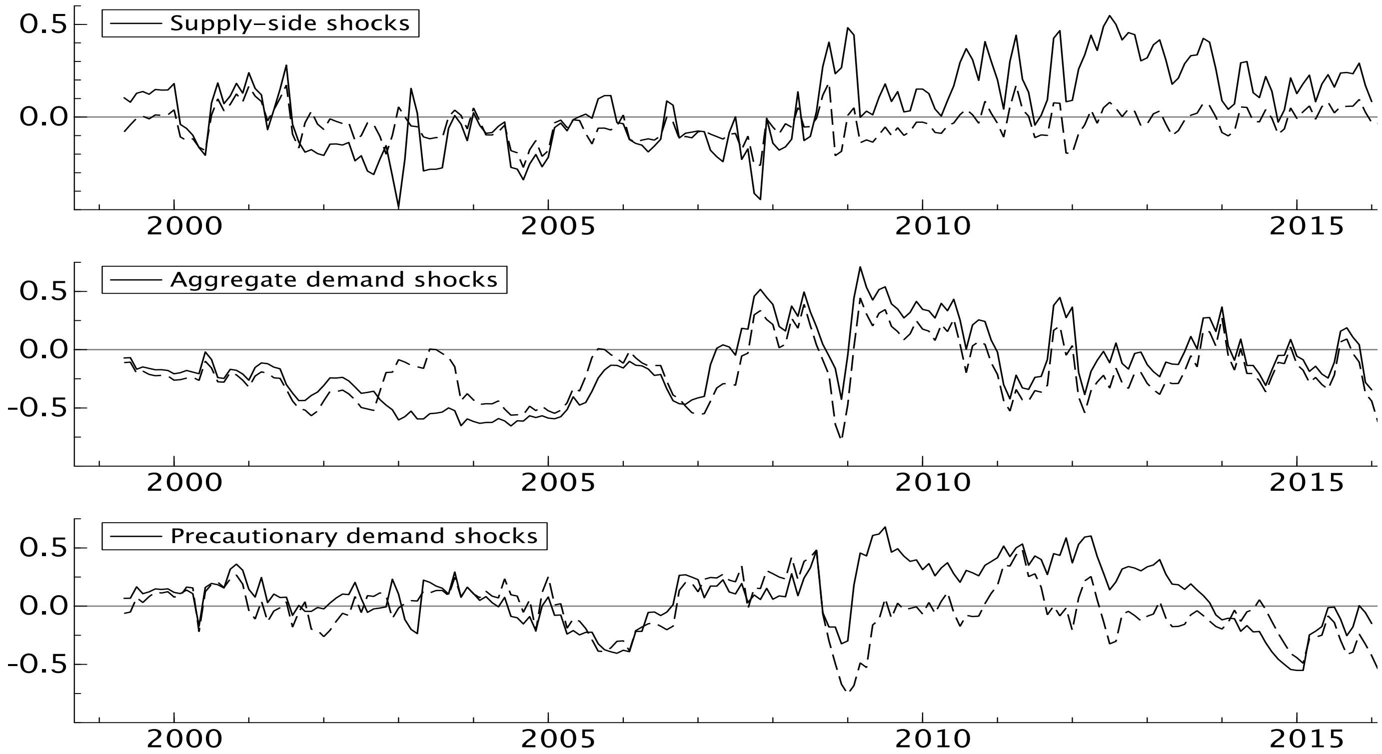
Note: This Figure depicts the time-varying correlation between supply-side shocks, aggregate demand shocks, precautionary demand shocks and the 10-year Belgian sovereign yield spread (the difference between the Belgian sovereign bond yield and the yield on the German Bund). The solid line (dashed line) shows the correlation that includes (excludes) the control variables related to the omitted variable bias issue. The time period spans from January 1999 to January 2016.

Figure 4.8: Time-varying correlations between oil price shocks and the 10-year sovereign yield spread of Finland



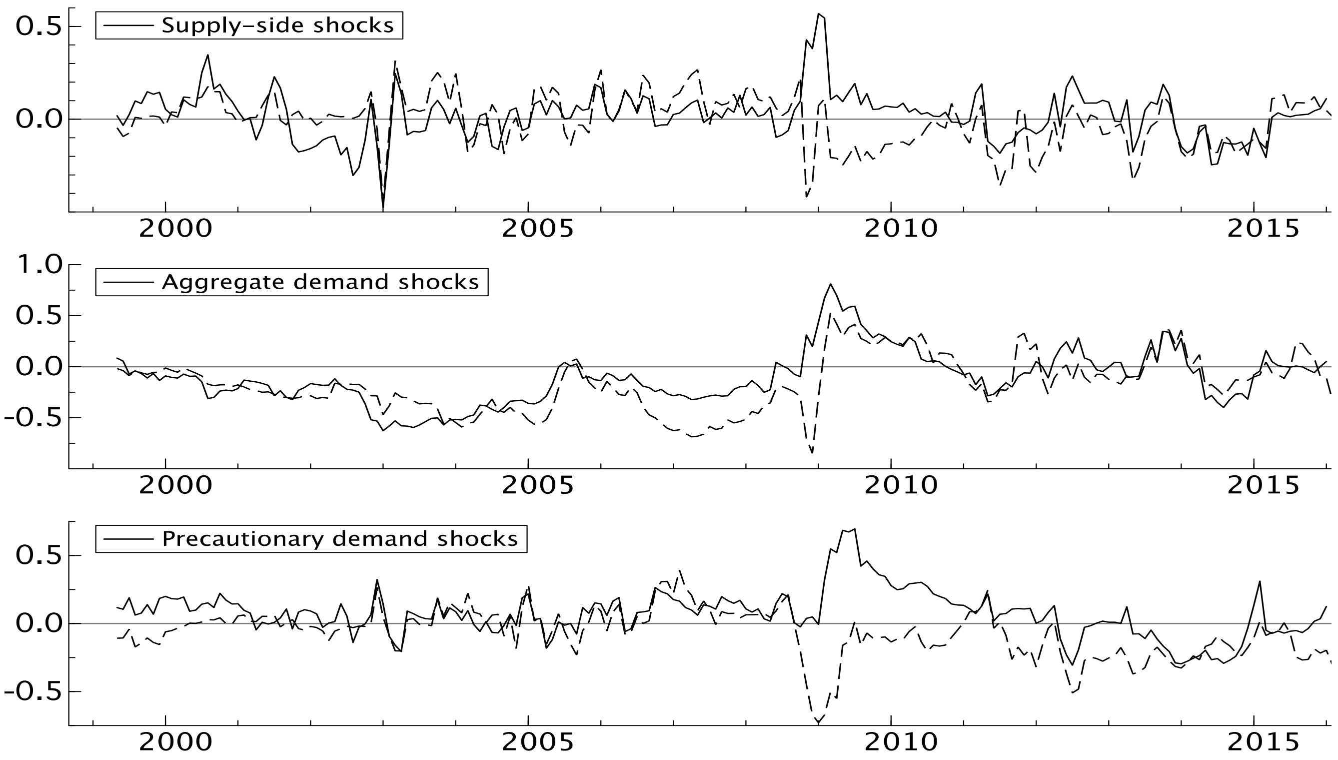
Note: This Figure depicts the time-varying correlation between supply-side shocks, aggregate demand shocks, precautionary demand shocks and the 10-year Finish sovereign yield spread (the difference between the Finish sovereign bond yield and the yield on the German Bund). The solid line (dashed line) shows the correlation that includes (excludes) the control variables related to the omitted variable bias issue. The time period spans from January 1999 to January 2016.

Figure 4.9: Time-varying correlations between oil price shocks and the 10-year sovereign yield spread of France



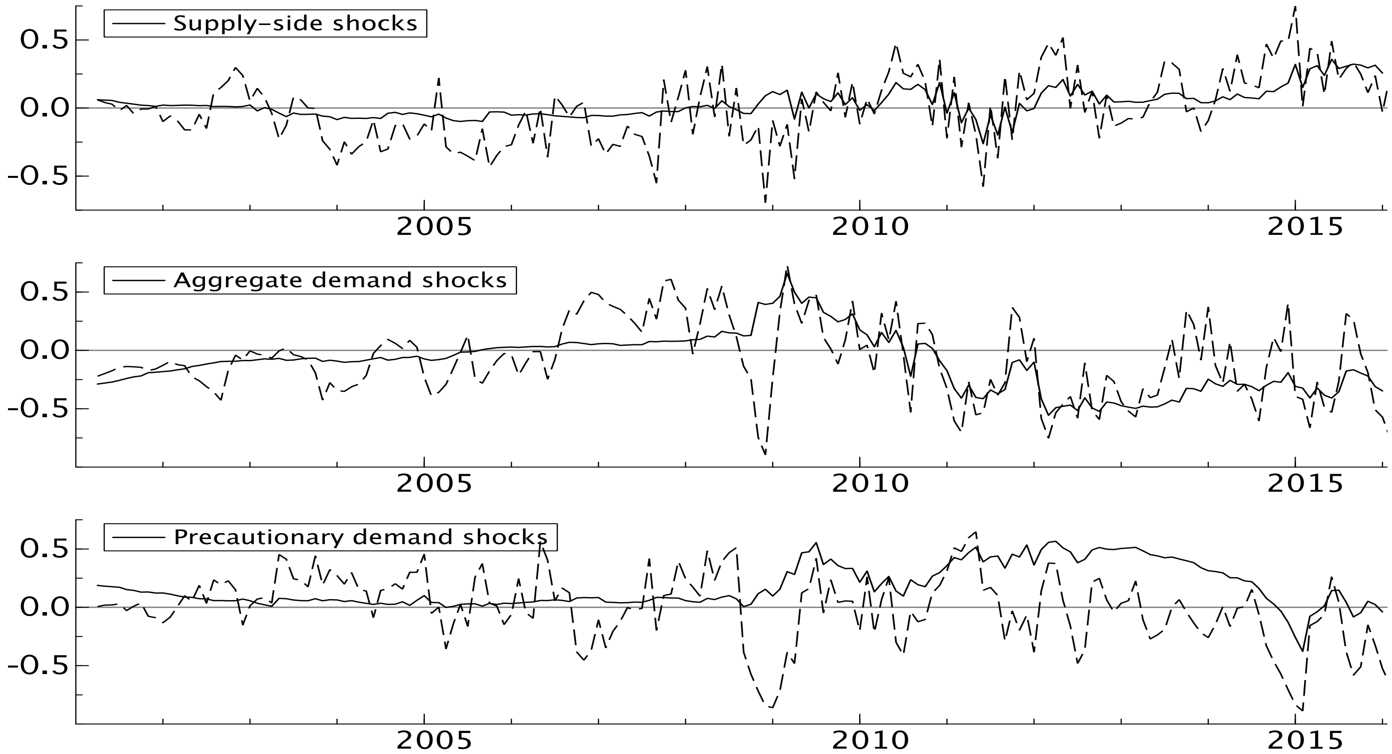
Note: This Figure depicts the time-varying correlation between supply-side shocks, aggregate demand shocks, precautionary demand shocks and the 10-year French sovereign yield spread (the difference between the French sovereign bond yield and the yield on the German Bund). The solid line (dashed line) shows the correlation that includes (excludes) the control variables related to the omitted variable bias issue. The time period spans from January 1999 to January 2016.

Figure 4.10: Time-varying correlations between oil price shocks and the 10-year sovereign yield spread of the Netherlands



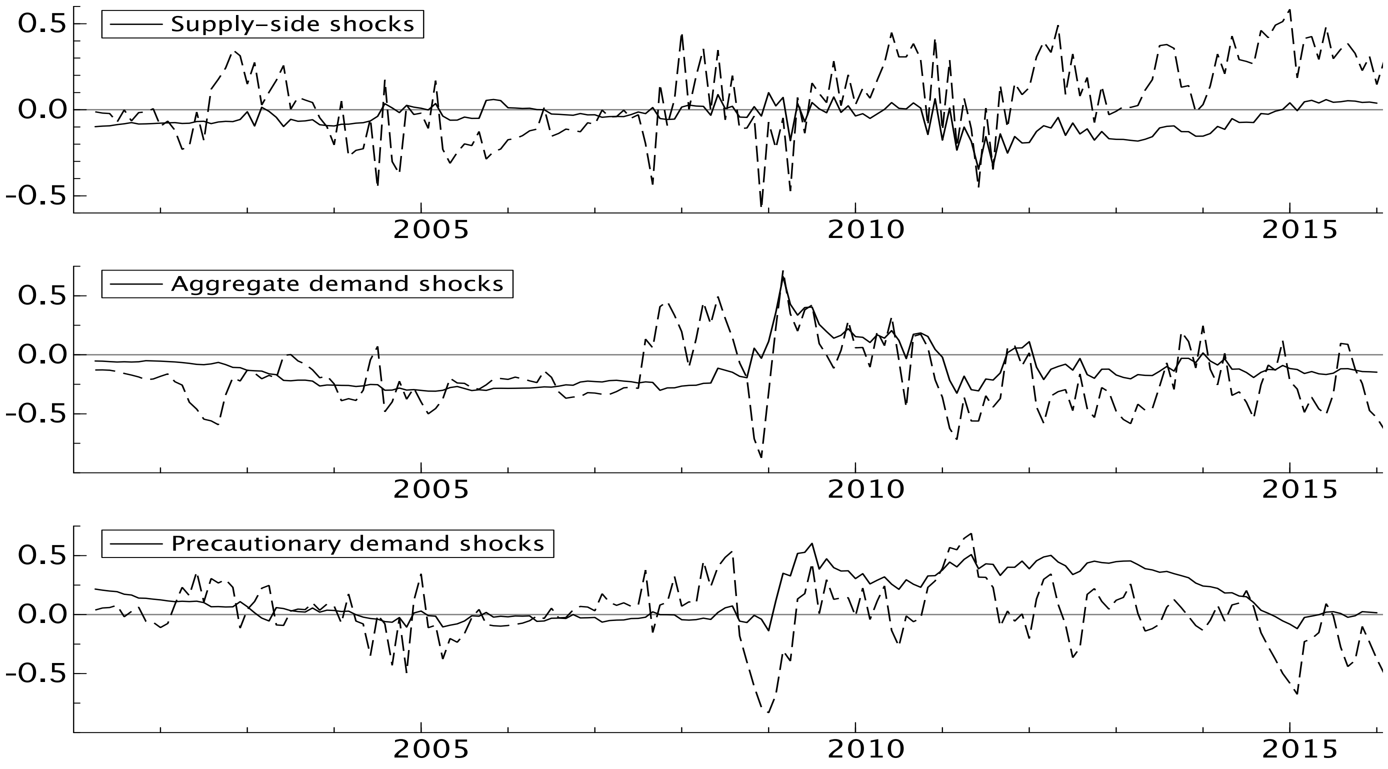
Note: This Figure depicts the time-varying correlation between supply-side shocks, aggregate demand shocks, precautionary demand shocks and the 10-year Dutch sovereign yield spread (the difference between the Dutch sovereign bond yield and the yield on the German Bund). The solid line (dashed line) shows the correlation that includes (excludes) the control variables related to the omitted variable bias issue. The time period spans from January 1999 to January 2016.

Figure 4.11: Time-varying correlations between oil price shocks and the 10-year sovereign yield spread of Greece



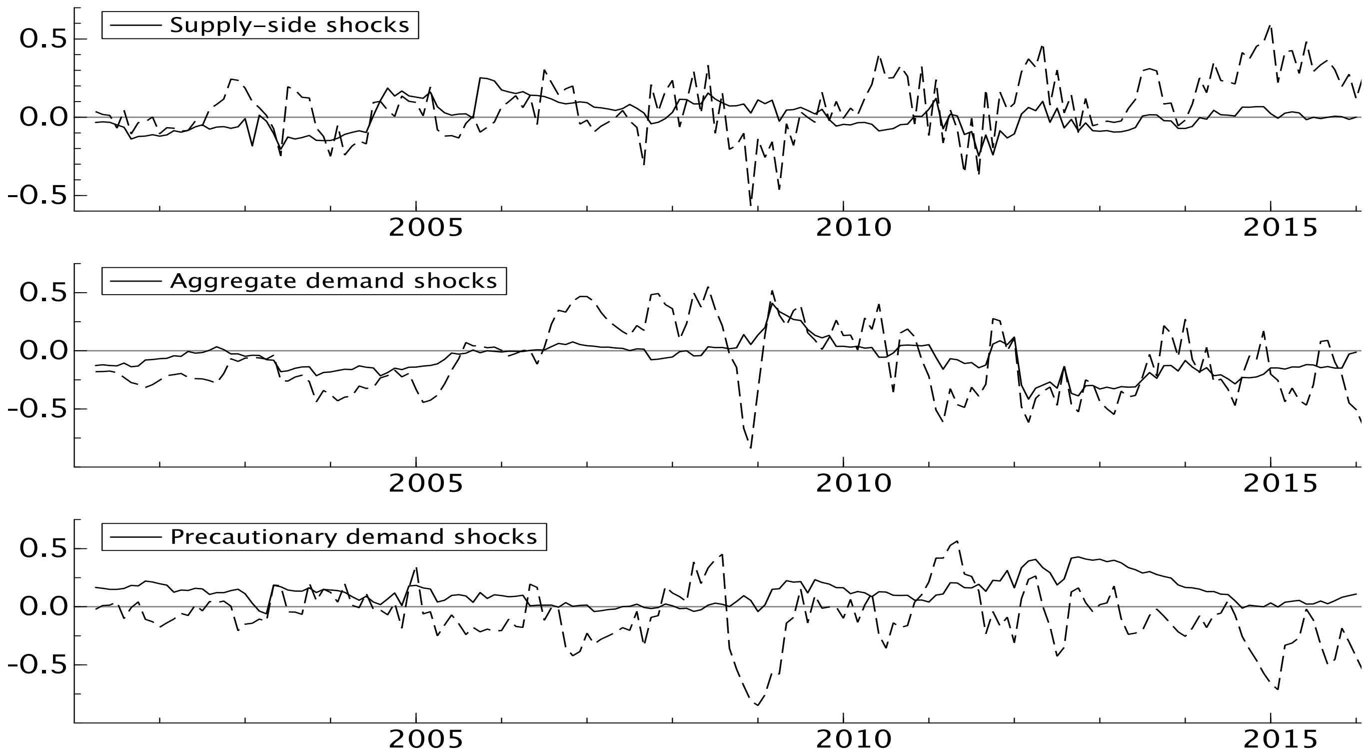
Note: This Figure depicts the time-varying correlation between supply-side shocks, aggregate demand shocks, precautionary demand shocks and the 10-year Greek sovereign yield spread (the difference between the Greek sovereign bond yield and the yield on the German Bund). The solid line (dashed line) shows the correlation that includes (excludes) the control variables related to the omitted variable bias issue. The time period spans from January 2001 to January 2016.

Figure 4.12: Time-varying correlations between oil price shocks and the 10-year sovereign yield spread of Ireland



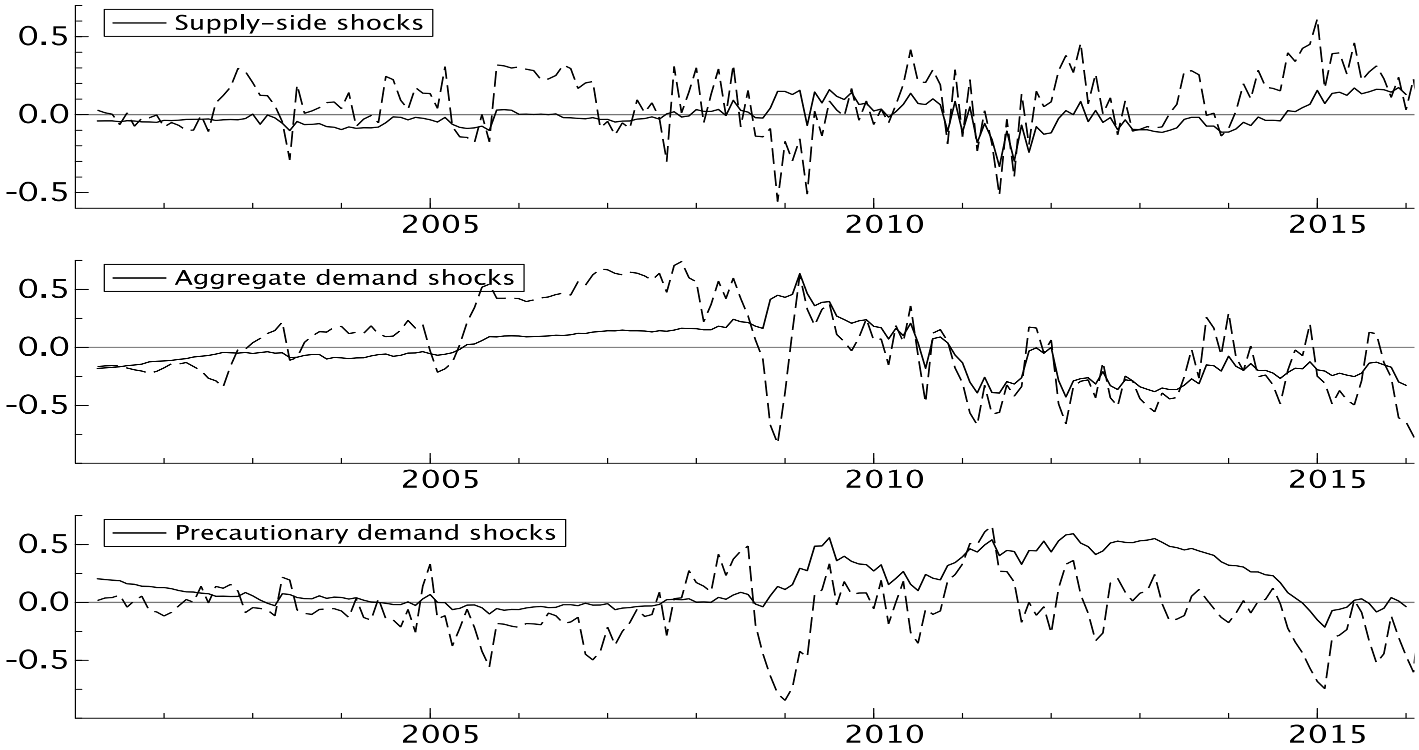
Note: This Figure depicts the time-varying correlation between supply-side shocks, aggregate demand shocks, precautionary demand shocks and the 10-year Irish sovereign yield spread (the difference between the Irish sovereign bond yield and the yield on the German Bund). The solid line (dashed line) shows the correlation that includes (excludes) the control variables related to the omitted variable bias issue. The time period spans from January 2001 to January 2016.

Figure 4.13: Time-varying correlations between oil price shocks and the 10-year sovereign yield spread of Italy



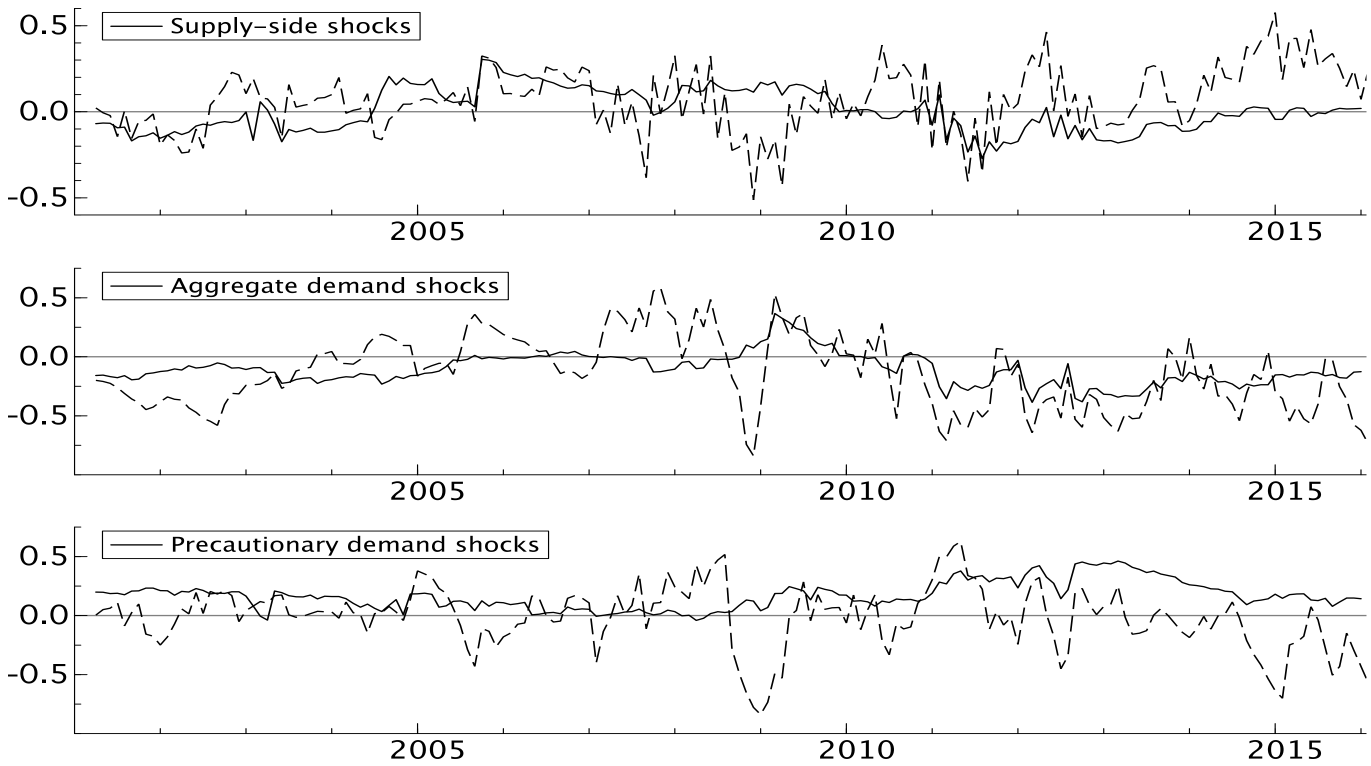
Note: This Figure depicts the time-varying correlation between supply-side shocks, aggregate demand shocks, precautionary demand shocks and the 10-year Italian sovereign yield spread (the difference between the Italian sovereign bond yield and the yield on the German Bund). The solid line (dashed line) shows the correlation that includes (excludes) the control variables related to the omitted variable bias issue. The time period spans from January 2001 to January 2016.

Figure 4.14: Time-varying correlations between oil price shocks and the 10-year sovereign yield spread of Portugal



Note: This Figure depicts the time-varying correlation between supply-side shocks, aggregate demand shocks, precautionary demand shocks and the 10-year Portuguese sovereign yield spread (the difference between the Portuguese sovereign bond yield and the yield on the German Bund). The solid line (dashed line) shows the correlation that includes (excludes) the control variables related to the omitted variable bias issue. The time period spans from January 2001 to January 2016.

Figure 4.15: Time-varying correlations between oil price shocks and the 10-year sovereign yield spread of Spain



Note: This Figure depicts the time-varying correlation between supply-side shocks, aggregate demand shocks, precautionary demand shocks and the 10-year Spanish sovereign yield spread (the difference between the Spanish sovereign bond yield and the yield on the German Bund). The solid line (dashed line) shows the correlation that includes (excludes) the control variables related to the omitted variable bias issue. The time period spans from January 2001 to January 2016.

Primarily, we focus our attention on some noteworthy features in order to paint an initial picture of the aforementioned relationship. It is evident that the correlations of both core and periphery countries are time-varying, which justifies the use of a dynamic rather than a static approach. Furthermore, we observe that the correlation patterns fluctuate and contain both positive and negative values. It is also apparent that correlations are influenced by the origin of the oil price shock and hence the trend of the correlations exhibits heterogeneous behaviour with respect to different oil price shocks during different time periods. More importantly, the differences in the two time-varying correlation lines suggest that the control variables are, on the whole, fundamental to determining the relationship between oil prices shocks and yield spreads. Therefore, these first observations provide support for the choice of our econometric framework and confirm that the origin of the oil price shock significantly matters to the correlation patterns and requires particular attention when we examine the link between oil prices and sovereign risk.

Turning our attention to country-specific time-varying correlations (focusing on the solid lines), it would seem that they do not provide support for our first hypothesis. In particular, the correlations are fluctuating very close to zero for all countries, except in the cases of France and Belgium (positive in the post-Great Recession period), as well as a clear negative correlation during 2001-2005, which is evident for all core countries. As far as the aggregate demand shocks are concerned, the results reveal that the second hypothesis seems to hold as on the whole, the correlations are negative. The only exception of substance is the 2009-2011 period, over which the correlations between aggregate demand shocks and yield spreads are positive. Finally, we maintain that our third hypothesis is largely confirmed since a positive correlation pattern is clearly exhibited for all countries, with very few exceptions (e.g., in France and Belgium during 2014-2015 and 2009, as well as in France, alone, during 2005-2006. Therefore, we document that the correlation patterns broadly show more conformity to our expectations regarding aggregate demand shocks and precautionary demand shocks, which reinforces our decision to construct and test three hypotheses.

It is interesting to observe that correlation levels are relatively close to zero until the beginning of the Great Recession, which primarily holds for the EMU periphery countries. This can be attributed to the fact that this period is closely related to the first years of transition to EMU and coincides with the convergence of sovereign bond yields (especially for the EMU periphery) and thus the minimisation of spreads (see, for example, Baele et al., 2004, Pagano and Von Thadden 2004, Codogno et al., 2003, Hartmann et al., 2003, Adam et al., 2002). Indeed, since the beginning of the transition until the early stage of the Great Recession, the difference between the 10-year bond yield issued by an EMU member-country and the German 10-year bond yield fluctuated within a very narrow range. In this regard, macroeconomic imbalances between core and periphery countries seemed to be ignored by the bond markets, which explains our findings of low or nearly zero correlation patterns between sovereign yield spreads and oil price shocks.

Furthermore, our results interestingly suggest that since the mid-2008 (which coincides with the most severe stage of the Great Recession) onwards, our correlations do not exhibit this low or almost zero patterns but instead they reveal moderate correlation levels with more volatile behaviour. Indeed, the deterioration of the macroeconomic fundamentals raised questions regarding the degree of financial integration of the

European government bond markets and shed more light into the actual relationship between sovereign yield spreads and oil price shocks.

4.5.2.2 Pre-Great Recession period

We continue our analysis by investigating the time-varying correlations between the sovereign yield spreads of core and periphery countries and different oil price shocks during specific episodes that were identified in the previous section. Initially, we refer to the pre-Great Recession period.

The early-2000 period is characterised by a recession in the world's largest developed economies (US and EMU) and is primarily associated with a negative aggregate demand shock, pushing oil prices to lower levels. The negative correlations of the bond yield spreads with the latter shock are justified by the fact that German bond market was perceived as a safe heaven, relative to the other European bonds. This implies that bond yields exhibited an increasing trend. However, the German Bund was less responsive to this event in comparison with the bond yields of the rest of the countries. Since this period does not imply important supply-side or precautionary demand events, our findings mostly reveal evidence of no correlation between sovereign yield spreads and supply-side or precautionary demand shocks.

Next, we focus on the terrorist attack of September (9/11) 2001 in the US, which exerted a strong negative impact on not only economic activity in the US but also output in the global economy, and caused, primarily, a precautionary demand shock, driving the oil prices towards higher levels. Our findings indicate, on the whole, a positive correlation between sovereign yield spreads and precautionary demand shocks, which is, as has been mentioned, in line with our initial expectations. Such behaviour is expected given that European countries, which are among the most prominent trade partners with the US, are expected to be impacted by the geopolitical uncertainty caused by the terrorist attacks. Once again, though, it is anticipated that Germany's economy, and hence its bond, would be less sensitive than the remaining European government bonds, leading the bond yield spreads to higher levels.

The next period covers the second war in Iraq that occurred in 2003, which is indicative of geopolitical uncertainty related to concerns about oil supply disruptions and consequently has the interpretation of a precautionary demand shock. Our results illustrate the expected correlations between sovereign yield spreads and the three oil price shocks. Interestingly, though, the largest peaks in the correlations between yield spreads and precautionary demand shocks are observed for the core EMU countries. This might suggest that the specific event caused more turbulence to the economies of these countries rather than the EMU periphery.

Continuing our analysis, we concentrate on the late-2005 period which featured the impact of the three Atlantic hurricanes, Katrina (August), Rita (September) and Wilma (October), and triggered supply-side shocks. We observe that, even though the anticipated correlations between sovereign yield spreads and the two demand-side oil price shocks are evident, the correlations with the supply-side shocks are mainly very close to zero. A plausible explanation for such a finding can be traced to the empirical evidence which suggests that supply-side shocks do not seem to trigger any responses from the financial markets. This is in line with previous studies which have confirmed the insignificant effects of supply-side shocks on stock markets (see, *inter alia*, Degiannakis et al., 2014, Filis et al., 2011). Therefore, oil supply disruptions during this period does not appear to raise concerns in the European government bond markets.

Finally, the period 2006-2007 is largely associated with the Chinese economic growth (rising demand for oil) and more generally the growth of emerging economies, which caused positive aggregate demand shocks. Our findings mainly confirm the anticipated negative correlations between sovereign yield spreads and aggregate demand shocks, although it is apparent that the correlations of the periphery countries are closer to zero. In fact, during this period the bond yields of core EMU countries, vis-a-vis the German Bund, are decreasing, while a flat yield spread is evident for the periphery countries. Hence, we maintain that this behaviour explains the higher magnitude of the correlations of the core countries, relative to the almost zero correlation level of the periphery countries. Furthermore, such a finding may be also explained by the fact that the Chinese economy is engaging more with the core EMU countries.

4.5.2.3 During and after the Great Recession

As far as the Great Recession (2007-2009) is concerned, we observe that during the second half of this period (i.e. late-2008 to 2009) a strong positive correlation (especially with the supply-side and aggregate demand shocks) between sovereign yield spreads and the three oil price shocks for all countries (with the exception of Belgium and France). This is a period when we experienced the collapse of the global oil prices from a peak of about $145 to $30 in less than a year, while at the same time bond yield spreads were also decreasing (particularly between German Bund and the bonds of the core EMU countries) in recognition that the Great Recession was coming to an end. The observed peak in most correlation figures during 2008-2009, while accommodating the effects of economic-related variables, provides further evidence of the close relationship between oil price shocks and bond yield spreads.

Continuing with the European debt crisis period that covers the remaining part of our sample period (2010-2016), we observe the considerable widening of the bond yield spreads, which coincided with several geopolitical events in the Middle East, as well as, the oil price slump in 2014-2015, when oil prices dropped by almost 75%. Having removed the potential effects of the economic-related variables (such as EPU, MPU and VOL), our findings reveal that the EMU bond yield spreads are strongly positively related to the precautionary demand shocks caused by the Middle East unrest. At the same time, given that this period also triggered negative aggregate demand shocks in the oil market, we further observe the anticipated negative correlations between sovereign yield spreads and aggregate demand shocks, which is particularly evident for the EMU periphery, possibly due to the fact that these economies are more vulnerable to abrupt changes in the oil market.

In addition, our findings suggest that the correlations between sovereign yield spreads and supply-side shocks during 2010-2016 are virtually zero for all countries, with the exceptions of the positive correlations in the cases of Belgium and France. The Arab Spring caused precautionary demand oil price shocks, as was mentioned earlier, while at the same time the real oil disruptions of the period also triggered some supply-side shocks. The fact that only Belgium and the French bond yield spreads are associated with the supply-side shocks can be explained by the fact that these are the two countries within our sample that have the strongest links with the Arab world. For instance, in

2015, about 34 million tons of crude oil which were imported to France came from the North Africa and the Middle East.[43]

Finally, with reference to the oil price slump of 2014-2015, it should be underlined that this period is dominated by aggregate demand shocks, as well as supply-side shocks. It is evident that during this period the correlation between bond yield spreads and precautionary demand shocks are reverting to zero, while the expected negative correlation with the aggregate demand shocks is mostly confirmed. Once again, the lack of strong correlations between the bond yield spreads and the supply-side shocks during 2014-2015 reveals the lack of importance of such shocks to the financial markets.

4.5.2.4 Some further remarks

Summarising our findings, we are able to point out one additional interesting feature. In particular, we do not observe noticeable differences in the correlation patterns between core and periphery countries, although more persistent positive or negative relationships are reported for the EMU periphery countries. A plausible explanation regarding the very little evidence of differentiation is that periphery countries appeared to be more dependent on oil imports (see, for instance, Gibson et al., 2012). In contrast, core countries might be less dependent on oil imports since they also use other sources of energy such as renewable or nuclear energy.[44] Reasonably, core countries will also be affected by oil price fluctuations. However, the magnitude of these responses is expected to be somewhat lower compared with those of periphery countries.

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[43] For more information, see: https://www.statista.com/statistics/745580/france-crude-oil-imported-by-region/

[44] The source of the information can be found on the Our Finite World site: https://ourfiniteworld.com/2012/03/05/why-high-oil-prices-are-now-affecting-europe-more-than-the-us/#comments

Hence, we provide support for a link between the oil market and sovereign risk. These new insights contribute greatly to the existing literature. For example, a number of recent studies which examine the link between oil and sovereign risk (i) do not concentrate their attention on the substantial European market which is, on aggregate, the largest oil-importer in the world, (ii) have not considered the disaggregation of oil prices to the different oil price shocks and (iii) have underplayed the importance of the time-varying approach. However, we have convincingly shown in this study that the aforementioned relationship is dependent on not only the different oil price shocks but also the different time periods when key economic and geopolitical events have taken place.

4.6. Conclusion

The aim of this study is to investigate the time-varying correlation between different shocks originating from the oil market and the 10-year sovereign yield spread of core and periphery countries in the EMU. We employ a set of five core countries (Austria, Belgium, Finland, France and Netherlands) and five periphery countries (Greece, Ireland, Italy, Portugal and Spain). In addition, we employ a set of control variables that impacts both the oil prices and sovereign yields, in order to capture the omitted variable bias issue. We use monthly data over the period from January 1999 to January 2016 for the core countries, whereas the sample period spans from January 2001 to January 2016 for the periphery countries. A scalar-BEKK time-varying framework is employed to explore the above relationship. Overall, this study expands the existing literature not only in examining the origin of the oil price change to test the aforementioned relationship but also in terms of introducing a time-varying rather than a static framework.

Our findings suggest some interesting empirical regularities. First, we cannot offer support to our first hypothesis regarding the negative correlation patterns between supply-side shocks and sovereign yield spreads. By contrast, our hypotheses regarding the two demand side shocks are generally supported by the evidence provided in this study. Second, the relationship between the different oil price shocks and sovereign yield spreads is indeed time-varying and depends on specific economic and geopolitical events that took place during the study period. Third, the correlation patterns appear to be less volatile in the pre-2008 period and passed into moderate and more volatile patterns in the post-2008 period. Finally, we do not observe important evidence of differentiation in the correlation patterns regarding the behaviour of core and periphery countries to different oil price shocks.

Our findings have important implications for financial market participants, in particular. For instance, it is worth noting that the time-varying correlations among oil price shocks and sovereign yield spreads could inform their dynamic asset allocation and portfolio diversification strategies. Therefore, although (high quality) sovereign bonds can act as a hedging instrument in periods of economic and geopolitical turmoil (see Bessler and Wolff, 2014), when bonds gain value, the degree to which they can be used to hedge risky investments will also depend on the oil price shocks over the period when such hedging is required. In addition, when contemplating investing in both oil and bond markets, consideration should be given to oil price developments, since aggregate demand shocks may serve in favour of great diversification opportunities (due to the negative correlations), whereas precautionary demand shocks could result in diminishing such opportunities (due to the positive correlations).

Further research may examine the time-varying relationship between oil prices (or their shocks) and the 10-year sovereign yield spread for economies that are not included in this study, such as Eastern European, North America, Asian and Latin America countries, as well as, for both oil-importing (i.e., China, Japan and the US) and oil-exporting countries (i.e., Norway, Russia, Canada and Mexico). The use of CDS spreads as an alternative proxy to measure sovereign risk is another promising area for further research. Finally, another avenue for future research may be to consider the examination of the time-varying correlation between oil prices changes and short-term sovereign yield spreads.

Chapter 5: Financial effects of precautionary demand for oil

5.1. Introduction

Since the seminal theoretical work by Barsky and Kilian (2002, 2004), and subsequently the quantitative analysis by Kilian (2009) followed by Hamilton (2009a,b) and Kilian and Park (2009), the origin of oil price shocks has become subject to intense debate in academic research and has further spurred a growing interest in the theme. Kilian (2009) disentangles three different types of oil price shocks, namely, supply-side shocks, aggregate demand-induced shocks and precautionary demand shocks. More specifically, supply-side shocks occur due to changes in world oil production, aggregate demand-side shocks arise from fluctuations in the global business cycle, while precautionary demand shocks are driven by concerns about the future availability of oil.

Although Kilian (2009) associates the precautionary demand shock with the convenience yield, he does not explicitly use the latter in his structural vector autoregressive model (SVAR). The convenience yield measures the benefits of holding barrels of oil. Brennan and Schwartz (1985) argue that the convenience yield refers to the benefits that accrue to the owner of the physical spot commodity (barrels of oil) but not to the owner of a future delivery of the commodity (oil futures contracts). In addition, Schwartz (1997) explains that the convenience yield depends on the scarcity of the barrels of oil and the changes in the inventory levels of the oil sector.

In this chapter, we evaluate the financial effects of a precautionary demand shock driven by the convenience yield. To this end, we build upon and extend Kilian's (2009) model that studies variation over time in precautionary demand shocks, along with supply-side and aggregate demand shocks. As aforementioned, precautionary demand shocks can be attributed to the uncertainty about the future availability of oil, which is generated by geopolitical unrest, primarily in the Middle East (e.g., the Arab Spring), but also elsewhere. Political tensions, conflicts and civil wars, not only in the Middle Eastern countries but also in North African region countries are only a few examples of severe concerns about shortages in future oil supply. Such events can cause an instantaneous increase in precautionary demand for oil, lead to greater demand for inventories and consequently trigger an immediate rise in the price of oil.

In particular, holders of barrels of oil (inventories) gain the value of the convenience yield (access to inventory holdings) which serves as an insurance premium against the aforementioned unexpected changes in the oil market. This allows oil producers to successfully overcome interruption or suspension of oil production, or to benefit from unanticipated variation in oil demand. The convenience yield makes the storage of oil more (less) valuable if market participants anticipate lower (higher) availability of oil in the future. Put it differently, the higher the uncertainty about the future availability of oil, the higher the oil convenience yield would be. As previously mentioned, precautionary demand for oil arises because of the uncertainty about the future availability of oil. Since the convenience yield measures the benefits associated with increasing expectations about future oil supply shortfalls and hence higher uncertainty in the oil market, it can be used to measure precautionary demand.[45]

[45]Alquist and Kilian (2010) employ a general equilibrium model to justify the extent to which shifts in expectations about future oil supply shortfalls can be explained by fluctuations in the convenience yield.

While research into the economic and financial effects of the oil price shocks on the economy is growing[46], the origins of precautionary demand and its economic and financial effects have received less attention. Specifically, our research is primarily motivated by Alquist and Kilian (2010) and Kilian (2009) who substantially clarify the nature of the precautionary demand shock in the oil market. As previously stated, Kilian (2009) associates shifts in precautionary demand with changes in the convenience yield, whereas Alquist and Kilian (2010) use the convenience yield in an empirical framework. In addition, our research is also related to Kilian and Murphy (2014) who disaggregate the precautionary demand into two components, namely the speculative demand shock and the idiosyncratic oil price shock. They introduce oil inventories in Kilian's (2009) framework in order to capture shifts in speculative demand, which are driven by speculative trading. The study by Kilian and Murphy (2014) is based on arguments which were presented by Alquist and Kilian (2010) arguments which indicate that speculative purchases may also be precautionary since they could represent increased uncertainty about future oil supply shortfalls. Furthermore, our study is influenced by Kilian and Park (2009), who include the US stock market block in their SVAR. Finally, our research is conceptually similar to Anzuini et al. (2015), who evaluate the macroeconomic effects of the precautionary demand for oil. Specifically, they use changes in the future-spot price spread to approximate for precautionary demand shocks.

[46] Several authors have considered the origin of the oil price shock to explain the impact of oil price shocks on the economy (see, among others, Antonakakis et al., 2017; Kang et al., 2017; Angelidis et al., 2015; Kang et al., 2015; Degiannakis et al., 2014; Abhyankar et al., 2013; Baumeister and Peersman, 2013; Wang et al., 2013; Basher et al., 2012; Broadstock et al., 2012; Filis et al., 2011; Kilian and Lewis, 2011 and Apergis and Miller, 2009).

Overall, the objectives of this chapter can be described as follows. First, we maintain that the convenience yield can approximate the precautionary demand shock and thus we disaggregate the Kilian's (2009) precautionary demand shock into two components, namely, the new precautionary demand shock (driven by changes in the convenience yield) and the idiosyncratic oil price shock. As previously noted, the convenience yield is used in order to capture shifts in precautionary demand which is not fully mentioned so far by the oil existing literature. Second, we use this innovation in order to test the responses of the US stock market returns and volatility to the new precautionary demand and idiosyncratic oil price shocks.

The choice of the US stock market block is influenced by the Kilian and Park (2009) empirical study which documents the distinct effects of different oil price shocks on US macroeconomic aggregates. Specifically, we employ the Standard and Poor's 500 and the Dow Jones Industrial Average index as the most commonly used benchmarks to measure the market capitalisation of the US stock market. Consequently, we employ their implied volatility indices to reflect investors' consensus view of expected stock market volatility. Thus, we also examine whether the responses of aggregate stock returns and volatility may differ greatly depending on the nature of the precautionary demand shock in the global oil market.

In the present study, we introduce the convenience yield which is thought of to capture uncertainty about the future scarcity of barrels of oil. For this purpose, we build on the recent study of Kilian (2009) and Kilian and Park (2009) by employing a SVAR model. We employ the 1-month, 2-month and 3-month futures contracts in order to estimate the convenience yield.[47] We use monthly data from January 1986 to December 2016. The chosen period is based on data availability.

The theoretical background and the contributions of this chapter can be described as follows. First, we disaggregate Kilian's (2009) precautionary demand shock into two components, namely, the new precautionary demand shock (driven by changes in the convenience yield) and the idiosyncratic oil price shock (caused by shocks to the real oil price). Second, we test how the US stock market returns and stock market volatility respond to precautionary demand and idiosyncratic oil price shocks. Third, our empirical models accommodate potentially large and disruptive effects of the global economic downturn of 2007-2009 (henceforth "Great Recession") on the status of the oil market as well as on the relationship between oil-market specific demand shocks and the US stock market performance. Thus, we investigate whether this decomposition causes changes in the crude oil market and whether the US stock market response to precautionary demand and idiosyncratic oil price shocks is qualitatively similar before and after the Great Recession.

The main findings are summarised as follows. First, a precautionary demand shock has a positive and significant effect on real oil returns for the 1-month, 2-month and 3-month futures contracts. Second, the convenience yield has significant information content about precautionary demand for oil. Third, both precautionary demand and

[47] This is due to the fact that the convenience yield is more responsive for supply/demand conditions and market price behaviour for shorter maturity futures contracts (see Milonas and Henker, 2001). Our choice for the selected contracts can be also attributed to the fact that futures contracts with shorter maturities (1-month, 2-month and 3-month) have significant information contents in predicting future movements and volatility in the spot price of oil (see Hammoudeh et. al., 2003). In addition, the selected contracts present higher trading volume and thus generate greater liquidity (see Hammoudeh and Yuan, 2008; Hammoudeh and Li, 2005) compared with futures contracts for other maturities.

idiosyncratic oil price shocks appear to have qualitatively different effects on stock market returns and volatility before and after the Great Recession. In fact, in the post-Great Recession, precautionary demand and idiosyncratic oil price shocks exert a positive effect on stock market returns, and a negative effect on stock market volatility, consistent with the financialisation hypothesis in the oil market.

The remainder of the chapter is structured as follows: Section 5.2 provides the review of the related literature. Section 5.3 presents the data and provides a preliminary analysis of variables used. The methodology is presented in Section 5.4. The empirical results are displayed in Section 5.5, while an in-depth discussion of the findings is provided in Section 5.6. Conclusions and points for further research are drawn in Section 5.7.

5.2. Literature review

5.2.1 The origins of oil price shocks

The seminal theoretical work by Barsky and Kilian (2002, 2004) which led to the first empirical structural analysis by Kilian (2009), as well as further empirical work by Hamilton (2009a,b) and Kilian and Park (2009), demonstrate that oil price fluctuations do not originate from the same source. Since then, the origin of the oil price shock, i.e. supply-side or demand-side shocks, has become a key research theme in energy economics. Indeed, fluctuations in the price of oil can originate either in the demand-side or in the supply-side of the economy.

Specifically, Kilian (2009) argues that supply-side and demand-side oil price shocks would generate different responses from the economy and the stock markets.

Industrialisation of the major emerging economies like China or India (see, for example, Kilian and Hicks, 2013)[48] – which reflect higher consumer spending and thus an increase in aggregate demand – illustrates the demand-side component of the crude oil price. By contrast, an oil supply disruption by global producers originated from geopolitical turmoil in the Middle East is an example of the supply-side component of the crude oil price.

In addition, Kilian (2009) identifies a third source of oil price shocks by further disentangling the demand-side oil price shock into the oil-market specific (precautionary or idiosyncratic) demand shock and the aggregate demand-induced oil price shock. The former occurs due to the uncertainty of future crude oil availability. The latter is driven by real economic activity. Kilian (2009) maintains further that oil price fluctuation during geopolitical events such as the Iranian Revolution and the time-line thereafter were caused by increased uncertainty of future oil availability (precautionary demand shocks) rather than physical supply disruptions (supply-side shocks).

Both Kilian (2009) and Hamilton (2009a,b) suggest that positive aggregate demand shocks are good news, despite the oil price increase, whereas Kilian (2009) posits that positive precautionary demand shocks tend to exercise a negative effect on economic activity. Furthermore, the magnitude of supply-side shocks appears to influence the economy less than the demand-side oil price shock. More specifically, Kilian (2009)

[48] Kilian and Hicks (2013) provide evidence that the unexpected increase in industrial commodity markets between 2003 and 2008 was mainly attributed to unexpected growth of Asian emerging economies such as China and India.

shows that demand-side driven oil price shocks tend to exercise more significant effects on oil prices than changes driven by shocks to the supply of crude oil.

5.2.2 The economic and financial effects of oil price shocks

Baumeister and Peersman (2013) and Kilian and Lewis (2011) illustrate the impact of oil price shocks on the economy. For example, Kilian and Lewis (2011) use a SVAR model to examine the effect of the real oil price fluctuations on US economic activity and inflation. They suggest that the US monetary policy does not receive any impact from oil price shocks since late 1980s and thus there is no effect on US real output and inflation. Along similar lines, Baumeister and Peersman, (2013) apply a time-varying parameter VAR to identify the effects of oil supply shocks on the US economy. They show that the variability in real oil prices since 1974 is better explained by the oil demand shocks, whereas oil supply shocks seem to impact the real oil prices in a smaller fraction. Furthermore, Filis and Chatziantoniou (2014) investigate oil-exporting countries (Norway and Russia) and oil-importing countries (UK, Germany, Netherlands, France, Italy, Spain, and Portugal) by employing a SVAR model. They indicate that the level of inflation is positively influenced by oil price changes in both oil-exporting and oil-importing countries. Studies related to the relationship between oil price shocks and the economy include papers by Degiannakis et al. (2014), Chen et al. (2014), Antonakakis and Filis (2013), Lippi and Nobili (2012), Kilian (2008a,b), Lescaroux and Mignon (2008) and Barsky and Kilian (2004).

Turning to the relationship between oil price shocks and stock markets, several authors utilise a SVAR model to study the effects of the various types of oil price shocks on stock market returns (see, among others, Abhyankar et al., 2013; Basher et al., 2012;

Apergis and Miller, 2009; Kilian and Park, 2009). They find that demand-side and supply-side oil price shocks have different effects on the stock market. Specifically, Kilian and Park (2009) show that demand-side oil price shocks cause a positive impact on the US stock market returns whereas supply-side shocks tend to provide a lower impact on stock returns. In addition, Basher et al. (2012) provide evidence of a positive (negative) effect of aggregate (precautionary) demand shocks on emerging market stock returns, whereas supply-side shocks do not have any influence on stock market returns. Furthermore, Abhyankar et al. (2013) find that oil price shocks driven by changes in aggregate demand have a positive effect on the Japanese stock market returns, whereas the stock market returns tend to react negatively to precautionary demand shocks.

By contrast, Apergis and Miller (2009) report that the stock market returns in eight developed countries do not respond significantly to aggregate demand, precautionary demand and supply-side oil price shocks. Authors such as Reboredo and Rivera-Castro (2014) investigate the relationship between oil markets and stock markets in Europe and the US by employing a wavelet multi-resolution analysis. They opine that stock market returns do not respond to oil price changes in the pre-financial crisis period (until June 2008) whereas a positive interdependence between oil and stock markets exists in the post-financial crisis period.

Wang et al. (2013), Filis et al. (2011) and Park and Ratti (2008) also illustrate the impact of oil price shocks on real stock returns by considering the country's position in the world crude oil market (i.e. oil-importing or oil-exporting). More specifically, Park and Ratti (2008) use a multivariate VAR and report that oil price shocks have a negative effect on stock market returns in the US and 12 European countries while oil price increases affect positively the stock market returns in Norway as an oil-exporting country. Furthermore, Wang et al. (2013) apply a SVAR and find that oil supply shocks depress stock market returns in both oil-importing and oil-exporting countries, whereas the impact of aggregate demand shocks on stock returns is negative and more persistent in oil-exporting countries than in oil-importing countries. With reference to the relationship between the oil price shocks and the stock market returns in a dynamic environment, Filis et al. (2011) employ a Dynamic Conditional Correlation asymmetric GARCH, or DCC-GARCH-GJR (Glosten, Jagannathan, and Runkle, 1993) model and find that the time-varying correlation does not differ between oil-exporting countries and oil-importing countries and further point out that demand-driven shocks exert a stronger influence on the correlation between oil and stock market returns than supply-side shocks.

Research on the relation between the various types of oil price shocks and stock market volatility is pioneered by Degiannakis et al. (2014). They employ a SVAR model and report that oil price shocks driven by aggregate demand tend to reduce stock market volatility of European stock markets whereas the precautionary demand and supply-side oil price shocks do not influence upon stock market volatility. Furthermore, Angelidis et al. (2015) use a SVAR model and suggest that when oil price shocks are disentangled they have the incremental power to forecast the state of the US stock market returns and the stock market volatility.

Moreover, Kang et al. (2015) use a SVAR model to test the effects of oil price shocks on the covariance of US stock market returns and volatility and suggest that positive aggregate demand and precautionary demand shocks affect negatively the covariance of return and volatility, whereas a disruption in oil production exercises a positive effect on the covariance of return and volatility. In a more recent study, Antonakakis et al. (2017) employing a SVAR model and focusing on 11 stock markets in either oil-importing and oil-exporting countries to examine the dynamic relationship between oil price shocks and stock market returns and volatility. They show that aggregate demand shocks (precautionary demand shocks, supply-side shocks) appear to be net transmitters of shocks to stock markets during economic recessions (geopolitical turbulence).

Furthermore, some studies closely related to our area of interest include papers by Anzuini et al. (2015) and Kilian and Murphy (2014). For example, Kilian and Murphy (2014) examine the role of speculative (inventory demand) shocks in order to capture shifts in expectations about future oil supply and demand. They use data for total US crude oil inventories scaled by the ratio of OECD petroleum stocks to US petroleum stocks as a proxy of speculative demand. The study by Kilian and Murphy (2014) is based on Alquist and Kilian (2010) arguments which indicate that speculative purchases may also be precautionary since they could represent increased uncertainty about future oil supply shortfalls. By employing a SVAR model they reveal that the oil price increase between 2004 and 2008 is driven by unexpected global demand shocks, whereas speculative shocks play an important role in the oil price fluctuations of 1979, 1986 and 1990.

Furthermore, Anzuini et al. (2015) examine the impact of precautionary demand shocks approximated by changes in the futures-spot price spread on US economic activity and inflation. They employ a two-stage identification procedure of a regression equation and a SVAR and use daily data over the period 1986-2008. They find that an unanticipated oil price increase driven by higher precautionary demand leads to a decrease in US economic activity 6 months after the impact and an immediate increase in CPI. In addition, they show that this shock raises oil inventories, depresses the stock market returns and increases stock market volatility.

Overall, we provide an alternative decomposition approach by including the convenience yield to approximate the precautionary demand shock in oil markets. Moreover, we expand the effect of precautionary demand shocks on the US stock market activity not only in the period before and during the peak of the Great Recession (e.g., the second half of 2008) as indicated by Anzuini et al. (2015) but also in the post-Great Recession. We seek to examine the consequences that the turmoil generated by the Great Recession brought to the US stock market. Thus, our research builds in this gap in order to provide some detailed evidence which have not been investigated so far in oil literature.

5.3. Data description and preliminary analysis

In this chapter, we collect monthly data for world oil production, global economic activity index, the crude oil spot price, the S&P500 index, the Dow Jones index, the VIX index and the VXD index. The sample runs from 1986:1 to 2016:12 a total of 372 observations. It is worth noting that the VIX index data series ranges from 1990:1 to 2016:12, whereas the VXD index data series ranges from 1998:1 to 2016:12 and this choice is driven by data availability. World oil production is used to identify oil supply shocks. Data on world oil production are obtained from the Energy Information Administration (EIA). Global economic activity index is constructed by Kilian

(2009).[49] We use this index to identify the aggregate demand-induced oil price shock. In the same spirit with Kilian (2009), we employ the refiner's acquisition cost of imported crude oil in the US as a proxy for oil spot price. Data on the spot price are extracted from EIA. We calculate the real oil price as the nominal oil spot price deflated by the US Consumer Price Index (CPI). Data on the US CPI is available from the Bureau of Labor Statistics of the United States.

The Standard and Poor's 500 (S&P500) index represents the performance of 500 stocks across all major industries in the US stock market, whereas the Dow Jones Industrial Average index represents the performance of 30 leading ("blue-chip") in their industry companies in the US stock market, including technology, financial services, retail, industrial and consumer goods. Both indices are considered as the most commonly basic benchmarks to measure the market capitalisation of the US stock market. Both series are retrieved from Datastream. The VIX index and the VXD index serve as key measures of the implied volatility of the S&P500 and the Dow Jones Industrial Average, respectively. Both indices are designed to reflect investors' consensus view of future (30-day) expected stock market volatility and considered as forward-looking variables. Data on VIX index and VXD index are retrieved from Datastream.

The convenience yield is chosen due to its information contents about future availability of the crude oil, which classifies the convenience yield as a forward-looking variable. Therefore, we use the convenience yield as a proxy of precautionary demand shocks (due to concerns about future availability of crude oil). The convenience yield is

[49] Kilian (2009) provides a detailed description of how the global economic activity index is constructed. The data can be found in Kilian's personal website (http://www-personal.umich.edu/~lkilian/).

computed from the oil spot price, the oil futures price and the risk-free interest rate. To this end, we retrieve the New York Mercantile Exchange (NYMEX) oil futures contracts of 1, 2 and 3 months to expiration as well the ICE LIBOR (Intercontinental Exchange, London Interbank Offered Rate) at 1, 2 and 3 months as a risk-free interest rate. Specifically, we follow Alquist et al. (2014) who argue that the LIBOR denotes a superior estimation of the borrowing costs experienced by firms in oil industry. Data on the oil futures prices and the interest rate are collected from Datastream. Finally, world oil production is seasonally adjusted and expressed in log-returns. Similarly, the oil spot price, the S&P500 index and the Dow Jones index are converted to real values and expressed in log-returns. In addition, the VIX index and the VXD index are expressed in natural logarithms.

To calculate the convenience yield (*CY*) in crude oil markets we adopt the recent approach proposed by Gospodinov and Ng (2013). This approach consists of calculating the net (of warehouse costs) percentage convenience yield as follows:

$$CY_{t,n} = \frac{(1 + \mathrm{i}_{\mathrm{t,n}})\mathrm{S}_{\mathrm{t}} - \mathrm{F}_{\mathrm{t,n}}}{\mathrm{S}_{\mathrm{t}}} \tag{1}$$

where $i_{t,n}$ is the risk-free interest rate set at time *t* with maturity *n*, S_t denotes the spot price of crude oil for delivery at time *t*, and $F_{t,n}$ denotes the futures price of crude oil set at time *t* for delivery at time *t+n*. Based on Fama and French (1988), the formulation of the convenience yield based on the assumption that the warehouse (storage space, insurance, transport, etc) costs are constant over time. This can be possibly attributed to the fact that warehouse costs are small in value and therefore inconsiderable, or data collection is hard to obtain due to the different types of warehouse costs.

Initially, we test the degree of integration of the variables by means of unit root tests. Results of the Augmented Dickey-Fuller (ADF), (Dickey and Fuller, 1981) and Phillips-Perron (PP), (Phillips and Perron, 1988) unit root tests are reported in Table 5.1 (Panels A and B). It is evident that the presence of a unit root for world oil production, real oil price, S&P500 index and Dow Jones index cannot be rejected. Both tests decisively reject the null of a unit root in the convenience yield, irrespectively of the maturity of a futures contract, in VIX index, in VXD index and in global economic activity index. Kilian and Murphy (2014) argue that the global economic activity index as a business cycle index is stationary by construction. This is because business cycles are deviations from the trend line and therefore stationary. Finally, the ADF and PP unit root tests show that the log-differences in world oil production, real oil price, S&P500 index and Dow Jones index are stationary.

Table 5.1: Augmented Dickey-Fuller (1981) and Philips Perron (1988) unit root tests.

			Panel A – ADF test			
	C		C&T		N	
PRO	-0.7501		-4.5001	**	2.0794	
ROP	-2.7242		-3.4659	**	-1.1875	
SP	-0.8971		-1.7887		1.1189	
DJ	-0.9254		-2.1900		1.3981	
DPRO	-20.5628	***	-20.5362	***	-20.3484	***
DROP	-11.9317	***	-11.9138	***	-11.9495	***
GEA	-3.5016	***	-3.4699	**	-3.5077	***
CYM1	-6.6748	***	-6.6636	***	-4.4464	***
CYM2	-5.9000	***	-5.9261	***	-4.8516	***
CYM3	-5.4718	***	-5.5333	***	-4.6493	***
RETSP	-21.0203	***	-21.0046	***	-20.8752	***
VOLVIX	-5.5524	***	-5.5415	***	-1.3737	
RETDJ	-20.9472	***	-20.9467	***	-20.7554	***
VOLVXD	-4.8114	***	-5.0750	***	-1.8705	*
			Panel B – PP test			
	C		C&T		N	
PRO	-0.3971		-4.2871		3.6002	
ROP	-2.1598		-2.9033		-1.1312	

SP	-0.9345		-1.8888		1.0892	
DJ	-0.8026		-2.0659		1.3919	
DPRO	-24.4754	***	-24.4608	***	-20.9779	***
DROP	-10.9617	***	-10.9341	***	-10.9879	***
GEA	-3.1386	**	-3.1192		-3.1442	***
CYM1	-9.2808	***	-9.2922	***	-7.3951	***
CYM2	-7.8473	***	-7.9271	***	-6.3782	***
CYM3	-6.8712	***	-6.9933	***	-5.6952	***
RETSP	-20.9710	***	-20.9572	***	-20.8089	***
VOLVIX	-5.3320	***	-5.3203	***	-1.4974	
RETDJ	-20.9738	***	-20.9764	***	-20.7399	***
VOLVXD	-4.5747	***	-4.8743	***	-1.4372	

Note: Unit root tests of world oil production (PRO), real oil price (ROP), S&P500 stock market index (SP), Dow Jones stock market index (DJ), world oil production growth (DPRO), real oil returns (DROP), global economic activity (GEA), convenience yield (CYM1, CYM2, CYM3), returns on the S&P500 stock market index (RETSP), VIX volatility index (VOLVIX), returns on the Dow Jones stock market index (RETDJ), and VXD volatility index (VOLVXD). M1 = one-month futures contract, M2 = two-month futures contract, M3 = three-month futures contract. For the ADF and PP unit root tests the null hypothesis is that the series features a unit root. In both tests, C denotes constant term, C&T denotes constant and time trend, N indicates no deterministic component in the test equation. Asterisk * (**, ***) denotes the 10% (5%, 1%) significance level. The sample period runs from January 1986 to December 2016. However, for VOLVIX (VOLVXD) index the period runs from January 1990 (1998) to December 2016.

Descriptive statistics are summarised in Table 5.2. With regard to S&P500 returns and Dow Jones returns, we observe a positive mean value which is indicative of the fact that both indices earn positive monthly returns on average. Real oil price changes are also have positive monthly average returns. The global economic activity index as a macroeconomic variable exhibits the highest volatility compared with the oil-market related variables and the financial variables. This is evident by the standard deviation, the minimum and maximum values. Furthermore, the convenience yield for the 3-month to maturity futures contract is more volatile than for the 1-month and 2-month to maturity contracts.

Our preliminary analysis suggests that the convenience yield is more volatile for longer maturity futures contracts, which is indicative of greater uncertainty about the future availability of crude oil. In addition, real oil returns, S&P500 returns and Dow Jones returns are negatively skewed, whereas similar results are observed for the convenience yield for the 1-month, 2-month and the 3-month to maturity. This can be possibly attributed to their frequent small gains and a few extreme losses. Skewness and Kurtosis statistics collectively indicate that the series are non-normally distributed. The observation of non-normality is confirmed by the Jarque-Bera statistic.

Table 5.2: Descriptive statistics of the series under investigation

	DPRO	DROP	CYM1	CYM2	CYM3	RETSP	VOLVIX	RETDJ	VOLVXD	GEA
Mean	0.0010	0.0004	-0.0542	-0.0539	-0.0526	0.0043	19.7830	0.0047	19.7737	-0.0049
Median	0.0012	0.0086	-0.0525	-0.0502	-0.0457	0.0082	17.5000	0.0083	17.8150	-0.0281
Maximum	0.0434	0.3747	0.2415	0.2399	0.2386	0.2349	63.6800	0.1667	52.9500	0.6636
Minimum	-0.0707	-0.3487	-0.3437	-0.3839	-0.4178	-0.2883	10.3200	-0.2539	9.8400	-1.3365
Std. Dev.	0.0098	0.0839	0.0871	0.0943	0.1023	0.0484	7.8008	0.0468	7.8881	0.2777
Skewness	-1.5648	-0.5918	-0.1088	-0.3359	-0.4836	-1.1713	1.9795	-0.9164	1.5205	-0.0738
Kurtosis	15.6886	5.6874	3.5058	3.4605	3.5387	11.2395	8.9877	8.0604	5.9392	4.3588
Jarque-Bera	2640.20***	133.30***	4.6982*	10.28***	18.99***	1134.29***	695.59***	447.77***	169.92***	33.32***
Probability	0.0000	0.0000	0.0955	0.0059	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

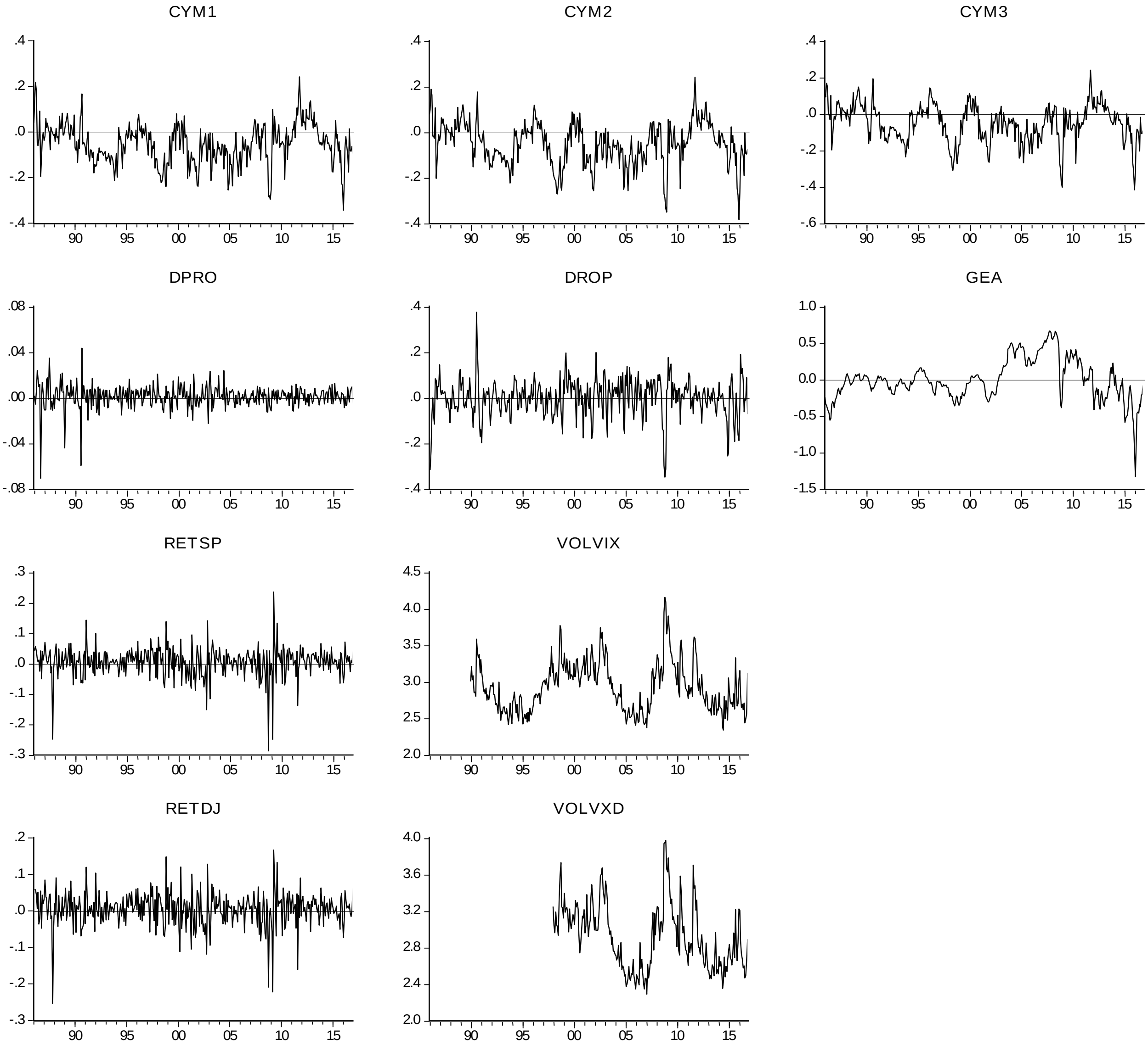
Note: This table summarises descriptive statistics (sample mean, median, maximum, minimum, standard deviation, skewness, kurtosis, the Jarque-Bera test statistic, and the p-value associated to the Jarque-Bera test statistic) of world oil production growth (DPRO), real oil returns (DROP), convenience yield (CYM1, CYM2, CYM3), returns on the S&P500 stock market index (RETSP), VIX volatility index (VOLVIX), returns on the Dow Jones stock market index (RETDJ), VXD volatility index (VOLVXD) and global economic activity (GEA). M1 = one-month futures contract, M2 = two-month futures contract, M3 = three-month futures contract. Asterisk * (**, ***) denotes the 10% (5%, 1%) significance level. The sample period runs from January 1986 to December 2016. However, for VOLVIX (VOLVXD) index the period runs from January 1990 (1998) to December 2016.

As aforementioned, the sample period runs from January 1986 to December 2016 and covers all major events that played an important role and caused changes in oil markets.[50] Figure 5.1 exhibits the time variation in the series in the sample period. It is evident that during the Great Recession, oil-market related variables (the convenience yield for all corresponding maturities and the real oil returns, apart from the world oil production changes) exhibit the highest volatility and extreme negative returns, the macroeconomic variable of the global economic activity index suffers a significant drop, the financial variables of the S&P500 returns and the Dow Jones returns are negative, highly volatile and exhibit significant troughs, whereas a peak is observed for the VIX index and the VXD index.

This preliminary analysis may suggest that during periods of severe recession oil markets move in the same directions with the financial markets (specifically, the relationship between real oil returns and stock market returns), which underlines the significant impact of the Great Recession in both markets. Having provided some preliminary findings, we proceed to the estimation of the empirical model.

[50] Oil price movements with important peaks and troughs are occurred due to the Persian Gulf Crisis of 1990-1991, the collapse of the Soviet Union, one of the three largest oil producers in the world in 1991, the Asian financial crisis of 1997-1998, the terrorist attack of September 2001, the second Iraq war (2003), the rising demand of oil from China (2006-2007), the Great Recession of 2007-2009, the OPEC's decision to cut its production quotas by 4.2 million barrels per day (2009), the Eurozone sovereign debt crisis in 2010, the increased supply of oil in North America (2010), the political instability in the Middle East of 2011, the continuing geopolitical unrest until 2014 and the appreciation of a US dollar by 10 percent together with the oil price collapse due to the decrease in global oil demand, both in the second half of 2014.

Figure 5.1: Time series employed in the study



Note: This Figure exhibits the evolution of the series during the sample period. In the first row, oil convenience yield (CY) is represented. In the second row, world oil production growth (DPRO), real oil returns (DROP) and global economic activity index (GEA) are depicted. In the third row, S&P500 stock market returns (RETSP) and implied volatility index (VOLVIX) are shown. In the fourth row, Dow Jones stock market returns (RETDJ) and implied volatility index (VOLVXD) are represented. M1 = one-month futures contract, M2 = two-month futures contract, M3 = three-month futures contract. The sample period runs from January 1986 to December 2016. However, for VOLVIX (VOLVXD) index the period runs from January 1990 (1998) to December 2016.

5.4. Methodology

To investigate the dynamic effects of the various types of oil price shocks, a SVAR framework motivated by Kilian (2009) is utilised. The SVAR approach is used to identify how the dependent variables in the system response to structural disturbances of the model. An advantage of the SVAR approach states on the need to impose restrictions required to the reduced form equation in order to control the structural parameters (innovations) of the model. These restrictions are related to contemporaneous relationships among the system's variables. The impulse response analysis detects the response of a variable to innovations in other variables or else the response of our variables to one standard deviation shock.

At this point, it is worth noting to provide the Kilian's (2009) framework in order to gain a clearer picture of our econometric approach. This framework features three dependent variables: changes in world oil production ($DPRO_t$), global economic activity index (GEA_t) and the real oil price (ROP_t). Therefore, we have the following representation:

$$e_t = \begin{bmatrix} e_{DPRO,t} \\ e_{GEA,t} \\ e_{ROP,t} \end{bmatrix} = A_0^{-1}\varepsilon_t = \begin{bmatrix} \alpha_{11} & 0 & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix} * \begin{bmatrix} \varepsilon_{SS,t} \\ \varepsilon_{AD,t} \\ \varepsilon_{PD,t} \end{bmatrix} \quad (2)$$

where,$\varepsilon_{SS,t}$ is the supply-side shock originated from the world oil production, $\varepsilon_{AD,t}$ is the aggregate demand shock caused by the global economic activity and $\varepsilon_{PD,t}$ represents the precautionary demand shock influenced by the real oil price.

Our SVAR model features four dependent variables: changes in world oil production ($DPRO_t$), global economic activity index (GEA_t), convenience yield (CY_t) and changes in the real price of oil ($DROP_t$). It should be mentioned that D represents the first difference between the values in month *t-1* and month *t*. Our SVAR differs from Kilian (2009) in using the convenience yield to identify the precautionary demand shock. In addition, we include the real oil returns instead of real oil price levels.

The SVAR form of order *k* (where the order *k* represents the appropriate number of lag length considered in the model) is given as follows:

$$A_0\, Z_t \;=\; \alpha_0 \;+\; \sum_{i=1}^{k} A_i\, Z_{t-i} \;+\; \varepsilon_t \tag{3}$$

where A_0 represents the (4x4) matrix which contains the contemporaneous relations among the coefficients, Z_t is the (4x1) vector of the four endogenous variables entering the SVAR model, i.e. Z_t= $(DPRO_t, GEA_t, CY_t, DROP_t)$, α_0 is the (4x1) vector for constants, A_i is the (4x4) matrix of coefficients to be estimated for *í = 1,2,3....k* , Z_{t-i} is the vector of lagged endogenous variables and ε_t is a (4x1) vector of the structural shocks (similarly, errors or innovations or disturbances) which are assumed to have zero covariance and be serially and mutually uncorrelated.

A reduced form representation of the structural model (2) is specified as:

$$Z_t \;=\; \beta_0 \;+\; \sum_{i=1}^{k} B_i\, Z_{t-i} \;+\; e_t \tag{4}$$

In order to get the equation (3) we require to pre-multiply all parts of the equation (2) by A_0^{-1}. This process implies that $\beta_0 \;=\; A_0^{-1}\alpha_0$, $B_i \;=\; A_0^{-1}A_i$, and $e_t \;=\; A_0^{-1}\varepsilon_t$

The latter describes the relationship between the structural shocks (ε_t) and the reduced form errors (e_t). The reduced form errors are linear combination of the structural shocks. Because the structural shocks are assumed to be orthogonal and therefore mutually uncorrelated, the variance covariance matrix of the structural shocks is required to be diagonal (each entry in the principal diagonal has the same variance of sigma square and the off-diagonal entries are zero). Overall, the matrix *D* is a diagonal matrix, σ^2denotes the variance and *E* is the unconditional expectations operation.

$$\mathrm{E}\,(\varepsilon_t \varepsilon_t') = \sigma^2 = \begin{bmatrix} \sigma_{SS}^2 & 0 & 0 & 0 \\ 0 & \sigma_{AD}^2 & 0 & 0 \\ 0 & 0 & \sigma_{PD}^2 & 0 \\ 0 & 0 & 0 & \sigma_{ID}^2 \end{bmatrix} = D \quad (5)$$

Similarly, the variance covariance matrix of the reduced form errors is:

$$E(e_t e_t') = E[(A_0^{-1}\varepsilon_t)'(A_0^{-1}\varepsilon_t)] = E(A_0^{-1\prime}\varepsilon_t' A_0^{-1}\varepsilon_t) = A_0^{-1}E(\varepsilon_t\varepsilon_t')A_0^{-1\prime}$$

$$= A_0^{-1}DA_0^{-1\prime} = \Omega \quad (6)$$

Although in the SVAR approach the structural shocks are assumed to be orthogonal and therefore mutually uncorrelated, this does not hold for the reduced form errors which are mutually correlated. This indicated by the matrix *Ω* which is a symmetric positive definite matrix (the entries above or below the principal diagonal are non-zero). Therefore, we impose a structural decomposition with aim to orthogonalise the reduced form errors. Equation (7) shows how the vector of reduced form errors (e_t) can be decomposed into structural disturbances (ε_t):

$$e_t = \begin{bmatrix} e_{DPRO,t} \\ e_{GEA,t} \\ e_{CY,t} \\ e_{DROP,t} \end{bmatrix} = A_0^{-1}\varepsilon_t = \begin{bmatrix} \alpha_{11} & 0 & 0 & 0 \\ \alpha_{21} & \alpha_{22} & 0 & 0 \\ \alpha_{31} & \alpha_{32} & \alpha_{33} & 0 \\ \alpha_{41} & \alpha_{42} & \alpha_{43} & \alpha_{44} \end{bmatrix} * \begin{bmatrix} \varepsilon_{SS,t} \\ \varepsilon_{AD,t} \\ \varepsilon_{PD,t} \\ \varepsilon_{ID,t} \end{bmatrix} \quad (7)$$

where,$\varepsilon_{SS,t}$ maps the supply-side shocks originated from the world oil production, $\varepsilon_{AD,t}$ represents the aggregate demand shocks caused by the global economic activity, $\varepsilon_{PD,t}$ denotes the precautionary demand shocks derived from the convenience yield and $\varepsilon_{ID,t}$ reflects the idiosyncratic oil price shocks caused by the real oil price.

Regarding our SVAR with convenience yield, the lower triangular matrix A_0^{-1} encompasses short-run restrictions that allow exactly identifying the structural shocks. Specifically, we identify these short-run restrictions by setting all entries located above the principal diagonal to zero. The restrictions are of recursive nature and may be explained as follows. First, due to the high adjustment costs and the unpredictability of the crude oil market, world oil production may not respond contemporaneously to aggregate demand shocks, precautionary demand shocks and idiosyncratic oil price shocks. World oil production is only instantaneously affected by supply-side shocks. The above recursive structure can be translated into the following restrictions: $\alpha_{12} = 0$, $\alpha_{13} = 0$, and $\alpha_{14} = 0$.

Second, global economic activity may not contemporaneously respond to precautionary demand shocks and idiosyncratic oil price shocks. The real economy requires time to react in uncertainty about the future oil supply shortfalls and real oil price changes. However, global economic activity is affected within the month by supply-side shocks and aggregate demand shocks. The ensuing restrictions are $\alpha_{23} = 0$ and $\alpha_{24} = 0$.

Third, the convenience yield is contemporaneously affected by supply-side shocks, aggregate demand shocks and precautionary demand shocks (own innovations), but not by idiosyncratic oil price shocks (real oil price changes). The convenience yield does not respond contemporaneously to oil price changes as it takes time for the market participants to adjust expectations about the future availability of oil based on the prevailing oil prices. The resulting restriction is $\alpha_{34} = 0$.

Finally, real oil price changes can be driven by supply-side shocks together with aggregate demand shocks, precautionary demand shocks and idiosyncratic oil price shocks (own innovations). For example, changes in global economic activity affect the real oil price due to the instantaneous response of the commodity markets. Thus, all types of shocks are allowed to contemporaneously impact on real oil returns. This is illustrated by non-zero coefficients in the fourth row.

At the next step of our analysis, we follow Kilian and Park (2009) to include the US stock market block. This SVAR allows the inclusion of stock market returns (measured by the S&P500 index or the Dow Jones index) or stock market volatility (measured by the VIX index or the VXD index) as a fifth variable in our SVAR model. This choice is justified by the fact that we want to test how the stock market returns and the stock market volatility respond to a precautionary demand shock and an idiosyncratic oil price shock.

$$e_t = \begin{bmatrix} e_{DPRO,t} \\ e_{GEA,t} \\ e_{CY,t} \\ e_{DROP,t} \\ e_{RET(VOL),t} \end{bmatrix} = A_0^{-1}\varepsilon_t = \begin{bmatrix} \alpha_{11} & 0 & 0 & 0 & 0 \\ \alpha_{21} & \alpha_{22} & 0 & 0 & 0 \\ \alpha_{31} & \alpha_{32} & \alpha_{33} & 0 & 0 \\ \alpha_{41} & \alpha_{42} & \alpha_{43} & \alpha_{44} & 0 \\ \alpha_{51} & \alpha_{52} & \alpha_{53} & \alpha_{54} & \alpha_{55} \end{bmatrix} \begin{bmatrix} \varepsilon_{SS,t} \\ \varepsilon_{AD,t} \\ \varepsilon_{PD,t} \\ \varepsilon_{ID,t} \\ \varepsilon_{RET(VOL),t} \end{bmatrix} \quad (9)$$

When we incorporate separately stock market returns and stock market volatility in our SVAR model, the restrictions in the lower triangular matrix A_0^{-1} (equation 9), can be explained as follows. In the first fourth rows, innovations in oil supply (supply-side shocks), global economic activity (aggregate demand shocks), inventory policies of the oil sector (precautionary demand shocks) and real oil prices (idiosyncratic oil price shocks) are not influenced by the stock market activity within one month period. As suggested by Kilian and Park (2009), this short-run restriction is indicated by the given aspect of considering innovations to the price of oil as predetermined with respect to US macroeconomic aggregates (including stock market returns and stock market volatility).

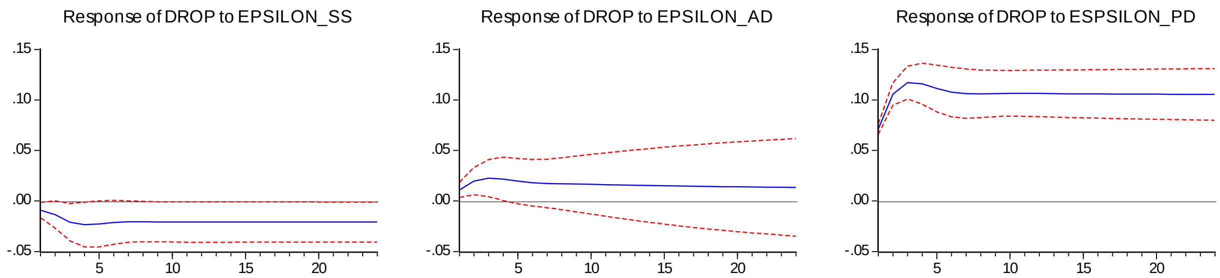
In the fifth row, stock market returns (RET) respond immediately to unexpected changes in all other variables. Stock market returns are contemporaneously influenced by macroeconomic news as well as innovations in the oil market (see Basher et al., 2012; Bjørnland, 2009). Similarly, stock market volatility (VOL) is assumed to respond contemporaneously to unanticipated changes, since the US stock market is a highly liquid market (see Degiannakis et al., 2014). In both SVAR model specifications, the Akaike Information Criterion (AIC) is employed to determine the lag order of the VAR model. We now turn to analyse our estimation results.

5.5. Empirical results

5.5.1 Benchmark SVAR

At the first step of our analysis we examine whether we can use the convenience yield to separate between precautionary demand shocks and idiosyncratic oil price shocks. To this end, we first consider Kilian's (2009) SVAR model with three endogenous variables, (the world oil production growth rate, the global economic activity index and the real oil returns) as our benchmark. It should be mentioned that we include the real oil price returns instead of the real oil price (levels) as suggested by Kilian (2009). Therefore, we adopt the term "benchmark" for this SVAR specification. Innovations to these three variables can be referred to as shocks to world oil production (supply-side shocks), to global economic activity (aggregate demand shocks) and to real oil returns (precautionary demand or idiosyncratic demand shocks). The structural impulse response functions are presented in Figure 5.2.

Figure 5.2: Structural VAR impulse responses based on benchmark SVAR



Note: The lines represent the accumulated impulse responses of the real oil returns (DROP) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD) and precautionary demand shock (EPSILON_PD) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles). The sample period runs from January 1986 to December 2016.

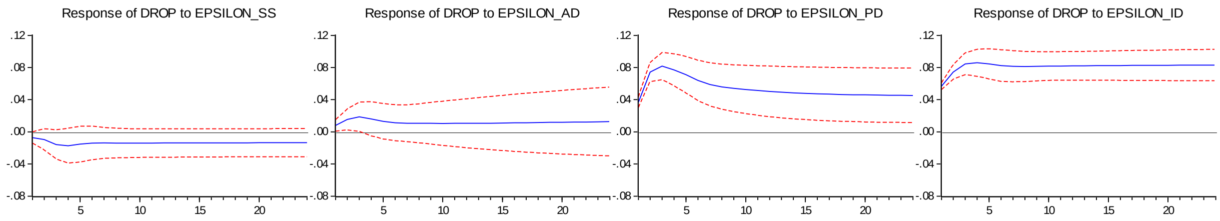
Figure 5.2 shows that a precautionary demand shock has a positive and significant effect on real oil returns. A more detailed scrutiny suggests that the variation of real oil returns varies from a low of 7.1% to a high of 11.7%. It is worth noting that Kilian (2009) uses real oil price levels and finds that a precautionary demand shock exerts a significant large and persistent positive impact on real oil prices and the variation in real oil price is consistent with our findings, although we use real oil returns. Consequently, we report that our results are qualitatively similar to those by Kilian (2009). We now extend our analysis by including the convenience yield, which is thought of to have information content that help disentangle the precautionary demand.

5.5.2 SVAR with the convenience yield

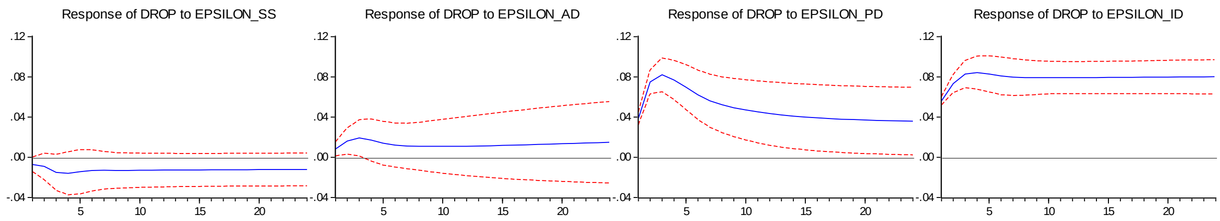
Figure 5.3 presents the response of real oil returns to a one standard deviation (one unit innovation) structural shock to world oil production (supply-side shocks), to global economic activity index (aggregate demand shocks), to convenience yield (precautionary demand shocks) and to real oil returns (idiosyncratic oil price shocks). Two-standard error bands are shown by dotted lines.

Figure 5.3: SVAR with the convenience yield

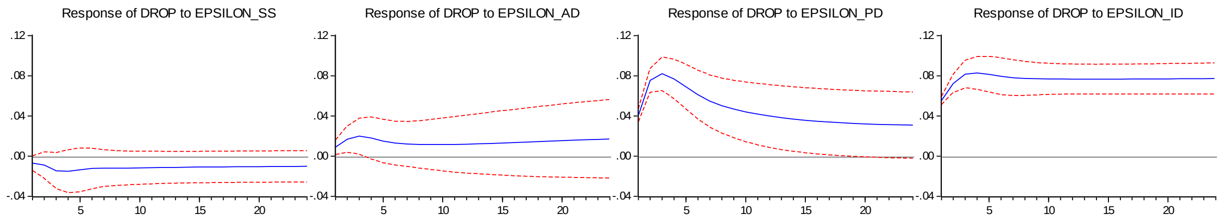
Panel A – Structural VAR impulse responses of the 1-month futures contract



Panel B – Structural VAR impulse responses of the 2-month futures contract



Panel C – Structural VAR impulse responses of the 3-month futures contract



Note: The lines represent the accumulated impulse responses of the real oil returns (DROP) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD) and idiosyncratic oil price shock (EPSILON_ID) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles). The sample period runs from January 1986 to December 2016.

5.5.2.1 Responses to oil supply-side shocks

Figure 5.3 shows a negative but insignificant response of real oil returns to an unanticipated positive oil supply shock, which represents technological advances to extract newly discovered reserves or the use of the existing reserves more efficiently.

This finding is consistent with the existing literature, which maintains that oil supply shocks do not inform changes in commodities and stock markets, and more generally changes in economic activity (see, for example, Antonakakis et al., 2014; Degiannakis et al., 2014; Baumeister and Peersman, 2013; Basher et al., 2012; Filis et al., 2011; Hamilton, 2009a,b; Kilian and Park, 2009).

5.5.2.2 Responses to aggregate demand shocks

We further observe from Figure 5.3 that an aggregate demand shock – possibly triggered by rising demand for crude oil due to the industrialisation of China and other emerging market economies during 2006-2007 – exerts a positive and significant (albeit in the short-term) effect on real oil returns. Increases in aggregate demand are regarded as positive news for the global economy, since they steer the economy through an economic expansion and give rise to a higher oil price. We therefore expect a positive response of real oil returns to an aggregate demand shock. This finding accords with the ex-ante expectation and is further supported by Kilian (2009) who also shows that an aggregate demand expansion triggers a positive, significant and persistent increase in the real price of oil.

5.5.2.3 Responses to precautionary demand shocks

Figure 5.3 also indicates that a precautionary demand shock – which signals increasing concerns about the future availability of oil – exerts a positive and significant effect on real oil returns. The response features a hump-shaped which peaks in the third month after a shock. An increase in the uncertainty about future oil supply shortfalls instigates a rise in the convenience yield, as oil market traders become more willing to pay for inventories (Anzuini et al., 2015).

Overall, a precautionary demand shock causes a positive and significant effect on real oil returns in both the SVAR with the convenience yield and benchmark SVAR. As earlier mentioned, the variation of real oil returns varies from a low of 7.1% to a high of 11.7% in benchmark SVAR, whereas the variability of real oil returns deviates between 3.7% - 8.2% (3.9% - 8.2%, 4.1% - 8.2%) for the 1-month (2-month, 3-month) futures contracts, regarding the SVAR with the convenience yield. It is worth pointing out that the largest response is attained three months after a shock, estimated at 11.7% (8.2%) for benchmark SVAR (SVAR with the convenience yield). It is worth mentioning that a precautionary demand shock has a stronger effect in benchmark SVAR than in the SVAR with the convenience yield.

A plausible explanation of this result could lie on the fact that in benchmark SVAR it is not possible to separate out an idiosyncratic oil price component. As a result, precautionary demand and idiosyncratic oil price shocks (coined as "a precautionary demand shock" in benchmark SVAR) collectively have a larger effect on real oil returns. By contrast, underlying our SVAR with the convenience yield is an identification strategy that allows identifying an idiosyncratic oil price component. Importantly, the significance of an idiosyncratic oil price shock could be a manifestation of a growing trend towards increased financialisation of the oil market.

In this regard, the financialisation of the oil market – which is allegedly triggered by the increased participation of hedge funds since 2003 – appears to alter the nature of the oil market. We provide an additional in-depth discussion on the financialisation of the oil market in Section 5.6. Since the idiosyncratic oil price component conveys information about speculative activity in the oil market, it may drive a wedge between the oil price and oil market fundamentals. Therefore, a historical decomposition is performed in Section 5.5.3 in order to shed light on the degree to which financialisation can influence real oil returns.

Overall, we should not lose sight of the fact that the convenience yield as a forward-looking variable associated with scarcity of crude oil contains information about developments in the physical oil market. More specifically, since the convenience yield represents the value of access to inventory holdings, it seems to be informative of changes in the level of crude oil inventories and therefore to changes in crude oil production. Thus, we do expect changes in the real oil price and consequently the real oil returns. This suggests that the convenience yield has the incremental power not only to inform about changes in current market conditions but also to forecast future developments. In this regard, we notice that the convenience yield is able to forecast future real oil returns. This is in line with Alquist et al. (2014) who examine the ability of convenience yields to interpret developments in the crude oil market fundamentals. They conclude that convenience yields have predictive power to explain changes in future crude oil inventories, future crude oil production, global demand for industrial commodities and the price of oil.

5.5.2.4 Reponses to an idiosyncratic oil price shock

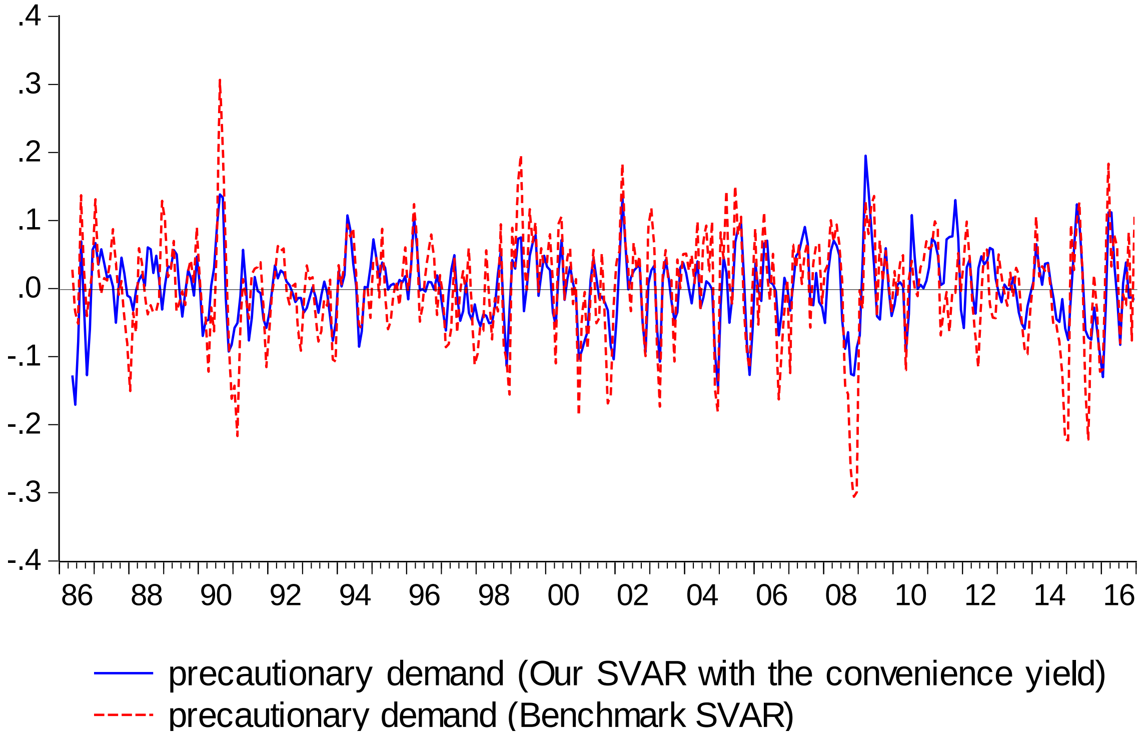
Figure 5.3 further reveals that an idiosyncratic oil price shock exercises a positive and significant effect on real oil returns for all futures contracts. Specifically, the response peaks at 8.5% (8.3%. 8.2%) three months after a shock for the 1-month (2-month, 3-month) futures contracts and then the effect levels off. Overall, our findings indicate that we are not able to capture the exact origin of precautionary demand, unless we disaggregate the precautionary demand into two components. As previously mentioned, the origin of the idiosyncratic oil price shock can be possibly attributed to the increased financialisation of the oil futures market and consequently to increased speculative activity. However, plausible explanations regarding the exact origin of this shock are required and need to be examined. At this stage, this information falls beyond the scope of this study.

5.5.3 Historical decomposition

In order to test the effect of all the oil price shocks (i.e. supply-side shocks, aggregate demand shocks, precautionary demand shocks and idiosyncratic oil price shocks) on real oil returns at each point in time a historical decomposition method is computed. Following Burbidge and Harrison (1985) and Kilian and Park (2009), this procedure requires three steps. First, we estimate a SVAR (see equation 3) which allows us to identify all oil price shocks. Second, based on the SVAR, we proceed to forecast the endogenous variables. Third, we decompose the forecast errors into the cumulative contribution of the aforementioned structural shocks. The cumulative effects from all oil structural shocks can be used to predict the behaviour of real oil returns. Therefore, the historical decomposition helps us to gather all relevant information regarding the above relationship.

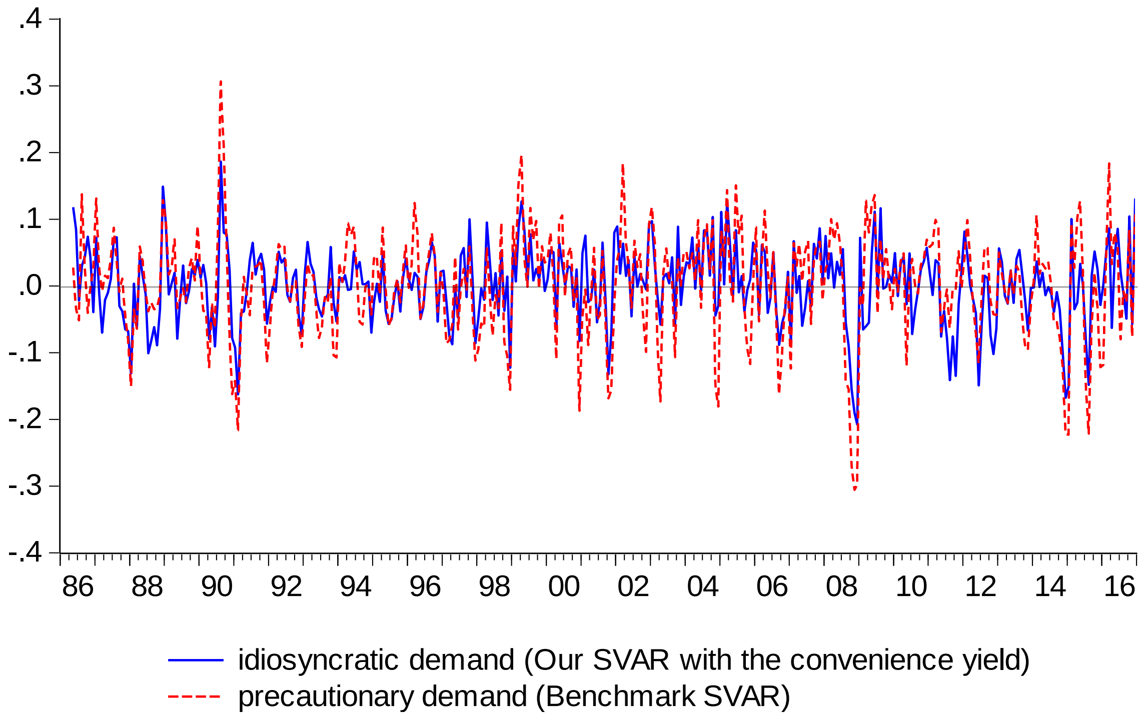
Figure 5.4 exhibits the historical decomposition of the precautionary demand (based on the SVAR with the convenience yield) shock for the 1-month futures contract and the precautionary demand shock based on the benchmark SVAR. Furthermore, the comparison between the historical decomposition of the idiosyncratic oil price shock regarding the SVAR with the convenience yield and the precautionary demand shock considering the benchmark SVAR is illustrated in Figure 5.5.

Figure 5.4: Historical decomposition of real oil returns



Note: This figure exhibits the precautionary demand component that results from a historical decomposition of real oil returns. The precautionary demand is estimated means of our SVAR with the convenience yield (solid blue line) and the benchmark SVAR (dashed red line). The convenience yield is constructed using data on the 1-month oil futures contract. The sample period runs from January 1986 to December 2016.

Figure 5.5: Historical decomposition of real oil returns



Note: This figure exhibits the precautionary demand and idiosyncratic demand components that result from a historical decomposition of real oil returns. The idiosyncratic demand is estimated means of our SVAR with convenience yield (solid blue line). The precautionary demand is estimated by means of the benchmark SVAR (dashed red line). The convenience yield is constructed using data on the 1-month oil futures contract. The sample period runs from January 1986 to December 2016.

Overall, our findings confirm that precautionary demand shocks based on the benchmark SVAR have a greater historical contribution to real oil returns compared to the precautionary demand shocks and idiosyncratic oil price shocks which are related to the SVAR with the convenience yield. The extent to which the SVAR with the convenience yield helps to identify precautionary demand shocks requires further attention. A comparison of our SVAR with the benchmark SVAR sheds light on the specific patterns, such as the period 1990-1991, the early-1999, the period late-2000 until early-2003, the Great Recession of 2007-2009 and the period from the second half of 2014 to early-2015, in which the precautionary demand shock was larger if the benchmark SVAR was used.

It should be noted that these patterns may not be influenced by Kilian's precautionary demand shocks. For instance, the period 1990-1991 is mainly associated with the Persian Gulf War. In this regard, Kilian and Murphy (2014) suggest that oil price fluctuations (a sharp increase in price) are strongly driven by flow supply shocks and moderately by speculative demand shocks in the episode of the invasion in Kuwait. They partly support evidence provided by Hamilton (2009a) who suggest that the oil price fluctuation during this period was attributed to supply shocks. Considering that supply shocks and speculative demand shocks appeared to be the main drivers of this period, we argue that precautionary demand shocks do not exercise any major effect on real oil returns during this period.

Moreover, an increase in oil price is observed in early-1999. This can be attributed to the agreement about a cut in oil production by OPEC and other oil-exporting countries during 1998. Overall, this agreement resulted in a decline in the world-wide oil production by 3.1 million barrels per day. Oil price changes originated by OPEC's production cuts are regarded as supply shocks. Thus, supply shocks seem to be a key driver of oil price fluctuations during this period.

As far as the period from late-2000 until early-2003 is concerned, we notice that there are episodes in which a downward pressure on oil price is observed, which can be attributed to oil production increases by OPEC members and non-OPEC producers. In addition, the recession that the developed countries experienced during that period was associated with a decrease in global demand growth. Thus, the observed variation over time in real oil returns over the above period was arguably driven by a combination of supply-side and aggregate-demand-induced oil price shocks. By contrast, precautionary demand shocks do not seem to influence the variation over time in real oil returns, as implied by the SVAR with the convenience yield.

Similarly, aggregate demand shocks appear to have a crucial role in explaining a sharp decline in oil prices around the peak of the Great Recession, which is also documented by Broadstock and Filis (2014). Moreover, we should not lose sight of the fact that the oil price trough is justified not only by changes in fundamentals but also by increased speculative activity[51], as illustrated by larger idiosyncratic oil price shocks.

We now turn the period from the second half of 2014 to the early-2015, which marks the end of a long period that began with the political instability in the Middle East in

[51] In July 2008, the report by Commodity Futures Trading Commission's (CFTC) indicate that increases in oil price during the period from January 2003 to June 2008 is largely attributed to the fundamental factors of supply and demand rather than speculative activity. However, due to the oil price peak of $145 per barrel and trough of $30 per barrel between July and December 2008, CFTC revised this report in 2009 by supporting the suggestion that oil price changes may be driven by financialisation (speculative activity) which induces oil prices to fluctuate above fundamentals. In this respect, Singleton (2013) argues that oil prices might be affected by increasing flows of funds from financial traders during 2008.

2011 and the continuing geopolitical unrest until mid-2014. Overall, this period appeared to raise fears about the future availability of oil and hence caused precautionary demand shocks to drive real oil returns. However, aggregate demand and supply factors seem to contribute significantly to a collapse in oil prices in the second half of 2014. Kilian and Baumeister (2015) argue that low global demand and positive supply-side shocks are associated with this episode. This indicates that precautionary demand shocks did not appear to instigate changes in the oil price during this period.

The above discussion prompts us to conjecture that precautionary demand shocks estimated by means of the SVAR with the convenience yield and the benchmark SVAR have different information contents. This conjecture can be verified by a more formal statistical test for equality of variances. First, we test for the equality of variances of precautionary demand shocks from the two aforementioned SVAR models. Second, we test if the idiosyncratic oil price shock in our SVAR and the precautionary demand shock in the benchmark SVAR have equal variances. A battery of tests we use comprises the F-test, the Bartlett test, the Levene test, and the Brown-Forsythe test. These tests assume homogeneous variance. Table 5.3 summarises the tests, which indicate that the null hypothesis is rejected. The tests provide evidence that precautionary demand and idiosyncratic oil price shocks estimated by means of our SVAR have different variation over time.

Table 5.3: Test for equality of variances			
Panel A - Precautionary demand shock (SVAR with the convenience yield) and precautionary demand shock (benchmark SVAR)			
Method	df	value	Prob
F-test	(367, 367)	2.2563	0.0000***
Bartlett	1	59.0681	0.0000***
Levene	(1, 734)	36.2832	0.0000***
Brow-Forsythe	(1, 734)	33.9786	0.0000***
Panel B – Idiosyncratic oil price shock (SVAR with the convenience yield) and precautionary demand shock (benchmark SVAR)			
Method	df	value	Prob
F-test	(367, 367)	1.8707	0.0000***
Bartlett	1	35.3696	0.0000***
Levene	(1, 734)	20.5567	0.0000***
Brow-Forsythe	(1, 734)	19.1700	0.0000***

Note: This table reports the results of testing for equality of variances. Panel A compares the variance between the precautionary demand shock in the SVAR with the convenience yield and the precautionary demand shock in the benchmark SVAR. Panel B compares the variance between the idiosyncratic oil price shock in the SVAR with the convenience yield and the precautionary demand shock in the benchmark SVAR. The test is measured by the F-test, the Bartlett test, the Levene test and the Brown-Forsythe test under the null hypothesis of variance homogeneity. If the null is rejected, there are significant differences in variances between the shocks. Degrees of freedom are denoted by (df). The p-value is associated to each test statistic. Asterisk * (**, ***) denotes the 10% (5%, 1%) significance level. The sample period runs from January 1986 to December 2016.

In addition, Table 5.4 summarises the value of variances related to the aforementioned shocks. Specifically, precautionary demand shocks based on the benchmark SVAR exhibit a higher variance compared to precautionary demand shocks and idiosyncratic oil price shocks in our SVAR with the convenience yield. This can be possibly attributed to the information contained in the convenience yield regarding market's valuation of holding oil inventories and generally market expectations about the physical oil market fundamentals including the price.

Table 5.4: Variance calculation of the oil price shocks

	Precautionary demand (SVAR with convenience yield)	Idiosyncratic demand (SVAR with the convenience yield)	Precautionary demand (benchmark SVAR)
Sum	0.4706	0.4549	0.4652
Obs	368	368	368
Mean	0.0013	0.0012	0.0013
Variance	0.0028	0.0034	0.0063
Std. Dev.	0.0530	0.0582	0.0796

Note: This table summarises descriptive statistics (sum, number of observations, mean, variance and standard deviation) of precautionary demand shocks and idiosyncratic oil price shocks (both based on the SVAR with the convenience yield) and precautionary demand shocks (based on benchmark SVAR). The sample period runs from January 1986 to December 2016.

In summary, the historical decomposition of real oil returns sheds light on the role of convenience yield as a key driver of precautionary demand shocks. In addition, while controlling for precautionary demand shocks, our modelling strategy helps to identify yet another important source of the variation over time in the real oil returns – idiosyncratic oil price shocks – that can be thought of capture speculative demand for oil. In particular, we claim that fundamental factors of global supply and demand together with speculative activity in the oil market can explain the variation over time in real oil returns. Thus, our results justify our consideration to disaggregate the precautionary demand into two components. Indeed, precautionary demand shocks (captured by the convenience yield) and idiosyncratic oil price shocks appear to provide a plausible explanation regarding the origin of precautionary demand.

5.5.4 Variance decomposition

Forecast error variance decomposition results for the variables under investigation in the SVAR model of the 1-month futures contract are reported in Table 5.5. The selected forecast period is related to 1, 3, 6, 12, 18 and 24 months in an attempt to identify the short-run and the long-run variation in our variables caused by each of the aforementioned shocks. We observe that the variation in world oil production growth is driven by its own (oil supply) shocks either in the very short-run or the very long-run. Specifically, this share remains above 96% for the overall selected forecast period. On the other hand, aggregate demand (precautionary demand, idiosyncratic oil price) shocks accounting for 0.43% (2.76%, 0.57%) for the last month of the selected forecast period.

In addition, fluctuations in global economic activity index are also attributed to its own (aggregate demand) shocks in shorter (1 month), medium (12 months) and longer (24 months) horizons. Overall, precautionary demand shocks and idiosyncratic oil price shocks together appear to explain about 10% at medium and longer horizons, whereas oil supply shocks do not seem to account for any variability in global economic activity index. Moreover, changes in the oil convenience yield are associated with its own innovations (precautionary demand shocks) and this share does not fall below 95% for the overall selected forecast period. The remaining three shocks do not generate any noticeable variation in the oil convenience yield.

Furthermore, the real oil price returns fluctuations are not totally attributed to their own shocks for the overall selected forecast period compared with the world oil production growth, global economic activity index and the oil convenience yield which are mostly explained by their own shocks in the same period. More specifically, own innovations account for a share of 68% in the first month which is the highest percentage whereas the same shocks generate up to 54% variation in each of the remaining selected months. We report that 28% of the variation in the real oil price returns is associated with the precautionary demand shocks approximated by the convenience yield in the first month only and then the effect remains constant around the share of 43% over the 24-month forecast period. Aggregate demand shocks and oil supply shocks do not generate any significant variability in the real oil price returns.

Turning our attention to the relationship between the oil convenience yield and the oil price, it is worth noting that precautionary demand as oil-specific uncertainty shocks play an important role in accounting for fluctuations in the real oil price returns.

Specifically, this shock drives a 43% persistent movement in the real oil price returns independently of the time period. This finding is also in line with conclusions documented by Alquist and Kilian (2010) that the real oil price movements are driven by oil uncertainty shocks (for example, uncertainty of future oil supply availability).

Table 5.5: Forecast error variance decomposition tests of the series under investigation, 1-month futures contract

Period	Oil supply shock	Aggregate demand shock	Precautionary demand shock	Idiosyncratic oil price shock
Panel A: Variance decomposition of world oil production growth				
1	100.00 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
3	97.491 (1.729)	3.356 (0.776)	1.607 (1.421)	0.543 (0.867)
6	96.267 (1.989)	0.489 (0.868)	2.671 (1.567)	0.572 (0.904)
12	96.174 (2.029)	0.493 (0.887)	2.757 (1.599)	0.574 (0.905)
18	96.163 (2.041)	0.493 (0.894)	2.768 (1.608)	0.574 (0.905)
24	96.162 (2.046)	0.493 (0.900)	2.769 (1.609)	0.574 (0.905)
Panel B: Variance decomposition of global economic activity index				
1	0.102 (0.535)	99.897 (0.535)	0.000 (0.000)	0.000 (0.000)
3	0.038 (0.581)	92.505 (2.694)	4.903 (2.106)	2.553 (1.435)
6	0.373 (1.068)	88.353 (4.758)	6.484 (3.433)	4.788 (2.725)
12	0.434 (1.243)	88.759 (5.383)	5.346 (3.987)	5.459 (3.348)
18	0.464 (1.299)	89.023 (5.590)	4.801 (4.259)	5.710 (3.526)
24	0.477 (1.321)	89.140 (5.706)	4.563 (4.422)	5.819 (3.599)
Panel C: Variance decomposition of the convenience yield M1				
1	0.446 (0.759)	1.576 (1.315)	97.977 (1.571)	0.000 (0.000)
3	1.006 (1.136)	3.332 (3.023)	95.417 (2.532)	0.243 (0.510)
6	0.869 (1.128)	2.829 (2.013)	96.047 (2.423)	0.252 (0.663)
12	0.840 (1.153)	2.819 (2.056)	96.020 (2.516)	0.319 (0.776)
18	0.838 (1.150)	3.072 (2.345)	95.728 (2.790)	0.360 (0.812)
24	0.838 (1.146)	3.269 (2.612)	95.509 (3.045)	0.382 (0.826)
Panel D: Variance decomposition of real oil returns				
1	1.070 (1.100)	1.326 (1.214)	28.920 (4.064)	68.682 (4.122)

3	1.426 (1.431)	1.934 (1.725)	42.063 (4.665)	54.539 (4.625)
6	1.538 (1.548)	2.181 (1.805)	42.778 (4.540)	53.501 (4.543)
12	1.529 (1.543)	2.173 (1.830)	43.118 (4.506)	53.178 (4.527)
18	1.528 (1.541)	2.175 (1.839)	43.138 (4.502)	53.157 (5.524)
24	1.528 (1.540)	2.178 (1.849)	43.138 (4.501)	53.154 (4.523)

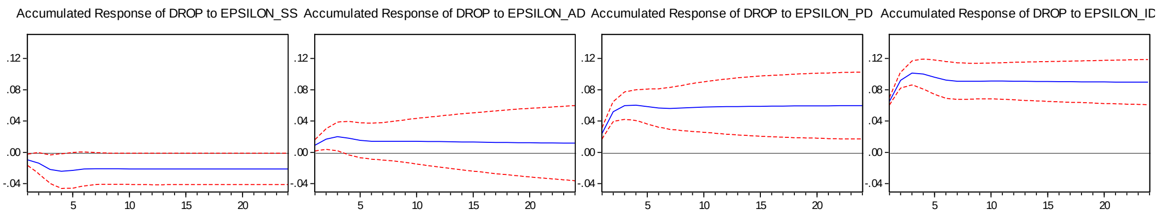
Note: The table reports the variation in world oil production growth, global economic activity index, convenience yield (M1) and the real oil returns driven by oil supply shocks, aggregate demand shocks, precautionary demand shocks and idiosyncratic oil price shocks. M1 = one-month futures contract. Standard errors are reported in parentheses and estimated by Monte Carlo simulations with 1,000 replications. The sample period runs from January 1986 to December 2016.

5.5.5 Robustness check

In order to evaluate the stability of our findings regarding the inclusion of the convenience yield as a measurement of the precautionary demand for oil, we consider the futures-spot basis (or spread) which is this price difference between futures price and spot price. Specifically, we consider the nearby or front month contract for the futures price. This proxy is similar to Anzuini et al. (2015), who use changes in the future-spot price spread to approximate for precautionary demand shocks. Robustness check results are summarised in Figure 5.6 and illustrate that a precautionary demand shock exerts a positive and significant impact on real oil returns. This is in line with our findings in Figure 5.3 regarding the SVAR with the convenience yield in which a precautionary demand shock causes a positive and significant effect on real oil returns. In a more detailed analysis, the SVAR with the convenience yield (futures-spot spread) leads to a rise of 4% (2.5%) on impact and 8% (6%) in month 3 to real oil returns. Thereafter, this impact staying permanently to 5% (6%) for the overall selected forecast period. Overall, we argue that our results are qualitatively similar for both SVARs.

Figure 5.6: SVAR with futures-spot spread

Structural VAR impulse responses of the 1-month futures contract



Note: The lines represent the accumulated impulse responses of the real oil returns (DROP) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD) and idiosyncratic oil price shock (EPSILON_ID) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles). The sample period runs from January 1986 to December 2016.

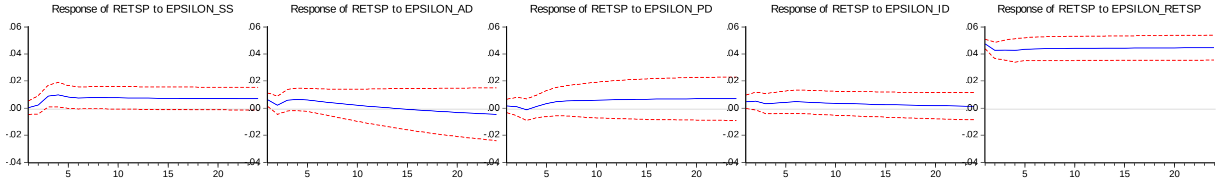
5.5.6 The response of stock market returns

We start with the response of stock market returns to a one standard deviation structural shock to convenience yield and real oil returns (see Figures 5.7 for the S&P500 and 5.8 for the Dow Jones). We observe similar patterns which are suggestive of the fact that throughout the overall study period, there is not any notable difference between the indices regarding their response to precautionary demand shocks (captured by the convenience yield) and idiosyncratic oil price shocks.

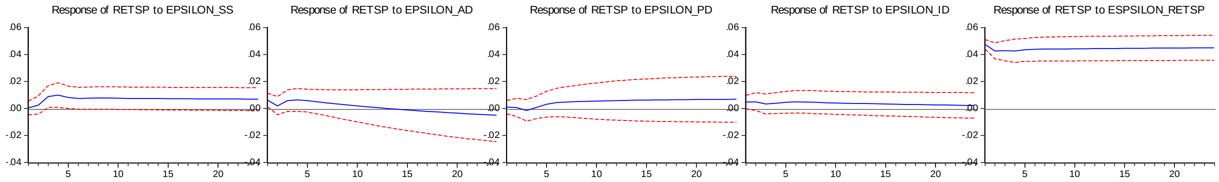
More specifically, for the 1-month, the 2-month and the 3-month futures contracts, precautionary demand shocks and idiosyncratic oil price shocks do not seem to exercise any significant effect on stock market returns for a time period up to 24 months. These findings are not in line with the existing literature (see, for example, Abhyankar et al., 2013; Basher et al., 2012; Filis et al., 2011; Kilian and Park, 2009), which documents that stock market returns tend to respond negatively to increasing precautionary demand shocks, as this is measured by Kilian (2009).

Figure 5.7: SVAR impulse responses of returns on the S&P500 stock market index: 1986:1 – 2016:12

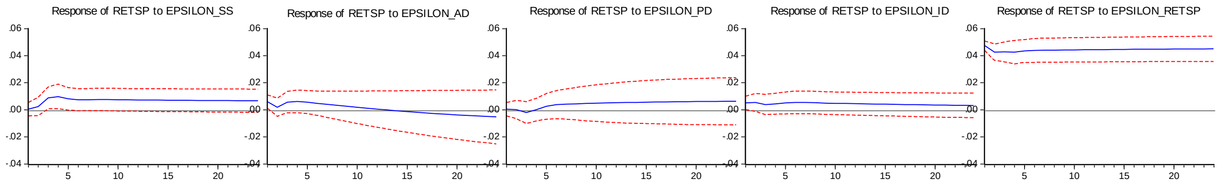
Panel A – Structural VAR impulse responses of the 1-month futures contract



Panel B – Structural VAR impulse responses of the 2-month futures contract



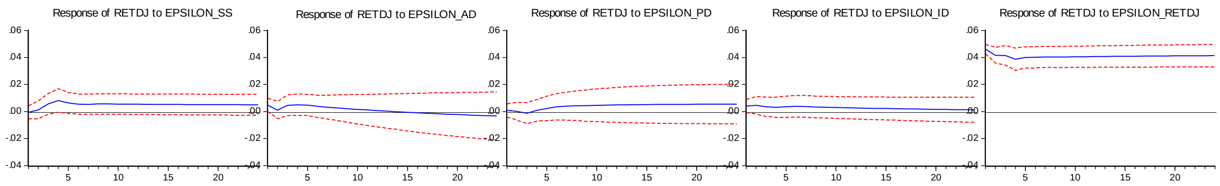
Panel C – Structural VAR impulse responses of the 3-month futures contract



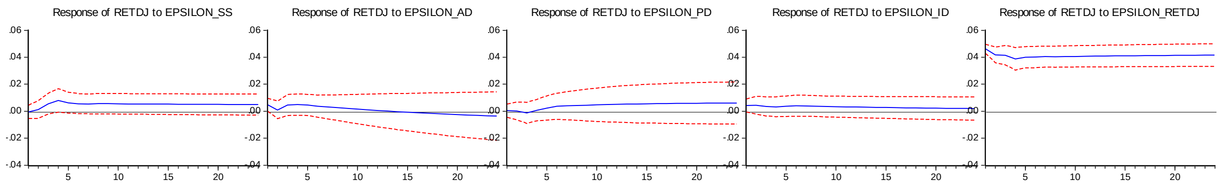
Note: The lines represent the accumulated impulse responses of returns on the S&P500 stock market index (RETSP) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD), idiosyncratic oil price shock (EPSILON_ID) and shock to returns on the S&P500 index (EPSILON_RETSP) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles).

Figure 5.8: SVAR impulse responses of returns on the DJ stock market index: 1986:1 – 2016:12

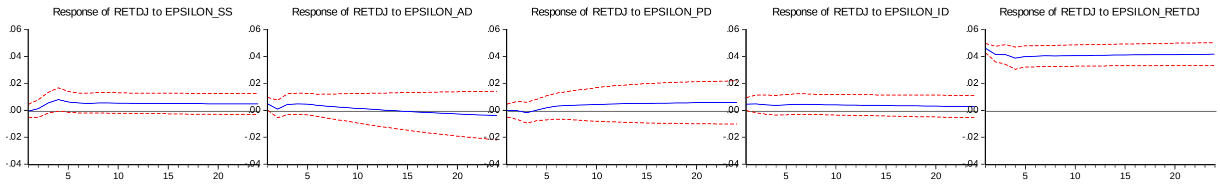
Panel A – Structural VAR impulse responses of the 1-month futures contract



Panel B – Structural VAR impulse responses of the 2-month futures contract



Panel C – Structural VAR impulse responses of the 3-month futures contract



Note: The lines represent the accumulated impulse responses of returns on the Dow Jones stock market index (RETDJ) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD), idiosyncratic oil price shock (EPSILON_ID) and shock to returns on the Dow Jones index (EPSILON_RETDJ) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles).

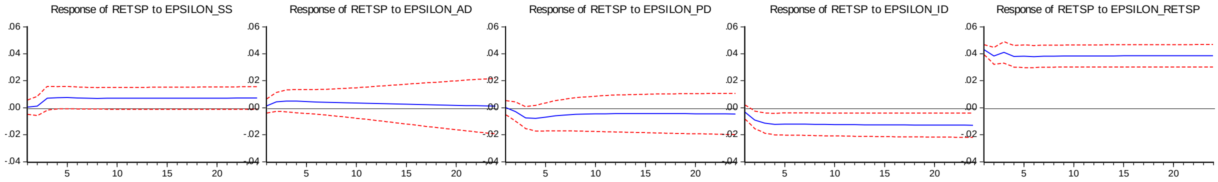
We now turn our focus on the Great Recession period. The choice of this period accords with our preliminary analysis which suggests that during periods of severe recession oil markets move in the same direction with the stock markets. Specifically, both markets are affected negatively due to increasing uncertainty caused by the Great Recession. We consider that this period is expected to paint a clear picture regarding the effects of precautionary demand shocks and idiosyncratic oil price shocks on stock market returns. As a result, our sample is divided into two sub-periods, the pre-Great Recession period from 1986:1 to 2008:8 and the post-Great Recession period from 2008:9 to 2016:12.[52]

The initial period of our interest is the pre-Great Recession period from 1986:1 to 2008:8. The impulse response functions in Figures 5.9 (S&P500) and 5.10 (Dow Jones) indicate a negative and significant response of the stock market returns to an idiosyncratic oil price shock for all maturities, whereas the response of the precautionary demand shock is negative and significant in the short-term. Our findings are in line with the previously mentioned studies that support the general consensus which indicates a negative correlation between stock market returns and oil-market specific demand shocks (precautionary demand shocks and idiosyncratic oil price shocks).

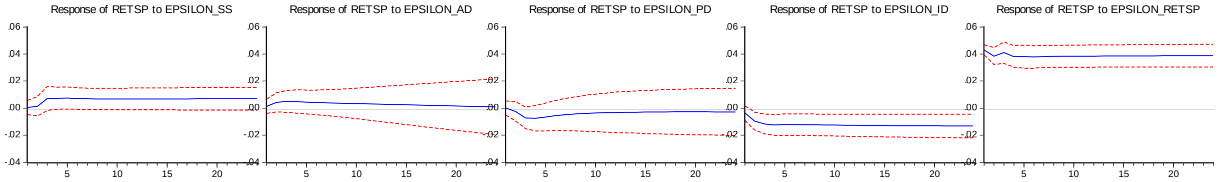
[52] According to the National Bureau of Economic Research (NBER), the Great Recession in the US lasted from December 2007 to June 2009. Although the financial crisis started in the US with the subprime mortgage crisis in July 2007, the most critical stage of the financial crisis began with the collapse of the investment bank Lehman Brothers in September 2008 and turned into a global financial crisis. This is in line with Reboredo and Ugolini (2016) who also suggest a similar date to distinguish between the period prior to and after the global financial crisis.

Figure 5.9: SVAR impulse responses of returns on the S&P500 stock market index: 1986:1 – 2008:8

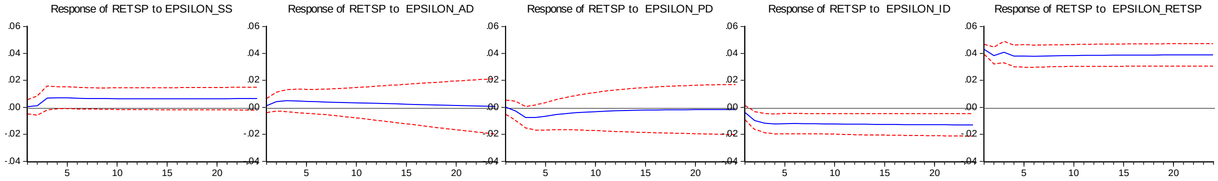
Panel A – Structural VAR impulse responses of the 1-month futures contract



Panel B – Structural VAR impulse responses of the 2-month futures contract



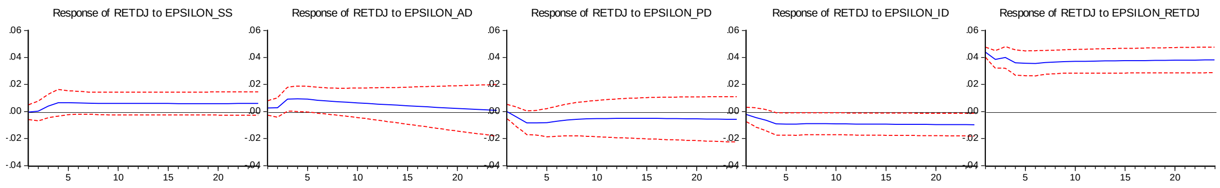
Panel C – Structural VAR impulse responses of the 3-month futures contract



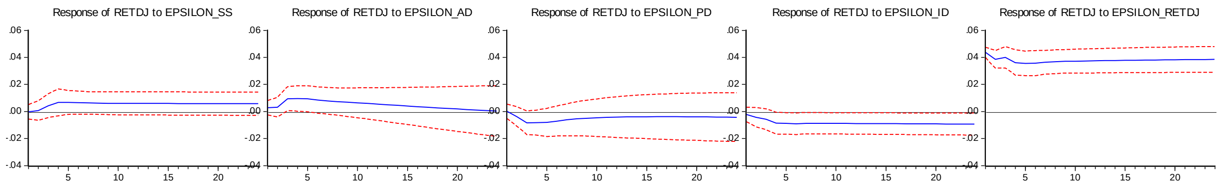
Note: The lines represent the accumulated impulse responses of returns on the S&P500 stock market index (RETSP) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD), idiosyncratic oil price shock (EPSILON_ID) and shock to returns on the S&P500 index (EPSILON_RETSP) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles).

Figure 5.10: SVAR impulse responses of returns on the DJ stock market index: 1986:1 – 2008:8

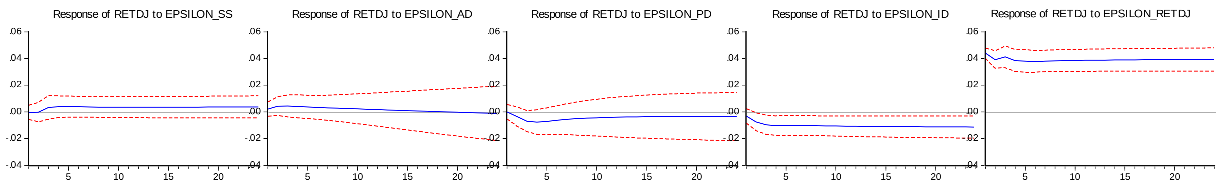
Panel A – Structural VAR impulse responses of the 1-month futures contract



Panel B – Structural VAR impulse responses of the 2-month futures contract



Panel C – Structural VAR impulse responses of the 3-month futures contract

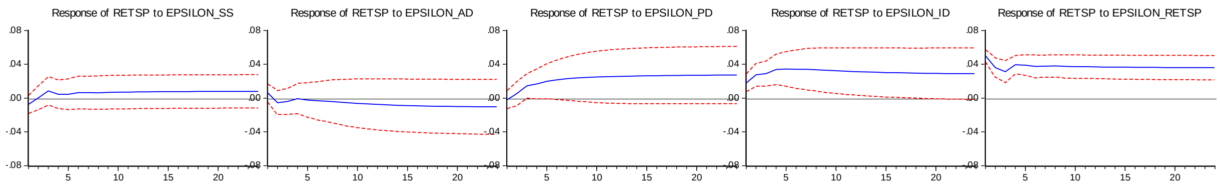


Note: The lines represent the accumulated impulse responses of returns on the Dow Jones stock market index (RETDJ) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD), idiosyncratic oil price shock (EPSILON_ID) and shock to returns on the Dow Jones index (EPSILON_RETDJ) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles).

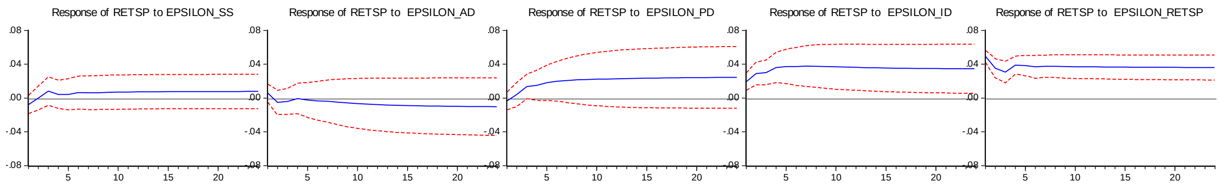
We further our analysis focusing on the post-Great Recession period from 2008:9 to 2016:12. The responses of stock market returns to precautionary demand and idiosyncratic oil price shocks are displayed in Figures 5.11 (S&P500) and 5.12 (Dow Jones). In general, stock market returns show a positive and significant response to an idiosyncratic oil price shock, irrespectively of the maturity, both in the long- and short-term. Similarly, a precautionary demand shock causes a positive effect on returns on the S&P500 and Dow Jones indices for all maturities. However, the effect is significant only in the short-term. This finding is not consistent with the ex-ante expectation.

Figure 5.11: SVAR impulse responses of returns on the S&P500 stock market index: 2008:9 – 2016:12

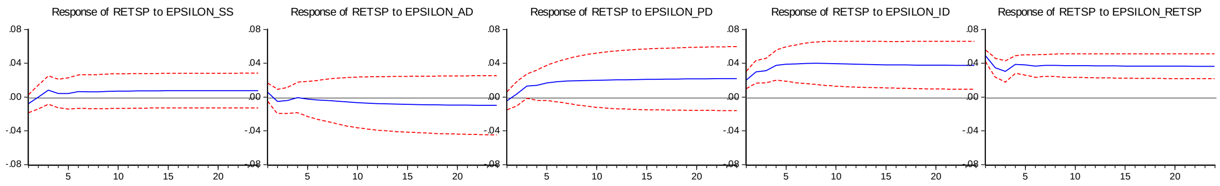
Panel A – Structural VAR impulse responses of the 1-month futures contract



Panel B – Structural VAR impulse responses of the 2-month futures contract



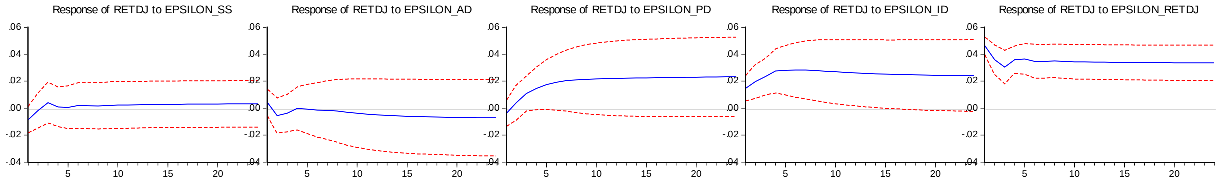
Panel C – Structural VAR impulse responses of the 3-month futures contract



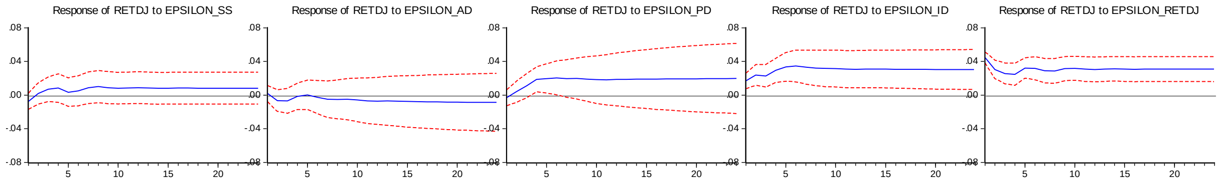
Note: The lines represent the accumulated impulse responses of returns on the S&P500 stock market index (RETSP) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD), idiosyncratic oil price shock (EPSILON_ID) and shock to returns on the S&P500 index (EPSILON_RETSP) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles).

Figure 5.12: SVAR impulse responses of returns on the DJ stock market index: 2008:9 – 2016:12

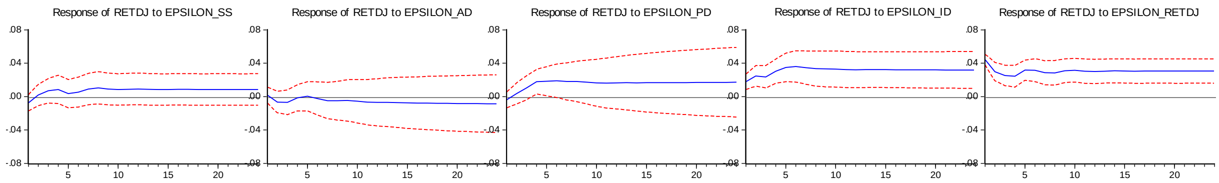
Panel A – Structural VAR impulse responses of the 1-month futures contract



Panel B – Structural VAR impulse responses of the 2-month futures contract



Panel C – Structural VAR impulse responses of the 3-month futures contract



Note: The lines represent the accumulated impulse responses of returns on the Dow Jones stock market index (RETDJ) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD), idiosyncratic oil price shock (EPSILON_ID) and shock to returns on the Dow Jones index (EPSILON_RETDJ) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles).

Overall, the responses of stock market returns to both precautionary demand and idiosyncratic oil price shocks appear to be in accordance with our expectation before the Great Recession, but they are seemingly counter-intuitive after the Great Recession. It is also important to note that the effect of our precautionary demand shock on the stock market returns is less significant compared to idiosyncratic oil price shock in both pre- and post-Great Recession period and confirms that the strongest effect is generated by idiosyncratic oil price shocks. This in turn, validates our decision to disentangle the precautionary demand into two components, and to use of the convenience yield to capture the precautionary demand shock. To gain a thorough picture about the above relationships, a more in-depth analysis is carried out in Section 5.6.

5.5.7 The response of stock market volatility

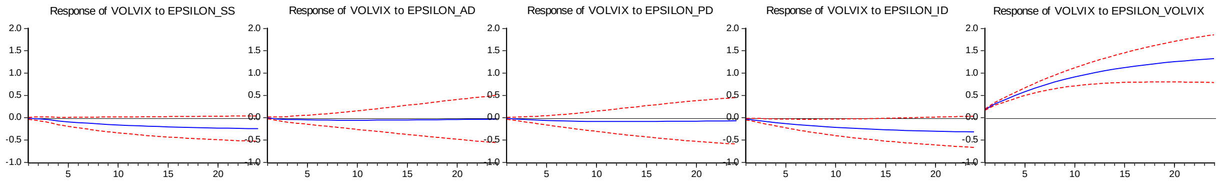
We further our analysis focusing on the effects of precautionary and idiosyncratic oil price shocks on stock market volatility, measured by the VIX index (the implied volatility of S&P500 index) and the VXD index (the implied volatility of Dow Jones index). We consider the time period of 1990-2016 for the VIX index and the time period of 1998-2016 for the VXD index. The choice of this time period is particularly based on the VIX and VXD data availability.

Our decision to employ measurements of implied volatility instead of any measurement of conditional volatility and realised volatility was motivated by a number of studies such as Christensen and Prabhala (1998), Fleming (1998), Blair et al. (2001), Giot (2003) and Koopman et al. (2005). They argue that accurate volatility forecasts for stock market returns are based on implied volatility, which is a forward-looking market volatility, compared with conditional volatility and realised volatility which are both regarded as current-looking market volatilities. Furthermore, in a more recent study, Antonakakis et al. (2017) use the implied volatility indices to investigate the dynamic structural relationship between the three oil price shocks (we employ the same shocks in our study) and stock market volatility. They report that the implied volatility is relatively smooth compared to the backward-looking volatilities. In addition, Maghyereh et al. (2016) argue in favour of implied volatilities since they depend not only on the market's expectations about future volatility but also on fears. If fears are high then options are priced with higher volatilities and a risk premium follows. In addition to this, Maghyereh et al. (2016) point out that the positive connectedness between oil and stock prices in the recent years is ideally controlled by focusing on implied volatility relations that account for cross market sentiments.

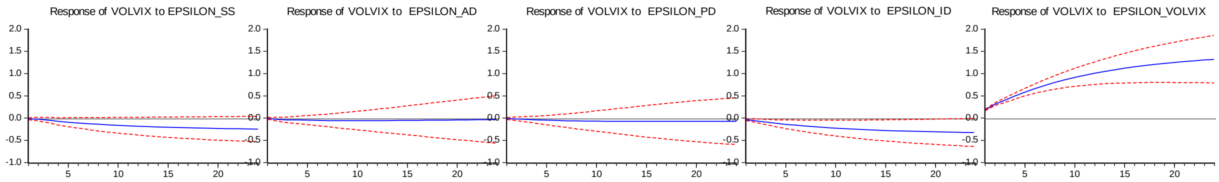
Figures 5.13 and 5.14 show an insignificant response of stock market volatility to a precautionary demand shock. In addition, the results indicate a negative and significant effect of an idiosyncratic oil price shock on VIX index and VXD index. Overall, the general consensus indicates that oil-market specific demand shocks are regarded as negative news to the stock market and thus are expected to lead to higher volatility. Related studies to this consensus include papers by Baum et al. (2010) and Bloom (2009).

Figure 5.13: SVAR impulse responses of stock market volatility VIX index: 1990:1 – 2016:12

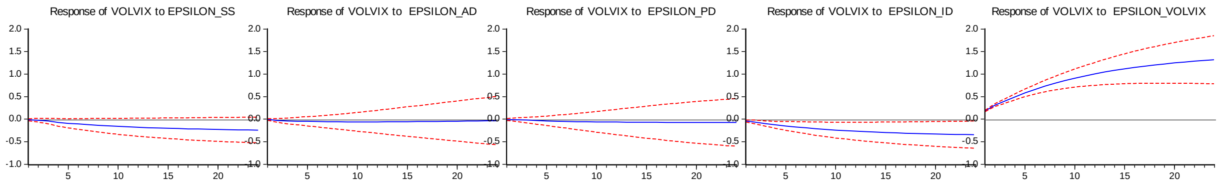
Panel A – Structural VAR impulse responses of the 1-month futures contract



Panel B – Structural VAR impulse responses of the 2-month futures contract



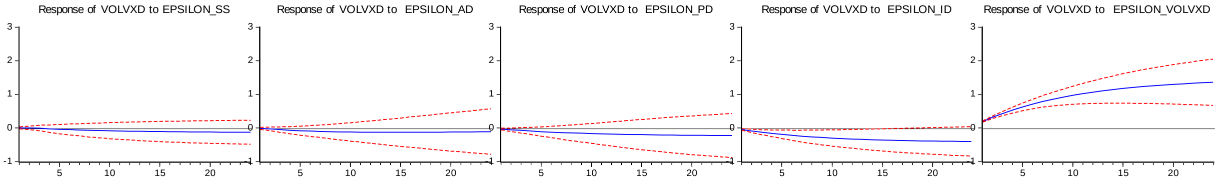
Panel C – Structural VAR impulse responses of the 3-month futures contract



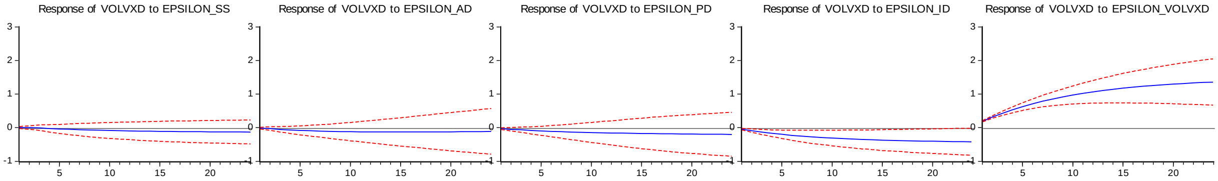
Note: The lines represent the accumulated impulse responses of the volatility VIX index (VOLVIX) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD), idiosyncratic oil price shock (EPSILON_ID) and shock to volatility VIX index (VOLVIX) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles).

Figure 5.14: SVAR impulse responses of stock market volatility VXD index: 1998:1 – 2016:12

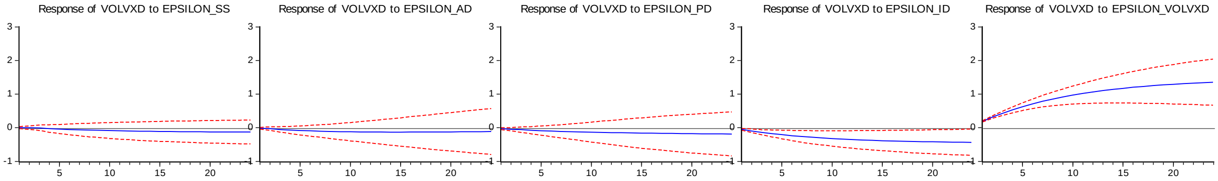
Panel A – Structural VAR impulse responses of the 1-month futures contract



Panel B – Structural VAR impulse responses of the 2-month futures contract



Panel C – Structural VAR impulse responses of the 3-month futures contract

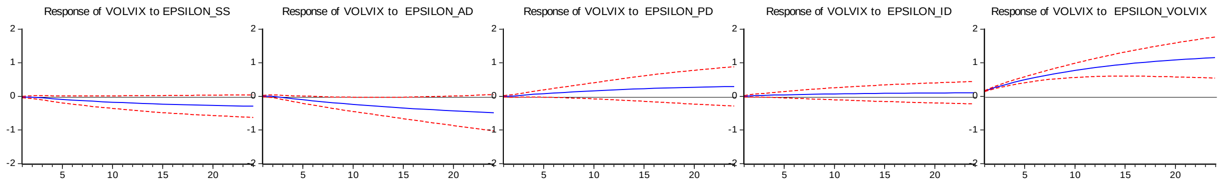


Note: The lines represent the accumulated impulse responses of the volatility VXD index (VOLVXD) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD), idiosyncratic oil price shock (EPSILON_ID) and shock to volatility VXD index (VOLVXD) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles).

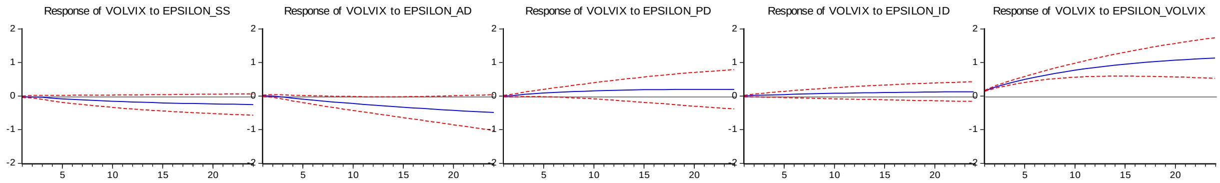
As in Section 5.5.6, we divide the sample period into the pre-Great Recession period (until 2008:08 inclusively), and into the post-Great Recession period (from 2008:09 to 2016:12 inclusively). Before the Great Recession, Figures 5.15 (VIX) and 5.16 (VXD) show a positive but insignificant response to an idiosyncratic oil price shock. Moreover, a precautionary demand shock has a positive and significant, albeit short-lived, effect on stock market volatility, particularly on the VXD index. Thus, our results lend only weak support to the ex-ante expectation of a positive relationship between oil-market specific demand shocks and stock market volatility.

Figure 5.15: SVAR impulse responses of stock market volatility VIX index: 1990:1 – 2008:08

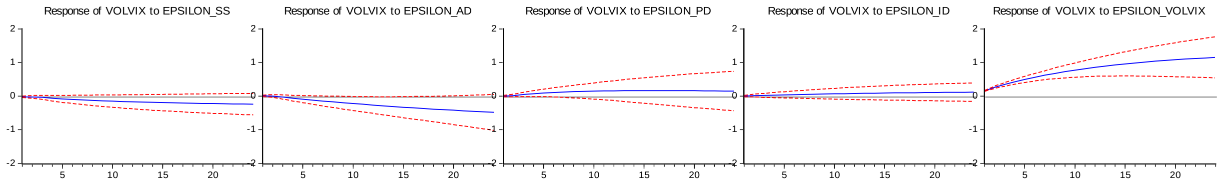
Panel A – Structural VAR impulse responses of the 1-month futures contract



Panel B – Structural VAR impulse responses of the 2-month futures contract



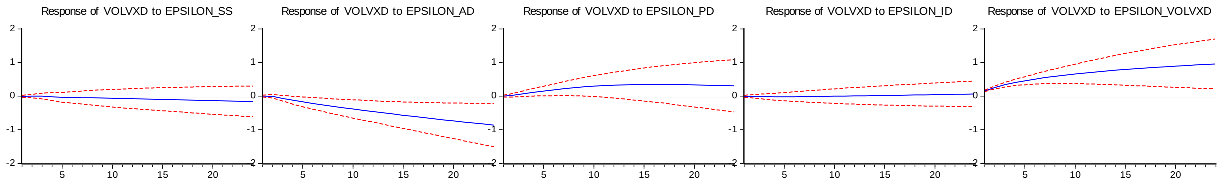
Panel C – Structural VAR impulse responses of the 3-month futures contract



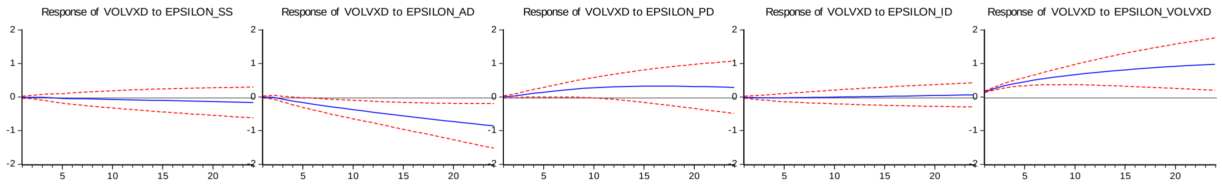
Note: The lines represent the accumulated impulse responses of the volatility VIX index (VOLVIX) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD), idiosyncratic oil price shock (EPSILON_ID) and shock to volatility VIX index (VOLVIX) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles).

Figure 5.16: SVAR impulse responses of stock market volatility VXD index: 1998:1 – 2008:08

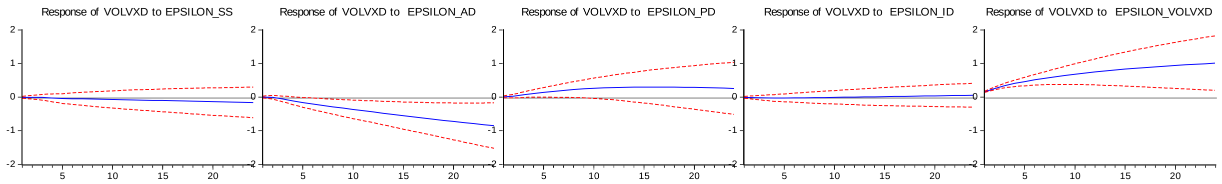
Panel A – Structural VAR impulse responses of the 1-month futures contract



Panel B – Structural VAR impulse responses of the 2-month futures contract



Panel C – Structural VAR impulse responses of the 3-month futures contract

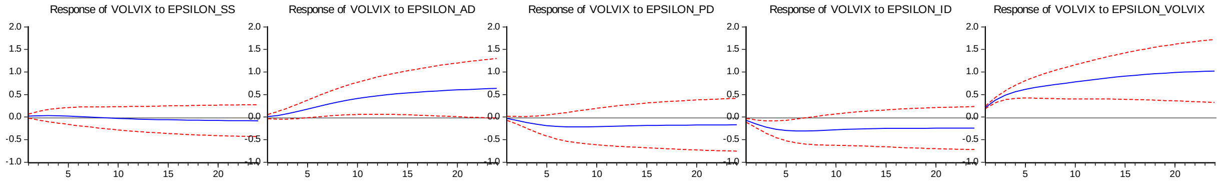


Note: The lines represent the accumulated impulse responses of the volatility VXD index (VOLVXD) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD), idiosyncratic oil price shock (EPSILON_ID) and shock to volatility VXD index (VOLVXD) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles).

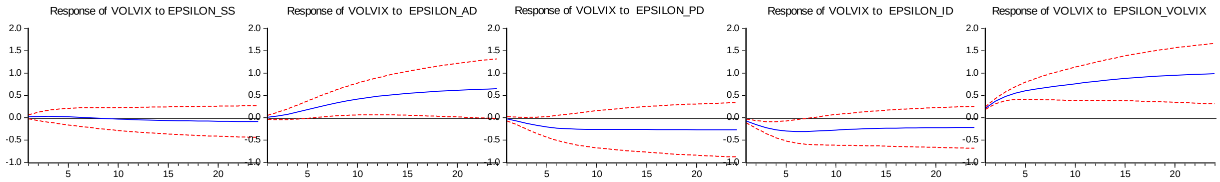
We now turn our attention to the last period of interest which is the post-Great Recession period running from 2008:9 to 2016:12. The response of stock market volatility is shown in Figures 5.17 (VIX) and 5.18 (VXD). The findings indicate that both precautionary demand and idiosyncratic oil price shocks have a negative and significant effect on stock market volatility. This direction is not consistent with the general consensus, according to which a positive reaction is expected. As mentioned in Bloom (2009), higher uncertainty shocks appear to be bad news for companies, cause a delay in investment projects, a reduction in hiring and productivity and therefore a higher stock market (financial) volatility is expected. Overall, the volatility response is seemingly counter-intuitive. Therefore, to attain a more in-depth knowledge we further analyse these results and provide an intuitive interpretation in Section 5.6.

Figure 5.17: SVAR impulse responses of stock market volatility VIX index: 2008:09 – 2016:12

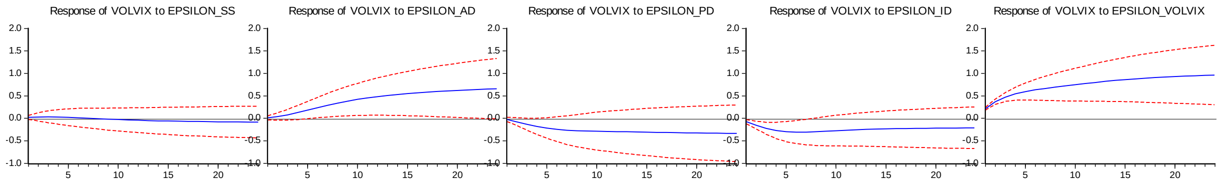
Panel A – Structural VAR impulse responses of the 1-month futures contract



Panel B – Structural VAR impulse responses of the 2-month futures contract



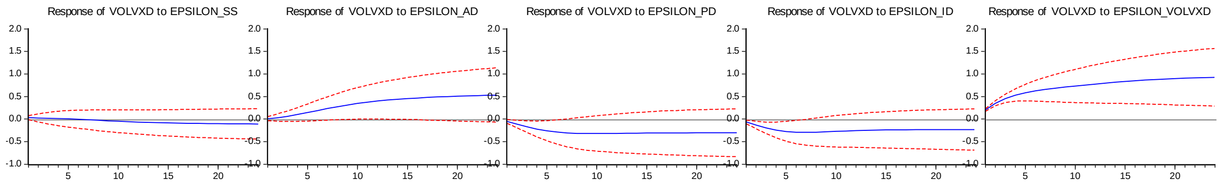
Panel C – Structural VAR impulse responses of the 3-month futures contract



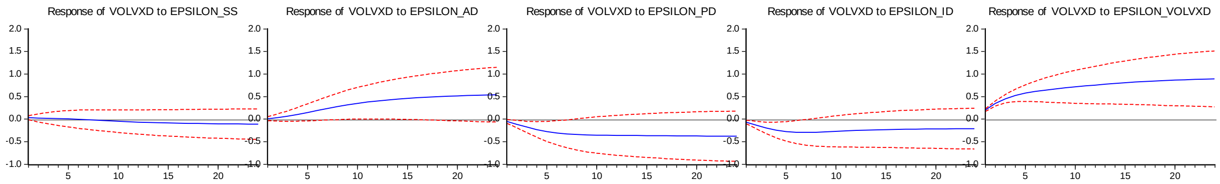
Note: The lines represent the accumulated impulse responses of the volatility VIX index (VOLVIX) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD), idiosyncratic oil price shock (EPSILON_ID) and shock to volatility VIX index (VOLVIX) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles).

Figure 5.18: SVAR impulse responses of stock market volatility VXD index: 2008:09 – 2016:12

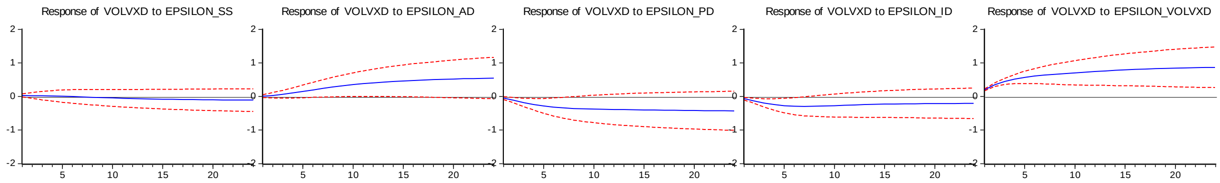
Panel A – Structural VAR impulse responses of the 1-month futures contract



Panel B – Structural VAR impulse responses of the 2-month futures contract



Panel C – Structural VAR impulse responses of the 3-month futures contract



Note: The lines represent the accumulated impulse responses of the volatility VXD index (VOLVXD) to a supply-side shock (EPSILON_SS), aggregate demand shock (EPSILON_AD), precautionary demand shock (EPSILON_PD), idiosyncratic oil price shock (EPSILON_ID) and shock to volatility VXD index (VOLVXD) respectively. Solid line represents the mean response. Dotted lines represent 95% confident interval (upper and lower quartiles).

5.6. Discussion of results

The convenience yield is thought of as a driver for precautionary demand. Overall, our findings confirm the expectation of a positive relationship between the precautionary demand and the real oil returns. A higher convenience yield encourages market participants to pay for oil inventories. This increases the inventory demand in the oil spot market. As inventories accumulate, the availability of crude oil for current use declines, which puts an upward pressure on the oil price.

In addition, based on our SVAR model with the convenience yield, the historical decomposition of real oil returns shows that a precautionary demand shock has a relatively weak effect on the oil price. In similar fashion, the effect of an idiosyncratic oil price shock is relatively stronger, which may have arisen from elevated speculative activity in oil futures market. Indeed, oil price movements are mostly attributed to changes in oil market fundamentals or speculative activity rather than fears about the future availability of oil. This is evident in our findings across a number of episodes (i.e. the period of 1990-1991, the early-1999, the period late-2000 until early-2003, the Great Recession of 2007-2009 and the period from the second half of 2014 to early-2015). In this regard, our decision to include the convenience yield in the SVAR seeks to ascertain the origin of precautionary demand in the oil market.

Next, we examine the response of stock market returns to precautionary demand and idiosyncratic oil price shocks originated in the crude oil market. Fears about future availability of oil and unexpected oil price movements are priced in the stock market. As aforementioned, we expect that stock market returns respond negatively to precautionary demand and idiosyncratic oil price shocks. Indeed, increases in the oil price lead to higher production costs, which in turn cause profits, future cash flows and thus stock market returns to decline. However, our results only partly support this consensus. Importantly, we find a significant short-lived effect of precautionary demand shocks on stock market returns, in both pre- and post-Great Recession period, irrespective of the maturity of a futures contract.

A plausible explanation of this relationship and specifically these short-lived effects can be attributed to the fact that oil inventories are more valuable and considered as more important for speculators in the shorter-run rather than in the longer-run. In practice, speculators are seeking quick returns from changing prices. In this respect, they prefer to buy and sell barrels of oil in the physical oil market because they do not intend to use crude oil. This could possibly explain the short-lived significant effects of precautionary demand shocks originated by the convenience yield on the stock market returns.

We further report the effects of an idiosyncratic oil price shock on stock market returns. The results show a negative (positive) and significant effect before (after) the Great Recession. Since the results disagree with the expected negative relationship after the Great Recession, we turn our attention to this period. The first plausible explanation regarding the positive effect of an idiosyncratic oil price shock can be attributed to the increasing levels of uncertainty in both oil and stock markets from September 2008. In particular, in this period oil price experienced a sharp drop, whereas stock markets crashed across a number of countries. After the Great Recession both oil and stock markets have been following a bearish trend and they continue moving in the same direction. These developments have contributed to a stronger co-movement between the two markets, which manifests in a positive relationship between the prices in two markets.

The second explanation can be attributed to the financialisation of the oil market. The growing trading volume in oil futures derivatives driven by institutional traders since 2003 has led to significant effects on the oil market. In this regard, anecdotal evidence indicates that the investment by institutional investors (i.e. pension funds, hedge funds, etc.) in commodity futures has grown from $15 billion in 2003 to $200 billion in mid-2008 (Tang and Xiong, 2012), and then to $250 billion in 2009 (Irwin and Sanders, 2011). The impact of financialisation has been studied by academic research in the recent years. Financial intermediaries, including hedge funds, insurance companies and pension funds, have recognised the importance of oil futures market derivatives as a financial asset that helps the owner to lay off risks or increase the value of investment (Fattouh et al., 2013).

More specifically, Büyükşahin and Robe (2014) emphasise the role of hedge funds in the quest for profitable investment opportunities, which typically arise around oil price peaks and troughs. In particular, they document that when the share of hedge funds in energy futures market increases by 1% the dynamic correlation between energy returns and equity returns reaching increases by 5%. Moreover, the increasing financialisation of commodity markets – which is linked with the growth of investment in the oil futures market – is associated with higher oil prices (Tang and Xiong, 2012). Furthermore, Silvennoinen and Thorp (2013) find that the conditional correlation between commodity futures returns and US equity returns increases in periods of higher stock market uncertainty. More recently, Sadorsky (2014) reports that the dynamic correlation between emerging market stock prices and oil prices grew considerably after 2008 with no tendency to revert back to the pre-2008 levels.

Other studies related to financialisation (speculative activity) of the oil market include Basak and Pavlova (2016), Adams and Glück (2015), Cheng et al. (2014), Hamilton and Wu (2014), Morana (2013), Singleton (2013), Alquist and Kilian (2010) and Büyükşahin et al. (2010). Overall, the growing purchase of oil-related assets (i.e. futures contracts) by speculators is indicative of the financialisation of the oil futures market. Thus, we suggest that the positive effect of an idiosyncratic oil price shock on stock market returns in the post-Great Recession period can be justified by speculative activity.

Noteworthy, our findings are in line with Filis et al. (2011), who provide evidence that a stronger positive link between oil prices and stock markets from oil-exporting and oil-importing countries is associated with the global financial crisis of 2008. Similarly, Creti et al. (2013) report an increasing correlation between US stock market and commodity markets during the 2008 financial turmoil. Also, the results are in agreement with Sadorsky (2014) who reports growing correlations between 21 emerging markets stock prices and oil prices in the post-2008 period. A positive and rising correlation between oil prices and stock prices from oil-exporting and oil-importing countries during the global financial crisis period is also reported in Guesmi and Fattoum (2014). Similar findings are reported by Broadstock et al. (2012) regarding the relationship between oil prices and energy related stocks in China following the global financial crisis of 2008, as well as Hammoudeh et al. (2014) who document a positive correlation between commodity futures and the Chinese stock market.

Our findings are also in accordance with previous studies that examine the period prior to and after the Great Recession (see, *inter alia*, Reboredo and Ugolini, 2016; Tsai, 2015; Reboredo and Rivera-Castro, 2014; Mollick and Assefa, 2013). Specifically, Mollick and Assefa (2013) and Tsai (2015) provide evidence that US stock market returns are negatively (positively) affected by oil prices prior to (after) the global financial crisis. Moreover, Reboredo and Rivera-Castro (2014) find that oil price changes exert a positive effect on European and US stock market returns after the global financial crisis, but not before it. Finally, Reboredo and Ugolini (2016) document a weak co-movement between oil prices and developed and emerging stock market prices in the pre-crisis period and a strong positive co-movement after the onset of the global financial crisis. It is worth mentioning that our findings regarding the pre-Great Recession are in line with Anzuini et al. (2015). By using data until 2008, they find that a precautionary demand shock exerts a negative and significant effect on US stock market returns.

Finally, our study also scrutinises the response of stock market volatility to precautionary and idiosyncratic oil price shocks as the final part of this Section. Uncertainty related to oil-market specific demand shocks is considered as negative news to stock market participants, which may result in a delay in their investment decisions (see Bloom, 2009) and consequently may drive up volatility. It is thus expected that precautionary demand and idiosyncratic oil price shocks will have a positive effect on stock market volatility. Overall, our results are only consonant with the ex-ante expectation in the pre-Great Recession period. Indeed, before the Great Recession, the effect on volatility is positive and significant, albeit short-lived. Thus, the uncertainty arising from oil-market specific demand shocks was provoking volatility increases in the US stock market. As earlier mentioned, the positions by institutional traders in the oil futures market were relatively low until 2003. In other words, the use of oil derivatives as a financial asset attracted limited attention by market participants. This indication provides evidence to support the argument according to which commodity markets (including oil) have been segmented from financial markets before the Great Recession. Studies related to the segmentation between commodity and stock markets include papers by Erb and Harvey (2006), Gorton and Rouwenhorst (2006) and De Roon et al. (2000).

After the Great Recession, the response to oil-market specific demand shocks has become negative and significant, consistent with the financialisation hypothesis and heighted speculative activity in the oil market. This finding is counter-intuitive and is not in line with the general consensus which indicates that higher oil-market specific demand shocks exercise a positive influence on the stock market volatility. Indeed, the increased participation of hedge funds in the oil futures market provides evidence to support the argument that the performance of commodities in stock markets appears to change substantially. In particular, the large investment inflows by institutional traders could justify the dynamic relationship between commodity markets and stock markets especially during the Great Recession and the years onwards. Thus, the integration of commodity and stock markets can be attributed to a changing dynamic relationship between the two markets. Specifically, our results lend support to Brunetti et al. (2016), who show that hedge funds' trading provides liquidity to the stock market and reduces market volatility.

More specifically, Brunetti et al. (2016) investigate the impact of speculation on commodity market volatility related to the US oil futures market. They find that positions held by hedge funds (speculators) in the oil futures market are positively related to contemporaneous oil futures returns and stabilise these markets by improving price discovery. They also indicate that hedge funds (non-commercial traders) cause a decrease in market volatility by taking positions opposite to commercial entities (dealers, manufacturers) with hedging needs in the oil futures market. In brief, they show that hedge funds' trading improves market liquidity and drives down the financial stress which in turn reduces the stock market volatility.

Our results are partly consistent with the findings of Degiannakis et al. (2014) who indicate that positive precautionary demand shocks have a negative but insignificant effect on volatility in the European stock market. In addition, our findings are in line with Kang et al. (2015) who argue that a positive precautionary demand shock exercises a negative and significant effect on volatility (realised, conditional and implied) in the US stock market. Moreover, our findings are consistent with those by Anzuini et al. (2015) who find that a positive precautionary demand shock exercises a positive and significant effect on the stock market volatility before the Great Recession. Overall, we suggest that the relationship between precautionary demand shocks and stock market volatility does not carry on consistent over time but reveals heterogeneous patterns with a particular attention to the pre- and post-Great Recession.

5.7. Conclusion

Our study builds on the works of Kilian (2009) and Kilian and Park (2009), to investigate the nature of the precautionary demand shocks by providing a detailed analysis including the convenience yield as a proxy of uncertainty in crude oil market. This uncertainty arises from the expectation about the future availability of oil. In addition, we examine the responsiveness of the US stock market returns and stock market volatility to oil-market specific demand (precautionary demand and idiosyncratic oil price) shocks. We use monthly data over the period from January 1986 to December 2016. Regarding the stock market returns, we employ the US stock market indices of S&P500 and Dow Jones, whereas the aggregate US stock market indices of VIX and the VXD are used to measure the stock market volatility. A structural vector autoregression (SVAR) model is employed to investigate the endogenous relationships between the estimation variables.

More specifically, the main contribution of this study is that it employs the convenience yield in order to capture shifts in precautionary demand in the oil market arising from fears about the future availability of oil. We extend Kilian's (2009) SVAR by disaggregating the precautionary demand into two components, namely, the new precautionary demand shock (based on the convenience yield) and the idiosyncratic oil price shock. We maintain that the convenience yield acts as a good approximation to a precautionary demand shock. We confirm that the convenience yield reflects the uncertainty about shortfalls of supply relative to expected demand, as suggested by Kilian and Park (2009).

Overall, we provide evidence that our SVAR consideration indicates that oil price changes are affected in a smaller magnitude by precautionary demand shocks, whereas the largest effect is generated by idiosyncratic oil price shocks. This can be attributed to the fact that the idiosyncratic character of the oil price may possibly reflect the increasing financialisation of the oil futures markets and consequently highlight the role of speculative activity. Hence, we argue that our consideration to separate the magnitude of the actual precautionary demand influenced by the convenience yield with this of the idiosyncratic oil price shock holds.

Furthermore, this study contributes to the existing literature not only in introducing the convenience yield in order to capture the uncertainty about future oil supply shortfalls, but also in exploiting the impact of this motivation on the stock market returns and stock market volatility in order to validate further our innovation. We seek to identify different magnitudes and patterns in the attention of the research. The examination of the origin of the oil price shocks and the impact on stock market activity is important in order to understand better this dynamic relationship. In this analysis, our findings indicate that precautionary demand and idiosyncratic oil price shocks trigger different responses from the US stock market. We pay particular attention to the Great Recession due to the fact that oil markets and stock markets are largely affected by this period.

Turning our attention to the period prior to the Great Recession, we document that precautionary demand (idiosyncratic oil price) shocks exert a negative and significant in the short-term (short-term and long-term) effect on stock market returns. Moreover, precautionary demand (idiosyncratic oil price) shocks exercise a positive and significant (insignificant) impact on stock market volatility. These findings are in line with the ex-ante expectations which are clearly explained in the empirical analysis section. Nevertheless, our findings highlight the key role of the post-Great Recession period to account for counter-intuitive developments in stock market activity. Thus, we consider that the period after the Great Recession is our keystone.

To be more explicit, considering the post-Great Recession, we find that the effect of the precautionary demand shock on the stock market returns is positive and significant for a very short period of time, whereas stock market returns are significantly and positively affected by idiosyncratic oil price shocks. Furthermore, stock market volatility exhibits lower levels in response to precautionary demand shocks and idiosyncratic oil price shocks. We suggest that the financialisation of the oil futures markets and the increased speculative trading activity provide superior information in explaining new patterns on the relationship between oil markets and stock markets in the post-Great Recession.

The findings may be of interest to investors and energy traders who want to obtain information for the oil market and the stock market behaviour in the pre- and post-Great Recession. Due to the increased participation of hedge funds and consequently the financialisation of the oil market the recent years, an interesting avenue for further research is to assess whether a speculative shock can be incorporated into the SVAR model. As aforementioned, Kilian and Murphy (2014) argue that expectations about the uncertainty of the future oil supply shortfalls can be also explained by financialisation (speculation) in the oil market. On this matter, unexpected shifts in the demand for global above-ground crude oil inventories can be used to capture a speculative demand shock.

Finally, given the different magnitudes and patterns between oil price shocks and stock market activity in the pre- and post-Great Recession, another area for future work would be to examine the above relationship in a time-varying environment. Specifically, the use of time-varying approaches which allow time series to vary over time such as a time-varying parameter vector autoregression (TVP-VAR) model rather than static approaches can be considered in order to understand the dynamic correlations between oil price shocks and stock market returns or volatility.

Chapter 6: Conclusion

6.1. Introduction

This research study attempts to explore further the link between oil price movements and financial markets performance by containing three empirical chapters. Based on the purposes of each empirical chapter, the gap in the existing literature is clearly indicated. It is worth noting that each empirical chapter also presents its own research aims and contributions that generated from the denoted gap. It should be mentioned that similar or different sets of data have been used, different time periods have been examined and different econometric approaches have been employed among the three empirical chapters in order to conduct this research study. In this regard, the first empirical chapter examines the WTI/Brent oil futures price differential and the *globalisation-regionalisation hypothesis*. The second empirical chapter investigates the relationship between oil price shocks and EMU sovereign yield spreads. The third empirical chapter examines the financial effects of changes in the precautionary demand for oil.

With reference to the data frequency, the use of monthly data is preferred due to data availability from a variety of commercial suppliers. Furthermore, this study follows the existing literature and adopts the variables that other relevant studies have commonly used. For instance, the first empirical chapter uses oil price data of WTI and Brent futures since both have the most actively and highly liquid traded oil futures contracts (source: Bloomberg). The second empirical chapter uses oil spot price data of Brent (source: Datastream). This is due to the fact that Brent is considered as the European crude oil benchmark and is largely consumed locally in Europe. Finally, following Kilian's (2009) empirical work, the third empirical chapter uses oil price data in the form of US refiner's acquisition cost of imported crude oil (source: EIA).

The sample period in each empirical chapter depends on the data availability. For example, the sample period of the second empirical chapter ranges from January 1999 (2001) to January 2016 for core (periphery) countries. In this chapter, we seek to investigate the relationship between oil price shocks and the 10-year sovereign yield spread of the (core and periphery) country members of the EMU, which was established in January 1999. Since Greece (deemed a periphery country) joined EMU in January 2001, the sample period is adjusted for the periphery countries to begin from this period.

It is worth noting that the year 2016 represents the end period of this study. It should be mentioned that in the first and the third empirical chapters the sample period ends in December 2016, whereas in the second empirical chapter the end period is January 2016, due to data availability. During the period of this study, the empirical tests were repeatedly performed in order to include the most recent developments in the oil markets and the financial markets, to capture all the available market information, to obtain the most accurate results and finally to provide the most plausible explanations, either expected or unexpected, in accordance with the economic theory. In this regard, the final update of the variables under consideration was the year 2016 and the final update for the empirical results was the beginning of 2017 for the three empirical chapters given the submission of this thesis in July 2018.

Turning to the methodology, each empirical chapter employs a different econometric model. The first empirical chapter uses i) a battery of single-equation multiple linear regression models, which aim to assess the determinants of the WTI/Brent oil futures differential, and ii) a SUR model which serves as a robustness check. The second empirical chapter uses i) a SVAR model, and ii) a time-varying Scalar-BEKK model. The third empirical chapter employs a

SVAR. Overall, all estimated models have been well explained by the extant literature and have been extensively utilised by the research community.

Having summarised the chosen data and econometric methods, this chapter concludes the main findings achieved from each empirical chapter and further attempts to offer a combination of findings to form a joint entity. Even though each empirical chapter is associated with different strands of the oil-related literature, we seek to present some common ground for the findings reported in the empirical chapters on the relation among oil markets, financial markets and the macroeconomy. Finally, we make reference to the policy implications and the limitations of this study and suggest avenues for future research.

6.2. Findings from each empirical chapter

Starting with the first empirical chapter, the determinants of the WTI/Brent oil futures differential and the *globalisation-regionalisation hypothesis* in the oil futures market are examined. Traditionally, the oil futures differential (WTI futures price minus Brent futures price, which is expressed in logarithm) is measured as the difference between the quality and freight rates (location) in the two crude oil markets. Therefore, we ask whether a set of oil-market specific and oil-futures market specific determinants in differential form are informative about variation in the WTI/Brent oil futures differential. To this end, we examine three futures contracts maturities (i.e. 1, 3 and 6-month contracts), which are regarded as short-term maturities.

The findings indicate that the WTI/Brent oil futures differential is influenced by the convenience yield spread, the oil production spread, the oil consumption spread, the open interest spread, and the trading volume spread. Overall, these determinants exercise a significant impact on the oil futures differential and therefore all drive a significant wedge and contribute to disparities between the WTI and Brent oil futures prices in the short-run. This provides evidence that the oil futures market appears to be regionalised in the short-run.

Turning to the second empirical chapter, the time-varying correlations between different shocks originating from the oil market and the 10-year sovereign yield spread of the core (Austria, Belgium, Finland, France and Netherlands) and the periphery (Greece, Ireland, Italy, Portugal and Spain) countries in the EMU are investigated. The 10-year sovereign yield spread is the difference between the yields of 10-year sovereign bonds issued by a member of the EMU and the yield of the 10-year sovereign bond issued by Germany (Bund).

The findings reveal that the correlations between different oil price shocks and sovereign yield spreads is time-varying and depends on specific economic and geopolitical events that took place during the study period. Our hypotheses about a negative (positive) correlation related to aggregate (precautionary) demand shocks are mostly confirmed, whereas the data do not offer full support to our hypothesis regarding the negative correlation patterns with reference to supply-side shocks. In addition, the correlation patterns appear to be less volatile in the pre-2008 period and passed into moderate and more volatile patterns in the post-2008 period. Finally, we do not find evidence of differentiation in the correlation patterns of sovereign yield spreads between core and periphery countries to different oil price shocks.

The third empirical chapter, which is based on the contributions of Kilian (2009) and Kilian and Park (2009), seeks to explore the exact origin of the precautionary demand shocks, which represent the uncertainty about the future availability of oil. In this regard, the convenience yield is used to capture this uncertainty within the crude oil market. This innovation implies that the precautionary demand is disaggregated into two components, namely, the new precautionary demand shock (based on the convenience yield) and the idiosyncratic oil price shock. In addition, we use this innovation in order to test how the US stock market returns and stock market volatility respond to precautionary demand and idiosyncratic oil price shocks. We maintain that the convenience yield acts as a good approximation to a precautionary demand shock. Also, the findings document that oil price changes are driven in a smaller magnitude by precautionary demand shocks, whereas the largest effect is generated by idiosyncratic oil price shocks. A plausible explanation is ascribed to the fact that the idiosyncratic character of the oil price may possibly reflect the increasing financialisation of the oil futures markets.

Turning our attention to the impact of this innovation on the US stock market activity, we pay particular consideration to the Great Recession due to the fact that both oil and stock prices collapsed during this period. Even though stock market returns (stock market volatility) show the expected negative (positive) responses to precautionary demand shocks and idiosyncratic oil price shocks prior to the Great Recession, this does not hold after the Great Recession. Indeed, stock market returns (stock market volatility) respond positively (negatively) to precautionary demand shocks and idiosyncratic oil price shocks. Once again, the increasing financialisation of the oil market seems to alter the effects of precautionary demand and idiosyncratic oil price shocks on the stock market after the Great Recession.

6.3. The combination of empirical findings

The detailed analysis of the empirical findings allows us to detect common relations that are achieved from each individual empirical chapter and draw useful conclusions. An important common finding is the financialisation of the oil market. As aforementioned, oil-related products such as futures contracts or physical inventories have been considered as financial assets by traders and investors over the last decade. They invest in oil futures markets in an attempt to reduce the value of their investment risk or to increase the value of their investment revenues. Expressed differently, it seems that the oil market is not only affected by physical (fundamental) energy traders' activity but also influenced by financial (non-fundamental) traders' positions. For example, a large purchase of oil futures contracts by speculators triggers rises to expected oil spot prices. This provides an incentive to oil producers to decrease current oil production and hold inventories which in turn reduces the current availability of barrels of oil in the market.

With regard to this study, the first empirical chapter provides evidence of financialisation in the case of financial indicators such as open interest and trading volume. These two factors reflect hedging demand activity and trading information in the oil futures markets. We provide evidence that the oil futures market is significantly affected by these two indicators. The magnitude of financialisation is also noticeable in the third empirical chapter, given that stock market returns and stock market volatility exercise unexpected patterns in response to different oil price shocks. Specifically, the beginning of the post-Great Recession, which coincides with the mid-2008 period, corresponds to new developments in the oil futures market that influence largely stock market activity. This can be attributed to increasing speculative trading in the oil futures market.

Another important common finding is related to the convenience yield in the oil market which could approximate the uncertainty about the future availability of oil and hence it can be used to measure precautionary demand. To this end, it is important to note that the first empirical chapter and the third empirical chapter highlight the importance of this variable to justify unexpected changes in precautionary demand for oil. In this regard, the first empirical chapter considers the political instability in the Middle East from the beginning of 2011, onwards, as a cause of increasing concern about the future availability of oil. In turn, this episode triggered a precautionary demand shock, which was consequently reflected in the convenience yield which represents the insurance premium against unexpected disruptions of oil supply. Adopting the same line of reasoning, the third empirical chapter uses the convenience yield to approximate shifts in precautionary demand for oil. In the light of the findings, the convenience yield is performing a useful role and appears to reflect the uncertainty of expected supply relative to expected demand.

A further important common finding is associated with the origin of the oil price shock, either from the demand-side or the supply-side of the economy. In this regard, the second empirical chapter and the third empirical chapter consider oil price changes with a particular attention to their origin. In particular, oil price shocks can be disentangled into supply-side shocks, aggregate demand shocks and precautionary demand shocks. On general principles, the origin of the oil price change is an important topic in order to establish a more thorough picture of the relationship between oil markets and financial markets and, hence, to evaluate their actuals effect on the economic activity. It is worth noting that the second empirical chapter indicates that the correlations between sovereign yield spreads and oil price shocks show heterogeneous patterns among the three shocks during a number of episodes in the oil market. Similarly, the third empirical chapter suggests the disaggregation of precautionary demand into two components and notices that this alternative decomposition presents different magnitudes and patterns.

Finally, the significant impact of the Great Recession of 2007-2009 on the global economy and the financial markets reflects an additional common theme. In particular, during this period and specifically in the second half of 2008, financial markets and institutions collapsed. Stock market returns experienced high levels of volatility and significant negative returns. The unprecedented levels of global uncertainty contributed to a significant economic downturn in the world economy. Similarly, a dramatic steep fall in oil prices has originated from the significant decline in global economic activity and the fact that the oil market appeared to be financialiased during that period. In this respect, the second empirical chapter and the third empirical chapter provide evidence that the relationship between oil markets and financial markets is largely affected by the Great Recession.

6.4. Policy implications

This research study provides interesting new insights for the attention of market participants, such as financial investors and energy traders. Initially, the first empirical study offers a better understanding of the fundamental oil market and financial market predictors of the oil futures differential and consequently the status of the oil futures market as regionalised in the short-run. Therefore, market participants should be benefit from the findings of this study since they need to know to what extent the oil futures market is affected by the physical oil market factors of supply and demand, as well as financial indicators. In addition, market participants who trade oil futures contracts in both WTI and Brent crude oil futures markets should gain in terms of managing their asset portfolios and protect themselves against adverse future price movements.

By considering the second empirical chapter, the time-varying correlations among different oil price shocks and sovereign yield spreads could inform financial markets participants about their dynamic asset allocation and portfolio diversification strategies. For instance, although sovereign bonds can act as a hedging instrument in periods of turmoil, the degree to which they can be used to hedge risky investments will also depend on the oil price shocks over the period when such hedging is required. Moreover, when considering investing in both oil and bond markets, attention should be given to oil price events, since aggregate demand shocks may serve in favour of greater diversification opportunities (due to the negative correlations), whereas precautionary demand shocks could result in diminishing such opportunities (due to the positive correlations).

Along the same line of interest, the third empirical study provides superior information to market participants regarding the behaviour of oil markets and the stock markets by particularly focusing on the pre- and post-Great Recession. This is due to the fact that the recent evidence of the financialisation of the oil market and the increasing speculative trading activity indicate new patterns in respect of the relationship between oil markets and stock markets. Specifically, the impact of financialisation on the oil market is mainly endorsed in the post-Great Recession. Therefore, the findings of this study may offer benefits to those market participants who hold oil-related products and stock market products in order to make portfolio rebalances or to make risk management decisions. They also gain advantages by receiving information about stock market volatility as a basic component of derivative pricing.

6.5 Limitations

This research consists of three empirical chapters. Each empirical chapter clearly presents its own aims, contributions, dataset, econometric approaches and empirical findings. Overall, the structure of all econometric models is clearly justified and no technical issues during the investigation process were detected, while satisfactory information has been extracted. Furthermore, plausible explanations and discussion were provided by taking into consideration the economic theory related to the empirical results, even for those that appeared to be unanticipated. In addition, the empirical findings are linked with the existing literature in order to test if they are in line with previous studies and appeared to represent new insights to the growing oil-related literature. Although each empirical chapter reflects a different strand of the literature and hence different research outcomes, we are able to detect substantial associations in terms of a general observation. On general principles, we maintain that this research study has been carefully organised and conducted. However, a few limitations could be mentioned.

The adoption of proxy variables could be considered as a general limitation, although all time series data are measured with error. This issue arises when the required time series are not free of charge and therefore significant amount of payments is needed in order to collect the accurate data. In this regard, the use of proxies which are strongly related to the variables of interest must be indicated. In this study, all empirical chapters employ proxy variables. Overall, we argue that the use of proxy variables can be beneficial, given the lack of the original variables and could provide a precise and accurate measurement. However, this has maybe caused limitations in terms of creating some degree of error which might be greater than the typical error related to all time series data.

A second limitation can be attributed to the size of the data sample. It is evident that the sample size depends on the needs of each empirical chapter and the data availability. Therefore, different sample periods are employed with a particular attention to the sample start date. For example, the sample period in the first empirical chapter runs from 1993 to 2016 whereas the time period in the third empirical chapter spans from 1986 to 2016. Although the sample period differs substantially, this can be justified by the aforementioned data availability. However, this could be possibly regarded as a limitation, which is based on the argument concerning what is the precise number of observations to generate an effective sample size and further meaningful data.

A third limitation concerns the use of robustness checks in order to evaluate the stability of our findings. Although two robustness checks are presented in the first empirical chapter and one robustness check is employed in the third empirical chapter, this does not hold for the second empirical chapter. Overall, a robustness exercise represents an alternative approach to examine whether estimated findings remain robust in the case of adding or removing variables from the estimated model. If the coefficients of the robustness checks do not alter this is indicative of structural validity. To this end, it appears plausible to employ robustness exercises. The information provided by these tests helps to manage the uncertainty generated to the researcher regarding the validity of his/her model by comparing with other alternative specifications.

6.6 Future research

This research study is comprised of analysis within three empirical chapters in order to expand the existing literature by examining relationships that have previously not been explored. The findings of this study are satisfactory in covering the indicated aims and filling specified voids. In this regard, superior information has been provided for the attention of the research community. However, research in the oil market area is still growing and the attention of the researcher should be expanded to new strands. Therefore, this study attempts to offer exciting avenues for future research, based on the findings of each empirical chapter which represents a different strand in the oil-related literature.

Further potential research regarding the *globalisation-regionalisation hypothesis* includes the consideration of additional crude oil benchmarks other than WTI and Brent, such as, the

Dubai/Oman. This would suggest a more thorough picture of the degree in which the state of the international oil futures market is globalised or regionalised. In addition, an interesting question that the future study might address regarding the determinants of oil futures differential is the adoption of time-varying parameter models. This helps to identify whether the oil futures differential is affected by physical market and financial market factors at different time periods. Furthermore, it would be interesting for future research to investigate the effect of renewable energy sources on the total energy sources, including petroleum. The increasing use of renewable energy sources could influence the dependence upon fossil fuels and consequently lead to reduced levels of oil production and oil consumption and further affect the convenience yield. These factors are regarded as significant determinants of the oil futures differential.

With reference to the relationship between oil price shocks and sovereign risk, our decision to employ 10-year sovereign yield spreads in the EMU, which is in aggregate the largest oil-importer of the world, provides interesting areas for further research. For instance, the consideration of sovereign CDS spreads which can be used as an alternative measurement to approximate sovereign risk in the EMU, since a widening of CDS spreads can be indicative of higher levels of country's risk. Furthermore, the examination of the time-varying correlation between the 10-year sovereign yield spread and oil prices (or shocks) for developed and emerging countries, either oil-exporters or oil-importers, is another promising area for future research. Finally, the inclusion of shorter-term sovereign yield spreads as proxies of sovereign risk is also recommended.

Regarding the financial effects of precautionary demand for oil, future study may examine whether a speculative shock can be incorporated into the SVAR model. This can be justified by the fact that the oil market appears to be highly financialised due to the increased participation of hedge funds in recent years. The extent to which the financialisation (speculation) in the oil market has altered its nature requires further attention. This is the reason why global, above-ground crude oil inventories can be used to capture a speculative demand shock which in turn will be incorporated within the SVAR model. In addition, another area that future research should be examining is the link between oil markets and the stock markets in a time-varying environment. To this end, a time-varying parameter vector autoregression (TVP-VAR) model should be employed with aim to allow the correlations between oil price shocks and stock market returns or volatility to vary over time.

Appendix

FORM UPR16

Research Ethics Review Checklist

Please include this completed form as an appendix to your thesis (see the Research Degrees Operational Handbook for more information

UNIVERSITY of PORTSMOUTH

Postgraduate Research Student (PGRS) Information		**Student ID:**	433928
PGRS Name:	Mr Michail Filippidis		
Department:	Economics and Finance	**First Supervisor:**	Dr Renatas Kizys
Start Date: (or progression date for Prof Doc students)		01/10/2012	

Study Mode and Route:	Part-time	☒	MPhil	☐	MD	☐
	Full-time	☐	PhD	☒	Professional Doctorate	☐

Title of Thesis:	Essays on econometric analysis of commodity markets
Thesis Word Count: (excluding ancillary data)	63,094

If you are unsure about any of the following, please contact the local representative on your Faculty Ethics Committee for advice. Please note that it is your responsibility to follow the University's Ethics Policy and any relevant University, academic or professional guidelines in the conduct of your study

Although the Ethics Committee may have given your study a favourable opinion, the final responsibility for the ethical conduct of this work lies with the researcher(s).

UKRIO Finished Research Checklist:
(If you would like to know more about the checklist, please see your Faculty or Departmental Ethics Committee rep or see the online version of the full checklist at: http://www.ukrio.org/what-we-do/code-of-practice-for-research/)

a) Have all of your research and findings been reported accurately, honestly and within a reasonable time frame?	YES NO	☒ ☐
b) Have all contributions to knowledge been acknowledged?	YES NO	☒ ☐
c) Have you complied with all agreements relating to intellectual property, publication and authorship?	YES NO	☒ ☐
d) Has your research data been retained in a secure and accessible form and will it remain so for the required duration?	YES NO	☒ ☐
e) Does your research comply with all legal, ethical, and contractual requirements?	YES NO	☒ ☐

Candidate Statement:		
I have considered the ethical dimensions of the above named research project, and have successfully obtained the necessary ethical approval(s)		
Ethical review number(s) from Faculty Ethics Committee (or from NRES/SCREC):		
If you have *not* submitted your work for ethical review, and/or you have answered 'No' to one or more of questions a) to e), please explain below why this is so:		
I have not submitted my thesis for ethical review, since it does not employ any primary data collection.		
Signed *(PGRS)*:	M. Filippidis	**Date:** 31/07/2018

UPR16 – April 2018

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